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Volume 5 | Issue 2 | April 2023 | Page1-77
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Contents

Articles

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ARTICLE

Establishing the Forecasting Model with Time Series Data Based on Graph and Particle Swarm Optimization

*Le Thi Luong, Tran Thi Thanh, Nghiem Van Tinh**, Bui Thi Thi*

Faculty of Electronic, Thai Nguyen University of Technology, Thai Nguyen, 250000, Vietnam

ABSTRACT

In recent years, a wide variety of fuzzy time series (FTS) forecasting models have been created and recommended to handle the complicated and ambiguous challenges relating to time series data from real-world sources. However, the accuracy of a model is problem-specific and varies across data sets. But a model's precision varies between different data sets and depends on the situation at hand. Even though many models assert that they are better than statistics and a single machine learning-based model, increasing forecasting accuracy is still a challenging task. In the fuzzy time series models, the size of the intervals and the fuzzy relationship groups are thought to be crucial variables that affect the model's forecasting abilities. This study offers a hybrid FTS forecasting model that makes use of both the graph-based clustering technique (GBC) and particle swarm optimization (PSO) for adjusting interval lengths in the universe of discourse (UoD). The suggested model's forecasting results have been compared to those provided by other current models on a dataset of enrollments at the University of Alabama. For all orders of fuzzy relationships, the suggested model outperforms its counterparts in terms of forecasting accuracy.

Keywords: Forecasting; FTS; Fuzzy relationship group; GBC; Enrolments; COVID-19

1. Introduction

Forecasting the future of any phenomenon assists in making better judgments in uncertain situations. When forecasting particular events in the past, some researchers employed popular linear forecasting techniques, such as regression analysis, exponential moving averages, and autoregressive integrated moving averages (ARIMA). Nevertheless, conventional

*CORRESPONDING AUTHOR:
Nghiem Van Tinh, Faculty of Electronic, Thai Nguyen University of Technology, Thai Nguyen, 250000, Vietnam; Email: nghiemvantinh@tnut.edu.vn

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time series forecasting models have the disadvantages of being unable to cope with forecasting problems in linguistic values historical data and insufficient data. To address the drawbacks of traditional time series forecasting approaches, Song and Chissom [1,2] proposed two FTS models based on fuzzy logic [3] and fuzzy mathematics approaches to forecasting the number of enrollments at the University of Alabama. However, in the defuzzification process, their methods included sophisticated max-min operations and the construction matrix of fuzzy relationships $R(t-1, t)$. As a consequence, Chen [4] has developed a first-order FTS model by using basic arithmetic computations in the defuzzification process, which takes less time than performing the max-min complex composition operation [1,2].

The calculation of interval lengths and the establishment of fuzzy relationships (FRs) are two crucial factors in the FTS forecasting model that can considerably impact predicting effectiveness. To achieve more accurate forecasting results, several researchers have proposed various improvements from Song's model [2] and Chen's model [4] in aspects of mining the lengths of intervals [5-22], building fuzzy relationships [22-31], and fuzzy relationship groups [10-12].

For selecting interval lengths, Huarng [5] found out that variable interval lengths in the UoD highly influence the forecasting performance of the model. As a result, he suggested two novel ways based on the average and distribution for determining interval lengths in the fuzzy time series model. Yolcu et al. [15] proposed a strategy based on ratio optimization for interval length. His model is used to anticipate enrollments and inventory demand at the University of Alabama. Furthermore, using an optimization approach with a single-variable constraint, Egrioglu et al. [21] introduced a new method for determining the proper interval length in high-order FTS.

Recently, soft computing techniques and evolutionary algorithms are considered crucial tools for calculating interval lengths in the fuzzy time series sector. For instance, Chen and Chung [10] suggested the high-order model utilizing a genetic algorithm (GA) to divide intervals in the UoD for forecasting the University of Alabama enrollments. Additionally, Lee et al. [30] used a genetic algorithm to establish the various interval lengths in the high-order forecasting model using temperature and TAIFEX data. Besides that, they also used the simulated annealing algorithm to determine optimum interval lengths. Eren Bas et al. [32] introduced a novel modified genetic algorithm to eliminate subjectivity in determining the duration of each interval in the FTS model for forecasting "dead in vehicle road accidents" in Belgium and enrollments at the University of Alabama. Furthermore, to determine interval lengths, several optimization techniques, including the Artificial Bee Colony Algorithm, Particle Swarm Optimization, memetic algorithms, and ant-colony optimization, have been utilized in the universe of discourse. The comparison findings reveal that the PSO algorithm outperforms other algorithms in terms of success rate and solution quality. Additionally, certain comparison studies have indicated that the PSO-based outcomes surpass the GA-based technique [33-36]. PSO applications in optimizing interval lengths in the FTS forecasting models have been demonstrated in research works [12,18,20,22-27,34-36]. Kuo et al. [12] introduced a unique forecasting model for improving predicting error by combining the PSO with FTS. By suggesting a new defuzzification rule, Kuo et al. [23] presented a novel FTS model for forecasting TAIFEX. Two research works [24,34] established two-factor high-order FTS models for predicting distinct situations from the same perspective of employing PSO in altering interval lengths. Furthermore, Chen and Bui [26] used the PSO not only to achieve optimal interval partitioning but also to generate optimal weight vectors for forecasting the TAIFEX and NTD/USD exchange rates. Moreover, clustering techniques also have been used in the FTS model to determine the optimal interval such as K-means [37], fuzzy C-means [38], and automatic clustering [11,39]. Cheng et al. [40] have presented a fuzzy forecasting model with two advantages: the PSO to achieve optimal intervals and the K-means method to split the subscripts of the fuzzy sets at the current states of FRs. Dincer [17] used the fuzzy k-medoid clustering technique to handle outliers and abnormal data time series for forecasting air pollution.

Another approach based on fuzzy time series, some of the authors in works [41,42] introduced intuitionistic fuzzy time series (IFTS) and established an IFTS forecasting model to forecast the University of Alabama enrolment and State Bank of India (SBI) market share price on the Bombay stock exchange (BSE). The authors in research work [43,44] introduced hesitant probabilistic fuzzy sets in time series forecasting to address the issues of non-stochastic non-determinism and apply for forecasting the enrolments of the University of Alabama and the share market prizes of the State Bank of India.

Based on the study shown above, it is clear that selecting the optimal lengths of intervals and building fuzzy relationships are difficult and have a major impact on the model's predicting ability. Despite substantial advances in leveraging the duration of each interval and establishing predicting output rules, these difficulties continue to occupy the attention of academics. There are still a lot of approaches in the universe of discourse to identify the duration of intervals and generate forecasting output values from fuzzified values. To address these concerns, we present a novel hybrid FTS forecasting model that combines the Graph-based clustering approach with PSO in the selection of optimum lengths for dealing with various problems. The suggested forecasting model's performance is assessed using several real-world data sets, including enrollment data from the University of Alabama and confirmed COVID-19 instances from Vietnam. The findings obtained are compared to those of other approaches. The suggested strategy offers more accurate forecasts for the future values of the given enrollment time series.

The remainder of the paper is organized as follows: Basic concepts of fuzzy time series and algorithms are provided in Section 2. Section 3 proposes an FTS forecasting model that combines the GBC technique with PSO. Section 4 explains the application of the forecasting model and experimental findings. In Section 5, conclusions are offered.

2. Preliminaries

In this section, we describe some basic concepts of fuzzy time series [1,2] and related algorithms to serve as a foundation for our work.

2.1 Basic definitions of FTS

Song and Chissom [1,2] introduced the FTS concept originally, then Chen [4] improved it with a straightforward defuzzification method that was more precise. Some basic definitions of FTS are as below:

Definition 1: Fuzzy time series [1,2]

Let $Y(t)$ (t = ..., 0, 1, 2...), a subset of real number R, be the universe of discourse by which $f_i(t)(i = 1, 2...)$ are defined and if $F(t)$ is a collection of $f_1(t)$, $f_2(t)$,..., then $F(t)$ is called a FTS definition on $Y(t)$ *(t ..., 0, 1,2 ...)*.

***Definition 2*: ** Fuzzy relationships(FRs**)** [1,2]

Assume that $F(t) = A_k$ and $F(t-1) = A_i$, the first order relationship between $F(t-1)$ and $F(t)$ is denoted as a FLR: $A_i \rightarrow A_k$, where, A_k is the current state that dependent on previous state A_i.

***Definition 3*: ** m - order fuzzy relationships [1,2]

If $F(t)$ is dependent on previous state $F(t-1)$, $F(t-2)$,..., $F(t-m+1)$ $F(t-m)$, then $F(t-m)$,..., $F(t-2)$, $F(t-1) \rightarrow F(t)$ is called an m - order FLR. Time series with respect to this FLR is called an m - order FTS.

***Definition 4*: ** Fuzzy relationship groups (FRGs) [4]

The fuzzy relationships that Song and Chisom [1,2] presented in Definition 2, if they have the same left-hand side can be further grouped into an FRG. Assume the following FRs exist: $A_i \rightarrow A_k$, $A_i \rightarrow A_l$,.., $A_i \rightarrow A_m$; these FRs can be placed into the same FRG as : $A_i \rightarrow A_k, A_l \ldots, A_m$.

Definition 5: Time-variant fuzzy relationship groups [22]

The fuzzy relationship is presented by the relationship $F(t-1) \rightarrow F(t)$. If, let $F(t) = A_i(t)$ and $F(t-1) = A_j(t-1)$, the FR between $F(t-1)$ and $F(t)$ can be denoted as $A_j(t-1) \rightarrow A_i(t)$. Also at the time t, we only consider fuzzy relationships $A_j(t1-1) \rightarrow A_{i1}(t1)$; ...; $A_j(tn-1) \rightarrow A_{in}(tn)$ that occur before the fuzzy relationship $A_j(t-1) \rightarrow A_i(t)$ to make an FRG as $A_j(t-1) \rightarrow A_{i1}(t1), A_{i2}(t2), A_{in}(tn), A_i(t)$. It is referred to as first-order time-variant FRGs.

2.2 Graph-based clustering algorithm

Algorithms for graph-based clustering are effective at generating conclusions that are close to human intuition [45]. Building a graph on the set of data and using it as the basis for clustering is a frequent feature of graph-based clustering techniques developed in recent years [46]. In the GBC approach, each node in a graph represents a data object, and each object has connections with other objects. A set of things is said to form a cluster in this case if they are connected to one another but not to any other objects. Based on these ideas, our research [47] proposes a data clustering technique that uses a tree-like display of the information and constructs clusters automatically rather than the number of clusters user-predetermined. In particular, the graph-based clustering method is summarized into four procedures as follows:

(1) Root node location procedure (RNLP). This technique identifies the root node based on the provided data.

(2) Node insertion procedure (NIP). This technique inserts one element of the dataset and root node and places the elements in the proper position.

(3) Tree-making procedure (TMP). This procedure displays the tree from the provided data set and the root node.

(4) Clustering procedure (CP) based on nodes in the tree. This process makes logical node clustering using the tree that the TMP generated as input.

2.3 Particle swarm optimization algorithm

PSO was initially put up by Eberhart and Kennedy [48] for the purpose of locating the global optimal solution. A group of particles known as a swarm in PSO. Where each particle represents a potential solution and constantly navigates around the search space (d-dimensional space) in pursuit of the ideal answer. All particles (i.e., $Pmax$ particles) have fitness values to assess their performance during particle movement, and each particle recalls the best location from its own flight experience, which is called P_{best}. The best particle in the population as a whole is then referred to as G_{best}. Following Algorithm 1 is a brief summary of the PSO algorithm's steps:

Algorithm 1: The standard PSO algorithm

Step 1. Initialize random positions x_{ki}; random velocities v_{ki} in d dimensional space (i = 1,2,…,d);

- Positions of each k^{th} (k = 1,2, …, $Pmax$) particle's positions are randomly determined and kept in a X_{kd} given as follows:

$$X_{kd} = [x_{k,1}, x_{k,2}, \dots, x_{k,d}] \tag{1}$$

where x_{ki} denotes i^{th} position of k^{th} particle, N is the number of particles in a swarm.

- Velocities are generated at random and saved in the vector V_{kd} in Equation (2).

$$V_{kd} = [v_{k,1}, v_{k,2}, \dots, v_{k,d}] \tag{2}$$

Step 2: Based on the fitness function, P_{best_kd} and G_{best} particles given in Equations (1) and (2), respectively, are determined.

$$P_{best\_kd} = [p_{k,1}, p_{k,2}, \dots, p_{k,d}] \text{ and}$$
$$G_{best} = \text{minimum} (P_{best\_kd}).$$

Step 3: Similar to the ones shown [12], C_1 and C_2 are two learning factors, and ω is the time-varying inertia weight. In each iteration t, the parameter ω is calculated by using Equation (3) as follows:

$$\omega^t = \omega_{max} - \frac{t * (\omega_{max} - \omega_{min})}{iter\_max} \tag{3}$$

where, $iter\_max$ denotes the maximum iteration number.

Step 4: Values of velocities and positions are updated by using Equations (4) and (5), respectively.

$$V_{kd}^{t+1} = \omega^t * V_{kd}^t + c_1 * R1() * (P_{best_{kd}} - X_{kd}^t) + c_2 * R2() * (G_{best} - X_{kd}^t) \tag{4}$$

$$X_{kd}^{t+1} = X_{kd}^t + V_{kd}^{t+1} \tag{5}$$

Here, *R1*( ) and *R2*( ) are randomly generated values between [0, 1].

Step 5: Steps 2 to 4 are repeated until a predefined maximum number of iterations is reached.

3. An FTS forecasting model using graph-based clustering and PSO

This section's goal is to introduce a hybrid FTS model that combines PSO and GBC. This proposed model is named GBCFTS-PSO. The framework of the GBCFTS-PSO model is shown in **Figure 1**. It consists of three stages: (1) partitioning of intervals based on the GBC; (2) establishing the FTS model; and (3) choosing the best interval lengths by using the PSO.

3.1 Establishing the forecasting model using Graph-based clustering and fuzzy time series

The proposed FTS model's details are discussed in steps utilizing datasets of the number of new confirmed COVID-19 in Vietnam from June 15, 2021, to July 15, 2021, as shown in **Figure 2**. The followings are the steps of the suggested model:

Step 1: Using the GBC approach, divide data into *C* intervals.

In this step, four procedures from the Graph-based clustering algorithm in Section 2.2 are utilized to partition time series $X(t)$ into C clusters. The following are the short outcomes of these four procedures:

1) Root node location procedure (RNLP)

The dataset of newly confirmed COVID-19 instances is input $X(t)$ = (398, 414, 259, 471, ..., 2296, 2924, 1922); with (15/07/2021 $\leq t \leq$ 15/7/2021).

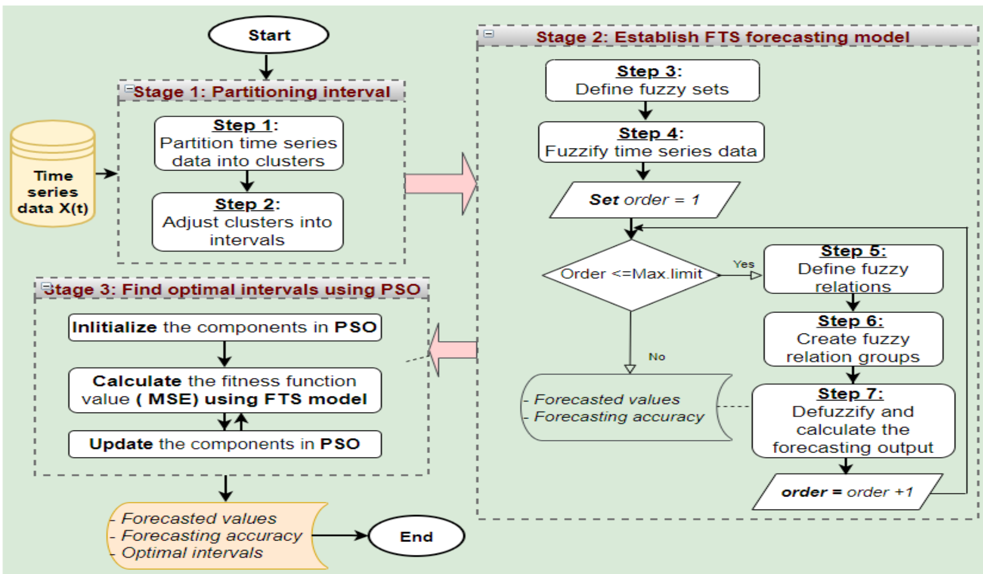

Figure 1. Framework of the proposed forecasting model based on GBC and PSO.

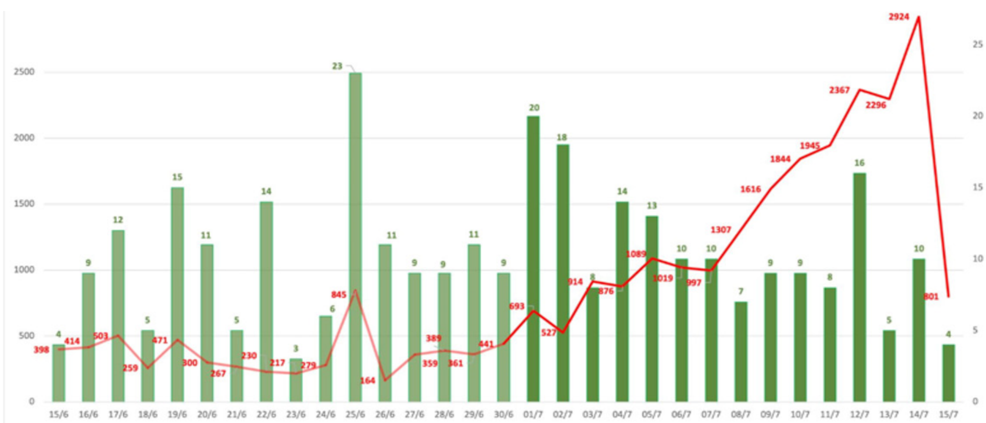

Figure 2. The dataset of number of confirmed cases of COVID-19 in Vietnam.

Source: https://ncov.moh.gov.vn

Calculate range $Rg = Xmax_{value} - Xmin_{value} = 2760$.

Calculate standard deviation of the time series as SD = 762.76.

$$w = \frac{R_g}{SD * N} = 0.12$$

Define universe of discourse (U) of the $X(t)$:

$U = [Xmin_{value} - w, Xmax_{value} + w] = [163.88, 2924.12]$

Calculate midpoint of U as: $Mid_u = (MIN_{value} + MAX_{value}) / 2 = 1544$.

Assign the Mid_u as root node: $Root = Mid_u = 1544$.

2) Tree make Procedure (TMP) and node insertion procedure (NIP)

For generating the tree, from the input dataset and Root node. We apply two procedures TMP and NIP to create tree and insert nodes into the tree. The results of these two procedures are shown in **Figure 3**.

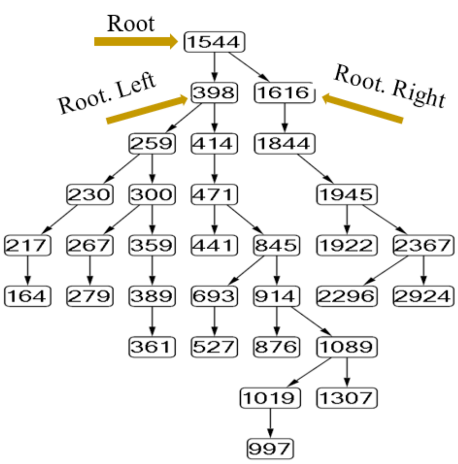

Figure 3. The tree depicts the input data of COVID-19 series based on two procedures TMP and NIP with root node of 1544.

3) Make the clusters from the tree in **Figure 3** based on Procedure 4 (CP)

Following the acquisition of the data tree depicted in **Figure 3**, the process of creating clusters is briefly described in accordance with the following conditions:

(1) Initially, check to see whether Root exists or not and check to see whether Root has left (Root. LEFT) and right (Root. RIGHT)

(2) Calculate the difference between the values of Root and Root. RIGHT, Root and Root. LEFT if both children exist for each Root. After that, create a cluster consisting of the Root and associated child that has the smallest difference.

(3) If there is just one child for each Root, create the cluster using either the Root and Root. LEFT or Root and Root. RIGHT.

(4) Continue repeating conditions 1-3 until all of the value from the tree's nodes has been added to the clusters.

From the above procedures, we obtain 15 clusters and their related cluster centers. Then, these clusters are then arranged in ascending order by the clustering centers, and the final results are listed in **Table 1**.

Step 2: Adjust these clusters into intervals

After applying the adjustment principles from clusters to intervals in the research work [49], we obtain 15 intervals u_i corresponding to the clusters in **Table 2**, and the midpoint values of these intervals are shown in **Table 3**.

Step 3: Identify the corresponding language term for each interval in Step 2

Each linguistic term can be defined by intervals that the historical time series data distributed among these intervals. For ten intervals in Step 2, we obtain 15 linguistic values of linguistic variables "*enrolments*" e.g., {{very very very few}, {very very few},

Table 1. Clusters and cluster centers.

No	Clusters C_i	Cluster center (V_i)	No	Clusters C_i	Cluster center (V_i)
1	(217,164)	190.5	9	(997)	997
2	(259,230)	244.5	10	(1089,1019)	1054
3	(300,267,279)	282	11	(1307)	1307
4	(359,389,361)	369.7	12	(1544,1616)	1580
5	(398,414)	406	13	(1844,1945,1922)	1903.7
6	(471,441)	456	14	(2367,2296)	2331.5
7	(693,527)	610	15	(2924)	2924
8	(845,914,876)	878.3			

Table 2. The intervals and midpoint values of them.

No	Intervals (u_i)	Midpoint	No	Intervals (u_i)	Midpoint
1	[164, 217.5]	190.8	9	[937.65, 1025.5]	981.6
2	[217.5, 263.25]	240.4	10	[1025.5, 1180.5]	1103
3	[263.25, 325.85]	294.6	11	[1180.5, 1443.5]	1312
4	[325.85, 387.85]	356.8	12	[1443.5, 1741.85]	1592.7
5	[387.85, 431]	409.4	13	[1741.85, 2117.6]	1929.7
6	[431, 533]	482	14	[2117.6, 2627.75]	2372.7
7	[533, 744.15]	638.6	15	[2627.75, 2924]	2775.9
8	[744.15, 937.65]	840.9			

{very few},{few}, …, {very many}, {too many}, {too many many}, {too many many many}}, which can be described with fuzzy sets A_i, e.g. {A_1, A_2, A_3,..., A_9, A_{15},}, respectively and calculated as follows:

$$A_i = {}^{a_{i1}}/_{u_1} + {}^{a_{i2}}/_{u_2} + \ldots + {}^{a_{ij}}/_{u_j} + \ldots + {}^{a_{i10}}/_{u_{15}} \quad (6)$$

where, the values $a_{ij} \in [0,1]$ denote the grade of membership of u_j in fuzzy set A_i and which is calculated in Equation (7). Here, the symbol '+' denotes the set union operator and the symbol '/' denotes the membership of u_j which belongs to A_i.

$$a_{ij} = \begin{cases} 1 & j = i \\ 0.5 & j = i-1 \text{ or } j = i+1 \\ 0 & others \end{cases} \quad (7)$$

Step 4: Fuzzy all historical time series data

In order to fuzzy all historical time series, the typical method is to convert historical data which belongs to the interval U into fuzzy sets. If the maximum membership value of fuzzy set A_i occurs at u_i, then the fuzzified historical value is considered as A_i. For example, the COVID-19 data on day 15/6/2021 equal to 398 belongs to the interval u_5 = [387.85, 431] and the highest membership value of fuzzy set A_5 occurs at u_5. So, it is fuzzified into A_5. The similar way for next years, we complete the results of fuzzification of enrolments data for all years, as listed in **Table 3**.

Step 5: Establish all mth- order FRs between the fuzzified data values. ($m \geq 1$).

To build fuzzy relationships, we need to find any relationship having the type $F(t-m)$, $F(t-m+1)$,..., $F(t-1) \rightarrow F(t)$, where, the left-hand side of FLR ($F(t-m)$, $F(t-m+1)$,..., $F(t-1)$) is called the current state and the right-hand side of FLR. ($F(t)$) is called the next state, respectively. Then, the m^{th} -order FLR is replaced by relationships in accordance with the corresponding fuzzy sets as: A_{im},, $A_{i(m-1)}$,…, A_{i2}, $A_{i1} \rightarrow A_k$.

In this way, we have achieved the first-order FRs for tall fuzzified data values, which are presented in column 4 of **Table 4**.

Here the linguistic value of F(16/7/2021) on the right-hand side of the last relationship is denoted by the symbol '#', which is used to represent the unknown linguistic value.

Step 6: Create all m—order time—variant FRGs

In this study, we develop fuzzy relation groups using the concept of a time-variant fuzzy relationship group [22], which was mentioned in Definition 5. Based on the present state of the FRs in **Table 4**, the FRs may be put into a group and entitled time vari-

Table 3. The results of fuzzification for COVID-19 time series.

Day	Actual data	Fuzzy sets	Maximum membership value	Linguistic value
15/6/2021	398	A_5	[**1** 0.5 0 0 0 0 0 0 0 0]	*"somewhat few"*
16/6/2021	414	A_5	[**1** 0.5 0 0 0 0 0 0 0 0]	*"somewhat few"*
-----	-----	----	------------------	----------------
14/7/2021	2624	A_{15}	[0 0 0 0 0 0 0 0 0.5 **1**]	*"too many many many"*
15/7/2021	1922	A_{13}	[0 0 0 0 0 0 0 0.5 **1** 0.5]	*"too many "*

ant-FRGs by examining the history of the emergence of the fuzzy sets on the future state of the FRs. From this approach, we obtain all first-order time-variant FRGs, as shown in **Table 5**. Where 30 groups (G1-G30) are in the training stage and one group (G31) is in the testing stage.

Table 4. The results of the first-order fuzzy relationships.

Day	No	Fuzzy set	First-order FRs
15/6/2021		A_5	
16/6/2021	1	A_5	$A_5 \rightarrow A_5$
	--	----	----------
14/7/2021	29	A_{10}	$A_{14} \rightarrow A_{15}$
15/7/2021	30	A_9	$A_{15} \rightarrow A_{13}$
16/7/2021	31	N/A	$A_{13} \rightarrow$ #

Table 5. The results of the first-order time-variant FRGs.

No	First-order Time-variant FRGs
G1	$A_5 \rightarrow A_5$
G2	$A_5 \rightarrow A_6$
----	--------------
G29	$A_{14} \rightarrow A_{14}, A_{15}$
G30	$A_{15} \rightarrow A_{13}$
G31	$A_{13} \rightarrow$ #

Step 7: Defuzzify the forecasting output values

Our defuzzified principles in the paper [49] are introduced to compute the forecasting value for all first-order and high-order time-variant FRGs in the training stage. In the testing, we apply a defuzzified principle [24] to compute with the unknown linguistic value. The forecasting rules are briefly represented as follows:

Principle 1: Calculate the forecasting value for known linguistic values

To obtain the forecasting results, we divide each corresponding interval concerning the linguistic value in the next state into four sub-intervals that have the same length and calculate the forecasted output value for each group based on Equation (8).

$$\text{Forecasted\_value} = \frac{1}{2*n}\sum_{i=1}^{n}(subm_{ik} + Value\_lu_{ik}) \quad (8)$$

where n is the total of fuzzy sets on FRG's next state.

- $\boldsymbol{subm_{ik}}$ is the midpoint value of one of four sub-intervals about the i-th linguistic value in the next state of FRG in which the real data at forecasting time falls.

- $\boldsymbol{Value\_lu_{ik}}$ is one of two values belonging to the lower and upper bounds of one of four sub-intervals with real data falling inside sub-interval u_{ik} at forecasting time.

Principle 2: Calculate the forecasting value with unknown linguistic values

In the testing phase, we determine the forecasting value for each FRG which has the unknown linguistic value occurring in the next state. Suppose there is the ^{m}th-order fuzzy relationship group whose next state is #, shown as follows: $A_{im}, A_{im-1}, \ldots, A_{i1} \rightarrow$ #.

Here the symbol '#' represents an unknown value, then the forecasted value of year i is calculated in accordance with [24] as follows:

$$\text{Forecasted value} = m_{i1} + \frac{\sum_{k=2}^{m} m_{i(k-1)} - m_{ik}}{2^{k-1}} \quad (9)$$

where, $m_{i1}, m_{i2},\ldots,m_{ik}$ are midpoints of $u_{i1}, u_{i2},\ldots,$ and u_{ik} $(2 \leq k \leq m)$, respectively.

Based on the two forecasting principles above, we complete forecasting results for COVID-19 confirmed cases prediction from 15/6/2021 to 15/7/2021 with first-order TV-FRGs under fifteen intervals, which are given in **Table 6**.

Table 6. The forecasting results for COVID-19 based on 1st-order fuzzy relationships.

Day	COVID-19 data	Fuzzy sets	1st-order forecasted value
15/06/2021	398	A_5	Not forecasted
16/06/2021	414	A_5	414.6
----	------	----	-------
14/07/2021	2924	A_{15}	2614.7
15/07/2021	1922	A_{13}	1898.4

To confirm the effectiveness of the suggested forecasting model, the mean square error (*MSE*) is employed as assessment criteria in terms of the forecasted accuracy. The formulas of both indices are calculated as follows:

$$MSE = \frac{1}{n}\sum_{i=m}^{n}(F_i - R_i)^2 \quad (10)$$

where R_i, F_i represent the real value and forecasting value at year i, respectively; n is the total number of forecasted data, *m* means the order of the FLR.

3.2 Using PSO to determine appropriate interval lengths

In this section, we present a hybrid FTS forecasting model termed GBCFTS-PSO, which combines graph-based clustering and PSO to produce optimal interval lengths with the goal of improving forecasted accuracy. In GBCFTS-PSO model, each particle denotes the partitioning of historical data into intervals. The number of intervals is obtained from the GBC algorithm (e.g., d intervals). The lower bound and upper bound of the UoD be p_0 and p_d, respectively. Each particle symbolizes a vector with d-1 elements as p_1, p_2, …, p_{d-2} and p_{d-1}, where $p_i \leq p_{i+1} (1 \leq i \leq d-1)$. Based on these d-1 elements, obtain the intervals set as $u_1 = [p_0, p_1]$, $u_2 = [p_1, p_2]$,…, $u_i = [p_{i-1}, p_i]$,… and $u_d = [p_{d-1}, p_d]$, respectively. When a particle transfers from one place to another according to Equations (4) and (5), d-1 elements must be sorted in ascending order such that $p_1 \leq p_2 \leq \ldots \leq p_{d-1}$. The function MSE (10) is employed to evaluate the forecasting accuracy of each particle. Algorithm 2 shows the entire process of the suggested model.

4. Experiment management and results evaluation

In this research, the GBCFTS-PSO model is applied for forecasting two time series datasets: The University of Alabama enrollment data [4] and the number of new confirmed COVID-19 in Vietnam from June 15, 2021, to July 15, 2021. Before implementing the suggested forecasting model, the time series datasets are briefly presented. The simulation and analysis findings for these data sets are then presented. The statistical properties of these time series data are provided below.

Algorithm 2: The GBCFTS-PSO algorithm

1**. Input**: Historical time series data
2**. Output**: The forecasting output and MSE value
Begin
***3.* Choose** the initial intervals by using the GBC technique and using forecasted steps in Subsection 3.1 to get the forecasting accuracy (MSE)..
4. ***Initialize***: number of particles: *Pmax,* number of maximum iteration: *iter_max*
- ✓ The initial positions of all particles be limited by: $p_0 + Rand(\ ) * (p_d - p_0)$; where, p_0 *and* p_d are the lower bound and upper bound of the universe of discourse UoD which is created by GBC; the intervals created by particle 1 are identical to the one created by GBC.
- ✓ The velocity V_{kd} of all particles be exceeded by: $V_{min} + Rand(\ ) * (V_{max} = - V_{min})$; $V_{min} = - V_{max}$
- ✓ In order to find Gbest, all particles' beginning positions are set to their personal best positions.

5. **while** (*iter* ≤ *iter_max*) **do**
5.1**. foreach** particle *kd*, (1 ≤ *kd* ≤ *Pmax*) **do**
- ✓ Based on Step 3 in Subsection 3.1, determine all intervals defined by the present position of the particle *kd.*
- ✓ Fuzzify all historical data described in Step 4 of Subsection 3.1.
- ✓ Establish all *m* – order FRs using Step 5 in Subsection 3.1
- ✓ Build all *m* – order time-variant FRGs using Step 6 in Subsection 3.1
- ✓ Forecast and defuzzify output values using Step 7 in Subsection 3.1
- ✓ Calculate the MSE values for particle *kd* based on Equation (10)
- ✓ The new *Pbest* of particle *kd* is saved according to the MSE values.

end for
5.2. The new *Gbest* of all particles is saved according to the MSE values
6. **foreach** particle kd, (1 ≤ *kd* ≤ *Pmax*) **do**
✓ The particle kd is moved to another location according to (4) and (5)
end for
✓ change ω according to **(3)**
end while
End.

4.1 Data description and relevant parameters of each time series

1) *The enrolments data of university of Alabama* [4]: Enrolments time series is applied to quite a wide range of areas in literature from the beginning of research [1,2]. This dataset contained 22 observations during the period from 1971 to 1992. One of the outcomes of these studies is compared to the proposed model. The universe of discourse of the enrollment data series is determined by the clustering algorithm as $U = [Xmin_{value} - w, Xmax_{value} + w]$ = [13054.84, 19337.16], where w = 0.16, $Xmin_{value}$ = 13055 and $Xmax_{value}$ = 19337 are the data series' minimum and maximum values.

2) COVID-19 data sets in Vietnam: This data set contains 31 observed values for new confirmed cases of COVID-19 in Vietnam from June 15, 2021, to July 15, 2021, as shown in **Figure 2**. The minimum and maximum values of the time series are $Xmin_{value}$ = 1164 and $Xmax_{value}$ = 2924. The universe of discourse of COVID-19 as U = [163.88, 2924.12] with w = 0.12.

For each dataset, the main parameters of the proposed model are intuitively determined, as shown in **Table 7**.

The suggested forecasting model has been executed 20 times with 10 intervals for enrolment data and 15 intervals for COVID-19 data. The best result from all runs is the final output.

4.2 Experimental results

Forecasting the enrolments of University of Alabama

The suggested model (GBCFTS-PSO) is used in this subsection to forecast enrolments with annual observations [4]. The results of five forecasting models in works [41-44,50] are chosen for comparison to demonstrate the performance of the suggested forecasting model based on first-order FTS under varied intervals. **Table 8** and **Figure 4** show the forecasted values and the forecasting accuracy between our suggested model and comparing models.

From the forecasting results in **Table 8** and **Figure 4**, it can be seen that the GBCFTS-PSO model gets the smallest MSE value of 39302.66 among all the compared models. The difference between the GBCFTS-PSO model and the models mentioned above is the way in which the fuzzy relationship group and

Table 7. The parameters of the GBCFTS-PSO model for forecasting enrolments and COVID-19.

Description for the parameters	Values of enrolments	Values of COVID-19
Number of particles	30	30
The max iteration number	150	150
The inertial weigh ω	0.9 to 0.4	0.9 to 0.4
The coefficient $C_1 = C_2$	2	2
The velocity in search range	[–100,100]	[–100,100]
The position in search range	[13054.84, 19337.16]	[163.88, 2924.12]

Table 8. A comparison of the forecasting results of the suggested model with its counterparts based on first-order fuzzy time series under 10 intervals.

Year	Actual	[41]	[43]	[44]	[50]	[42]	GBCFTS-PSO
1971	13055	-	-	-	-	-	
1972	13563	13693	13595.67	13680.75	13637	13682	13562.1
---	---	---	---	---	---	---	---
1991	19337	19500	19168.56	18972.15	18230	19311	19272.1
1992	18876	19500	19168.56	18972.15	18236	19311	19142.3
MSE value		243601	183723	186313	1800964	178665	39302.66

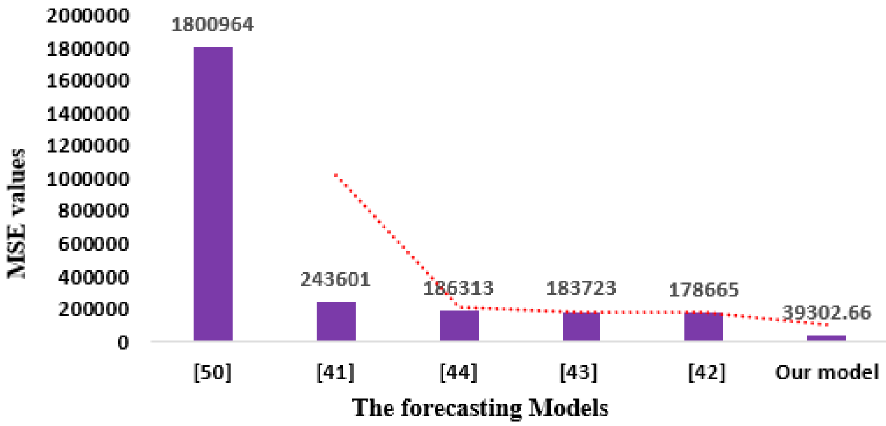

Figure 4. Comparing forecasting accuracy between our model and other models.

method of partitioning are applied to establish the forecasting model. This difference shows that the suggested forecasting model outperforms the previous model when used to evaluate enrollment data for the University of Alabam.

Additionally, in this study, we implement a forecasting model based on the high-order fuzzy relationship from orders 2 to 8 with a fixed number of intervals of 10. To verify the effectiveness of the forecasting model based on high-order fuzzy time series, four models listed in **Table 9** are selected for comparison. The comparison results in terms of MSE values listed in **Table 9** show that the GBCFTS-PSO model gives a lower MSE value than the models selected for comparison in all orders with 10 intervals. Among all fuzzy relationships done in the model, the GBCFTS-PSO model obtains the lowest MSE value of 71.5 with 4th-order fuzzy relationships.

Forecasting new confirmed cases of COVID-19

The GBCFTS-PSO model is also used to forecast the number of new COVID-19 cases that would be confirmed in Vietnam between June 15 and July 15, 2021. The GBCFTS-PSO model executes 20 separate runs for each order based on the parameters listed in **Table 7**, and the best outcome of these runs at each order of FRs is taken as the final forecasting result. The MSE value is used to measure the forecasting accuracy of the suggested model, which is based on the first-order FTS with various intervals. The obtained forecasting results from the proposed model are based on the first-order FTS with 15 intervals, which is shown in **Table 10**. For easy visualizing, the curves of actual value and forecasted value for the number of new confirmed cases each day are shown in **Figure 5**. From this figure, it can be seen that the forecasted value of the suggested model based on the first-order FLR is relatively close to the actual data.

In addition, to verify the superiority of the GBCFTS-PSO model based on the high-order FTS with the same number of intervals of 7. **Table 11** presents the forecasting results of the GBCFTS-PSO model in terms of the MSE value based on the

Table 9. A comparison of the results obtained between the GBCFTS-PSO model and its counterparts based on the various high-order FTS and different intervals.

Models	Number of orders						
	2	3	4	5	6	7	8
[10]	67834	31123	32009	24984	26980	26969	22387
[12]	67123	31644	23271	23534	23671	20651	17106
[25]	19594	31189	20155	20366	22276	18482	14778
[50]	8552	600.3	447.7	387.1	495.6	370.6	319.9
GBCFTS-PSO	2181	183.16	71.5	97.2	128.08	222.15	143

Table 10. The forecasting results of the first-order GBCFTS-PSO model with 15 intervals.

Date/month	Actual data	Forecasted values	Date/month	Actual data	Forecasted values
15/06/2021	398	----	01/7/32021	693	693.5
16/6/2021	414	404.7	2/7/2021	527	550.4
17/06/2021	503	455.2	3/7/2021	914	746.8
18/06/2021	259	262.1	4/7/2021	876	884.8
19/06/2021	471	464.1	5/7/2021	1089	1001.5
20/06/2021	300	286.5	6/7/2021	1019	1001.5
21/06/2021	267	390.8	7/7/2021	997	1001.5
22/06/2021	230	345.3	8/7/2021	1307	1067.6
23/06/2021	217	299.7	9/7/2021	1616	1622.9
24/06/2021	279	294.3	10/7/2021	1844	1835.5
25/06/2021	845	844.9	11/7/2021	1945	1944.7
26/06/2021	164	172.9	12/7/2021	2367	2369.2
27/06/2021	359	307	13/07/2021	2296	2296.5
28/06/2021	389	388.4	14/07/2021	2924	2918.4
29/06/2021	361	382.3	15/07/2021	1922	1924.3
30/06/2021	441	392.1			
MSE		4599.03			

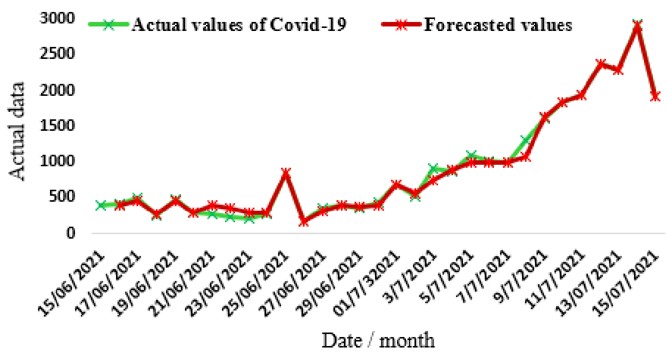

Figure 5. The comparison curves between the actual values and the forecasted values based on the first-order FRs.

Table 11. The forecasting accuracy of GBCFTS-PSO based on the high-order FTS with number of intervals equal to 15.

Orders of model	2nd-order	3rd-order	4th-order	5th-order	6th-order	7th-order	8th-order
MSE	930.05	628	218.06	268.3	356.5	423	415.08

various high-order FRs from 2nd-order to 8th-order. Among all orders of the suggested model with seven intervals, the best forecasting result has been found for the 4th-order FR which has the smallest MSE value equal to 218.06.

5. Conclusions

In this study, a hybrid FTS forecasting model for forecasting various issues is built by combining graph-based clustering and particle swarm optimization. The suggested model has solved two concerns that are seen to be significant and have a significant impact on forecasting accuracy, namely the issues with selecting interval length and how to create fuzzy relationship groups. The disadvantages of FTS models that use conventional fuzzy relationship groups are overcome by the recommended model, which uses the concept of a time-variant fuzzy relation group to produce the forecasting output results. By combining

GBC and PSO techniques in finding the optimal lengths of intervals from the universe of discourse, the forecasting efficiency of the proposed model can be significantly improved. Compared with conventional fuzzy time series models in this field, we employ a hybrid high-order fuzzy time series in order to forecast enrollment at the University of Alabama and the number of confirmed cases of COVID-19 in Vietnam. In many cases, the suggested model significantly outperforms other models on the dataset of enrolments and the simulated results on the dataset of confirmed cases of COVID-19 instances demonstrate that the suggested model gives remarkably better forecasting when using the high-order FTS. Details of the comparison are shown in **Tables 8 through 11**. Although compared to other forecasting models based on high-order FRs, our approach has higher forecasting capability. FLR determination in the high-order FTS model is more difficult and costly computationally than in the first-order. Therefore, in the near future, it would be wise to consider developing new techniques that can automatically decide the best order for high-order FRs.

Conflict of Interest

There is no conflict of interest.

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References

[1] Song, Q., Chissom, B.S., 1993. Fuzzy time series and its models. Fuzzy Sets and Systems. 54(3), 269-277.

[2] Song, Q., Chissom, B.S., 1993. Forecasting enrollments with fuzzy time series—Part I. Fuzzy Sets and Systems. 54(1), 1-9.

[3] Zadeh, L.A., 1965. Fuzzy Sets. Information and Control. 8(3), 338-353.

[4] Chen, S.M., 1996. Forecasting enrollments based on fuzzy time series. Fuzzy Sets and Systems. 81, 311-319.

[5] Huarng, K., 2001. Effective lengths of intervals to improve forecasting in fuzzy time series. Fuzzy Sets and Systems. 123(3), 387-394.

[6] Hwang, J.R., Chen, S.M., Lee, C.H., 1998. Handling forecasting problems using fuzzy time series. Fuzzy Sets and Systems. 100, 217-228.

[7] Yu, H.K., 2005. A refined fuzzy time-series model for forecasting. Physical A: Statistical Mechanics and Its Applications. 346(3-4), 657-681.

[8] Yu, H.K., 2005. Weighted fuzzy time series models for TAIEX forecasting. Physica A: Statistical Mechanics and Its Applications. 349(3-4), 609-624.

[9] Bosel, M., Mali, K., 2018. A novel data partitioning and rule selection technique for modelling high-order fuzzy time series. Applied Soft Computing. 63, 87-96.
DOI: https://doi.org/10.1016/j.asoc.2017.11.011

[10] Chen, S.M., Chung, N.Y., 2006. Forecasting enrolments using high-order fuzzy time series and genetic algorithms. International Journal of Intelligent Systems. 21, 485-501.

[11] Chen, S.M., Tanuwijaya, K., 2011. Fuzzy forecasting based on high-order fuzzy logical relationships and automatic clustering techniques. Expert Systems with Applications. 38, 15425-15437.

[12] Kuo, I.H., Horng, S.J., Kao, T.W., et al., 2009. An improved method for forecasting enrollments based on fuzzy time series and particle swarm optimization. Expert Systems with Applications. 36(3), 6108-6117.

[13] Loc, V.M., Nghia, P.T.H., 2017. Context-aware approach to improve result of forecasting enrollment in fuzzy time series. International Journal of Emerging Technologies in Engineering Research. 5(7), 28-33.

[14] Lu, W., Chen, X., Pedrycz, W., et al., 2015. Using interval information granules to improve forecasting in fuzzy time series. International Journal of Approximate Reasoning. 57, 1-18.

[15] Yolcu, U., Egrioglu, E., Uslu, V.R., et al., 2009. A new approach for determining the length of intervals for fuzzy time series. Applied Soft Computing. 9, 647-651.

[16] Liu, H.T., Wei, M.L., 2010. An improved fuzzy forecasting method for seasonal time series. Expert Systems with Applications. 37(9), 6310-6318.

[17] Dincer, N.G., Akkuş, Ö., 2018. A new fuzzy time series model based on robust clustering for forecasting of air pollution. Ecological Informatics. 43, 157-164.
DOI: http://dx.doi.org/10.1016/j.ecoinf.2017.12.001

[18] Huang, Y.L., Horng, S.J., Kao, T.W., et al., 2011. An improved forecasting model based on the weighted fuzzy relationship matrix combined with a PSO adaptation for enrollments. International Journal of Innovative Computing, Information and Control. 7(7), 4027-4046.

[19] Wang, L., Liu, X., Pedrycz, W., 2013. Effective intervals determined by information granules to improve forecasting in fuzzy time series. Expert Systems with Applications. 40(14), 5673-5679.

[20] Lu, W., Chen, X., Pedrycz, W., et al., 2015. Using interval information granules to improve forecasting in fuzzy time series. International Journal of Approximate Reasoning. 57, 1-18.

[21] Egrioglu, E., Aladag, C.H., Basaran, M.A., et al., 2011. A new approach based on the optimization of the length of intervals in fuzzy time series. Journal of Intelligent and Fuzzy Systems. 22, 15-19.

[22] Van Tinh, N., Dieu, N.C., 2018. Handling forecasting problems based on combining high-order time-variant fuzzy relationship groups and particle swam optimization technique. International Journal of Computational Intelligence and Applications. 17(2), 1-19.

[23] Kuo, I.H., Horng, S.J., Chen, Y.H., et al., 2010. Forecasting TAIFEX based on fuzzy time series and particle swarm optimization. Expert Systems with Applications. 37(2), 1494-1502.

[24] Hsu, L.Y., Horng, S.J., Kao, T.W., et al., 2010. Temperature prediction and TAIFEX forecasting based on fuzzy relationships and MTPSO techniques. Expert Systems with Applications. 37(4), 2756-2770.

[25] Huang, Y.L., Horng, S.J., He, M., et al., 2011. A hybrid forecasting model for enrollments based on aggregated fuzzy time series and particle swarm optimization. Expert Systems with Applications. 38(7), 8014-8023.

[26] Chen, S.M., Phuong, B.D.H., 2017. Fuzzy time series forecasting based on optimal partitions of intervals and optimal weighting vectors. Knowledge-Based Systems. 118, 204-216.

[27] Chen, S.M., Manalu, G.M.T., Pan, J.S., et al., 2013. Fuzzy forecasting based on two-factors second-order fuzzy-trend logical relationship groups and particle swarm optimization techniques. IEEE Transactions on Cybernetics. 43(3), 1102-1117.

[28] Chen, S.M., Chen, S.W., 2014. Fuzzy forecasting based on two-factors second-order fuzzy-trend logical relationship groups and the probabilities of trends of fuzzy logical relationships. IEEE Transactions on Cybernetics. 45(3), 391-403.

[29] Chen, S.M., Chung, N.Y., 2006. Forecasting enrollments of students by using fuzzy time series and genetic algorithms. International Journal of Information and Management Sciences. 17(3), 1-17.

[30] Lee, L.W., Wang, L.H., Chen, S.M., et al., 2006. Handling forecasting problems based on two-factors high-order fuzzy time series. IEEE Transactions on Fuzzy Systems. 14(3), 468-477.

[31] Lee, L.W., Wang, L.H., Chen, S.M., 2008. Temperature prediction and TAIFEX forecasting based on high-order fuzzy logical relationships and genetic simulated annealing techniques. Expert Systems with Applications. 34(1), 328-336.

[32] Bas, E., Uslu, V.R., Yolcu, U., et al., 2014. A modified genetic algorithm for forecasting fuzzy time series. Applied Intelligence. 41, 453-463.

[33] Panda, S., Padhy, N.P., 2007. Comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design. Ap-

plied Soft Computing. 8(4), 1418-1427.

[34] Park, J.I., Lee, D.J., Song, C.K., et al., 2010. TAIFEX and KOSPI 200 forecasting based on two-factors high-order fuzzy time series and particle swarm optimization. Expert Systems with Applications. 37(2), 959-967.

[35] Samsami, R., 2013. Comparison between genetic algorithm (GA), particle swarm optimization (PSO) and ant colony optimization (ACO) techniques for NO emission forecasting in Iran. World Applied Sciences Journal. 28(12), 1996-2002.

[36] Chen, S.M., Zou, X.Y., Gunawan, G.C., 2019. Fuzzy time series forecasting based on proportions of intervals and particle swarm optimization techniques. Information Sciences. 500, 127-139.
DOI: http://dx.doi.org/10.1016/j.ins.2019.05.047

[37] Van Tinh, N., Dieu, N.C., 2019. Improving the forecasted accuracy of model based on fuzzy time series and K-Means clustering. Journal of Science and Technology: Issue on Information and Communications Technology. 3(2), 51-60.

[38] Egrioglu, E., Aladag, C.H., Yolcu, U., 2013. Fuzzy time series forecasting with a novel hybrid approach combining fuzzy c-means and neural networks. Expert Systems with Applications. 40, 854-857.

[39] Wang, W., Liu, X., 2015. Fuzzy forecasting based on automatic clustering and axiomatic fuzzy set classification. Information Sciences. 294, 78-94.

[40] Cheng, S.H., Chen, S.M., Jian, W.S., 2016. Fuzzy time series forecasting based on fuzzy logical relationships and similarity measures. Information Sciences. 327, 272-287.

[41] Kumar, S., Gangwar, S., 2015. Intuitionistic fuzzy time series: An approach for handling non-determinism in time series forecasting. IEEE Transactions on Fuzzy Systems. 24(6), 1270-1281.

[42] Pant, M., Kumar, S., 2022. Particle swarm optimization and intuitionistic fuzzy set-based novel method for fuzzy time series forecasting. Granular Computing. 7(2), 285-303.

[43] Bisht, K., Kumar, S., 2016. Fuzzy time series forecasting method based on hesitant fuzzy sets. Expert Systems with Applications. 64, 557-568.

[44] Gupta, K.K., Kumar, S., 2019. Hesitant probabilistic fuzzy set based time series forecasting method. Granular Computing. 4(4), 739-758.

[45] Jaromczyk, J.W., Toussaint, G.T., 1992. Relative neighborhood graphs and their relatives. Proceedings of the IEEE. 80(9), 1502-1517.

[46] Anand, R., Reddy, C.K., 2011. Graph-based clustering with constraints. Advances in Knowledge Discovery and Data Mining: 15th Pacific-Asia Conference, PAKDD 2011; 2011 May 24-27; Shenzhen, China. Berlin Heidelberg: Springer. Part II 15. p. 51-62.

[47] Tinh, N.V., Thanh, T.T., Thi, B.T., 2021. An interval partitioning approach using graph-based clustering in fuzzy time series forecasting model. Data Mining and Knowledge Discovery. 9, 142-150.

[48] Kennedy, J., Eberhart, R., 1995. Particle swarm optimization. Proceedings of the 1995 IEEE International Conference on Neural Networks; 1995 Nov 27-Dec ; Perth, WA, Australia. USA: IEEE. p. 1942-1948.

[49] Tinh, N.V., 2020. Enhanced forecasting accuracy of fuzzy time series model based on combined fuzzy C-mean clustering with particle swam optimization. International Journal of Computational Intelligence and Applications 19(2), 1-26.

[50] Pattanayak, R.M., Panigrahi, S., Behera, H.S., et al., 2020. High-order fuzzy time series forecasting by using membership values along with data and support vector machine. Arabian Journal for Science and Engineering. 45(12), 10311-10325.

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ARTICLE

Comparison of Websites Employing Search Engine Optimization and Live Data

***Subhradeep Maitra*[1], *Laxminarayan Sahoo*[1*], *Supriyan Sen*[1], *Kalishankar Tiwary*[2]**

[1] *Department of Computer and Information Science, Raiganj University, Raiganj, 733134, India*
[2] *Department of Mathematics, Raiganj University, Raiganj, 733134, India*

ABSTRACT

This study compares websites that take live data into account using search engine optimization (SEO). A series of steps called search engine optimization can help a website rank highly in search engine results. Static websites and dynamic websites are two different types of websites. Static websites must have the necessary expertise in programming compatible with SEO. Whereas in dynamic websites, one can utilize readily available plugins/modules. The fundamental issue of all website holders is the lower level of page rank, congestion, utilization, and exposure of the website on the search engine. Here, the authors have studied the live data of four websites as the real-time data would indicate how the SEO strategy may be applied to website page rank, page difficulty removal, and brand query, etc. It is also necessary to choose relevant keywords on any website. The right keyword might assist to increase the brand query while also lowering the page difficulty both on and off the page. In order to calculate Off-page SEO, On-page SEO, and SEO Difficulty, the authors examined live data in this study and chose four well-known Indian university and institute websites for this study: www.caluniv.ac.in, www.jnu.ac.in, www.iima.ac.in, and www.iitb.ac.in. Using live data and SEO, the authors estimated the Off-page SEO, On-page SEO, and SEO Difficulty. It has been shown that the Off-page SEO of www.caluniv.ac.in is lower than that of www.jnu.ac.in, www.iima.ac.in, and www.iitb.ac.in by 9%, 7%, and 7%, respectively. On-page SEO is, in comparison, 4%, 1%, and 1% more. Every university has continued to keep up its own brand query. Additionally, www.caluniv.ac.in has slightly less SEO Difficulty compared to other websites. The final computed results have been displayed and compared.

Keywords: Search engine optimization; Live data; Off-page SEO; On-page SEO; SEO Difficulty

*CORRESPONDING AUTHOR:
Laxminarayan Sahoo, Department of Computer and Information Science, Raiganj University, Raiganj, 733134, India; Email: lxsahoo@gmail.com

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1. Introduction

Presently, search engines act as a centralized focus for all information, including those related to business, education, research, services [1,2], and so on. The patterns of searching have been substituted by search engines [3,4]. A lot of companies, organizations, banking industries, and educational establishments rely on search engines to bring people, students, and users [5]. These organizations need not spend cash on advertising by publishing ads in newspapers, magazines, television, radio broadcasting, etc. Most clients utilize search engines to find information when they make their business [6-8]. This search yields a list of URLs at which relevant information is probably present as a search result. The webpage link for the organization or institute will pop up in the search results to attract individuals for their purposes and revenue [9]. The positioning of the website link within the search result is another crucial factor related to search results. Being found on the top page of search results is preferable [10,11]. Website URLs must be search engine optimized in order to show up in results pages. SEO is the systematic technique of upgrading the internal and external characteristics of a website in order to maximize the number of exposures obtained from search engines [12-15]. SEO providers differ throughout their focus; some are highly specialized, while others take a more broad and general strategy. Many SEOs feel themselves to be in the broad subject of Web site optimization because optimizing a Web site for search engines can require examining so many factors. Websites have a variety of features such as content, links, structure, social networking sites, reputation, etc. These characteristics are crucial for making websites compatible with search engines [16]. Search engines rank web pages based on how relevant these characteristics seem to be. Here are some characteristics and their functions: The content exerts a strong influence on a one- or two-sentence description of the webpage's content. Keywords that are frequently used by internet users when searching should be the highlight of every website content. One factor used mostly by search engines for ranking is the prominence of a keyword. Trust is a fascinating characteristic of a website. Every company wants to boost the number of website visitors, or "traffic", to their web pages. A webpage develops a value based on its contents if it attracts a significant number of visitors. Webpage links might display in a favorable position in search engine results if the information is acceptable. The website may receive direct or referred traffic. The layout and development of a website are covered by web design characteristics. Since website speed is one of the factors considered by the search engine, websites should be developed to boost website performance. Websites should be developed for better accessibility [17,18], meaning that it should not take forever to start. Archiving a website is one method to accelerate loading. A web server's speed may be enhanced by writing good programming. URLs cannot be overcrowded; it should be simple and free of underscores [19,20]. **Table 1** lists the significant contributions of several authors to SEO and its applications.

Here, we investigated four websites' real-time data to see how the SEO technique might be used for things like brand queries, removing page difficulty, and website page rank. In every website, selecting relevant keywords is also essential. The right keyword could help to lessen the page difficulty for both on and off the page while also increasing brand query. In order to calculate Off-page SEO, On-page SEO, and SEO Difficulty in this article, we have considered live data. For illustrative purposes, we looked at the websites of four reputable Indian universities. Using live data and SEO, we were able to determine the Off-page SEO, On-page SEO, and SEO Difficulty. Finally computed results have been presented and compared.

2. Some technical preliminaries

To set up the rest of the work, various technical terms have been discussed in this section.

(i) Domain Authority

Domain Authority (DA) is a search engine ranking score developed by Moz that reflects how often

Table 1. Significant contributions of different authors to SEO and its applications.

References	Year	Significant contributions
Thatcher [21]	2008	The impact of web experience and task type on web search strategies
Monchaux et al. [22]	2015	Effects of prior domain knowledge and the challenge of the information problems to be solved on query techniques during information search
Kutlwano et al. [23]	2018	As indicators of search intent in sponsored search, keyword length and matching choices
Vyas [24]	2019	Analyzing state tourism websites with search engine optimization techniques
Mata et al. [25]	2020	Digital marketing and SEO: Current Situation and Future Prospects
Nadeem et al. [26]	2020	An innovative method of ranking without Off-page SEO
Varsha et al. [27]	2021	Search Engine Optimization: A Quick Overview
Saura [28]	2021	Framework, procedures, and performance measures for the use of data sciences in digital marketing
Lambrecht [29]	2022	Recommendations for Voice Search Optimization under the Influence of Digital Assistants on Search Engine Strategies
Erdmann [30]	2022	The long-term plan for choosing keywords in search engine optimization
Maitra et al. [31]	2022	Considering and analyzing the Amazon A10 and A11 search algorithms
Maitra et al. [32]	2022	Search engine optimization strategies and techniques
Maitra et al. [33]	2023	Selection of an Online Learning Platform during the COVID-19 Pandemic Using Multi-Criteria Decision Making and the TOPSIS Method

a website may rank in search engine result pages (SERPs). Domain Authority scores vary from 1 to 100 and higher values of DA reflect a higher probability of ranking.

(ii) Open Page Rank

The goal of the Open Page Rank effort was just to revive Page Rank measures such that different domains could have been compared easily. This is accomplished with the use of open-source data through Common Crawl and Common Search.

(iii) Off-page SEO Difficulty

The Off-page SEO Difficulty is a grade out of 100 that evaluates the link equity of the top ten results on Google's first page for a specified search query. It is calculated using the following formula:

$$\text{Off-Page SEO Difficulty} = 0.75 \times \text{Moz-DA Score} + 0.25 \times \text{Ten times of Open Page Rank Score}$$

(iv) On-page SEO Difficulty

The On-page SEO Difficulty is a grade out of 100 that shows how often the top 10 results for a specific search query are optimized. It can be scored using the set of rules as follows:

Rule 1: If the exact search query or its plural matches the page title then the score will be 15 points.

Rule 2: If the exact search query or its plural is present in the URL then the score will be 5 points.

Rule 3: If the exact search query or its plural is present in the description then the score will be 15 points.

Rule 4: If a comprehensive search query or its plural matches the page title then the score will be 25 points.

Rule 5: If a comprehensive search query or its plural is present in the URL then the score will be 10 points.

Rule 6: If a comprehensive search query or its plural is present in the description then the score will be 10 points.

Rule 7: If Google highlighted keywords present in the description, then the score will be 30 points.

Generally, the On-page SEO Difficulty score is ranging from 90 to 100.

(v) Brand Queries

Brand Queries are search keywords that include a brand's name. In such scenarios, Google will prefer displaying the brand's website and social media backlinks over any other website. As a result, ranking for brand queries is significantly more difficult. Search query as a brand query may be viewed in the following scenarios:

(a) For the first relevant result, Google displays site links.

(b) The top three responses all come from the same website.

(c) Two or more results on the first page of Google have come from social platforms like Twitter, Facebook, Linkedin, Instagram, etc.

(v) SEO Difficulty

The On-page Difficulty, Off-page Difficulty, and Brand Query Difficulty each contribute to the SEO Difficulty score. It is calculated using the following formula:

$$\begin{aligned}\text{SEO Difficulty} = (&0.65 \times \text{Off-Page Difficulty} \\ &+ 0.35 \times \text{On Page Difficulty}) \\ &+ 20\% \text{ bonus from branded quaries}\end{aligned}$$

2.1 Cost for search engine optimization

Search engine optimization (SEO) is a collection of techniques aimed at enhancing a website's positioning and usability in natural search results. These SEO techniques include On-page, Off-page, Technical, Mobile, and Content strategies, among others. Simply described, search engine optimization (SEO) is the process of making a website more effective so that it appears higher in search results on engines like Google, Bing, Yahoo, and others. When a user searches for a word or phrase related to the website, this will help the audience find the website on search engines. To assist customers in improving the search engine rankings of any website, the in-house professionals develop the full SEO strategy and also carry it out for customers. The in-house SEO specialists work nonstop to improve customer results on search engines. Putting the concept into action is a group of highly skilled SEO specialists who rank websites for the keywords that matter most to organizations.

Different SEO companies have different cost models but here are the four most common SEO cost models viz. (i) Hourly Rate, (ii) Project-Based, (iii) Monthly Retainer and (iv) Self-service.

Hourly Rate: When an SEO company or consultant charges by the hour for SEO work, this is known as hourly rate pricing. The hourly rate option enables one to contract with an SEO firm for a predetermined number of hours and pay them in accordance with those hours. It is suitable for small businesses with limited budgets.

Project-Based: When an SEO business charges a defined sum to accomplish a particular project, this is known as project-based SEO pricing. It helps businesses that have clear SEO goals.

Monthly Retainer: When a client pays a monthly charge for a predetermined set of SEO deliverables, this is known as a monthly retainer. It is helpful for all businesses that want to scale their SEO consistently.

Self-service: Self-service is exactly what it sounds like. One can visit the website of an agency, select the SEO work, and pay for it with a few clicks. It helps small and medium businesses who are happy to take more control of their SEO.

2.2 Uniform distribution

A random variable r is said to have a uniform distribution if its probability density function is given by:

$$f(r) = \begin{cases} \frac{1}{b-a} & \text{if } a \le r \le b \\ 0 & \text{otherwise} \end{cases}$$

We have denoted this distribution as $U(a,b)$, where a and b are two real-valued numbers such that $a < b$.

In Excel, we have generated random numbers using ***RAND ( )*** function, which returns random values between 0 and 1.

Therefore, any random values between a and b with $a < b$ can be generated using the following algorithm.

Algorithm 1

Step-1: Read as a,b inputs

Step-2: $m = \text{RAND}()$

Step-3: Return $a + m(b - a)$

3. Calculation of different SEO parameters

In this section, we have determined the Off-page SEO, On-page SEO, and SEO Difficulty of a few renowned Indian educational institutions, including the University of Calcutta (CU), Jawaharlal Nehru University (JNU), the Indian Institute of Management, Ahmadabad (IIM-A), and the Indian Institute of Technology, Bombay (IIT-B).

3.1 For Calcutta University

We have set the lowest and maximum limits of the MoZ DA for the University of Calcutta as 48.00 and 55.00, respectively. We considered the data over a 15-day period, and we generated 10 floating point values with a uniform distribution over the range [48.00, 55.00]. **Table 2** contains the computed 10 MoZ DA values. **Table 2** details University of Calcutta's Off-page SEO, On-page SEO, and SEO Difficulty. **Table 3** presents the details of Off-page SEO, On-page SEO and SEO Difficulty for University of Calcutta.

From Google Page Rank Checker (http://www.sitecheckers.pro/page-rank/) live data of Calcutta University we have taken Open Page Rank of University of Calcutta as 4.4. Top pages by linkings of this University are given in **Table 4**.

Table 2. 10 MoZ DA values for University of Calcutta.

No.	1	2	3	4	5	6	7	8	9	10
MoZ DA	52.02	49.47	51.54	48.80	51.83	53.49	53.95	51.25	48.98	53.42

Table 3. Off-page SEO, On-page SEO and SEO Difficultyfor University of Calcutta.

WEBSITE	Off-page SEO	On-page SEO	SEO Difficulty
www.caluniv.ac.in	50.00	94.88	65.70
	50.91	92.36	65.41
	50.34	91.69	65.48
	50.44	91.27	65.65
	50.27	92.14	65.58
	50.10	91.85	65.64
	50.48	93.48	65.65
	50.17	96.28	50.46
	50.15	98.77	50.50
	50.81	90.19	50.58

Table 4: Top pages by links of University of Calcutta.

Page/URL	Page Authority (PA)
https://www.caluniv.ac.in/	56
https://caluniv.ac.in/	49
https://www.caluniv.ac.in/About%20the%20university/university_frame.htm	46
https://www.caluniv.ac.in/about/vc.html	46
https://www.caluniv.ac.in/convocation-2012/hony_degrees.htm	45
https://www.caluniv.ac.in/university_campuses/university_frame.htm	45
https://www.caluniv.ac.in/student/student.html	44

Domain Authority (DA) of University of Calcutta in different search engines has been presented in **Table 5**. Graphical representation of discovered and lost linking domain of University of Calcutta has been shown graphically in **Figure 1**. Green for discovered linking and red for lost linking.

Table 5. Domain Authority (DA) of University of Calcutta in different search engine.

Domain Name	Domain Authority (DA)
https://en.wikipedia.org/	98
https://sites.google.com/	97
https://plus.google.com/	97
https://europa.eu/	97
https://github.com/	96
https://bbc.co.uk/	95
https://fr.wikipedia.org/	95

3.2 For Jawaharlal Nehru University

For Jawaharlal Nehru University, the MoZ DA lower and upper limits are 60.00 and 70.00 respectively. We considered the data throughout a 15-day period and we have considered 10 values using uniform distribution in a range of [60.00, 70.00]. **Table 6** contains the computed 10 MoZ DA values. Details on Jawaharlal Nehru University's Off-page SEO, On-page SEO, and SEO Difficulty are shown in **Table 7**.

We have collected the Open Page Rank of Jawaharlal Nehru University 4.5 from Google Page Rank Checker's (www.sitecheckers.pro/page-rank/) live data for the university. **Table 8** presents the Domain Authority (DA) of Jawaharlal Nehru University in different search engines. **Table 9** lists the top pages of this university that have links to them.

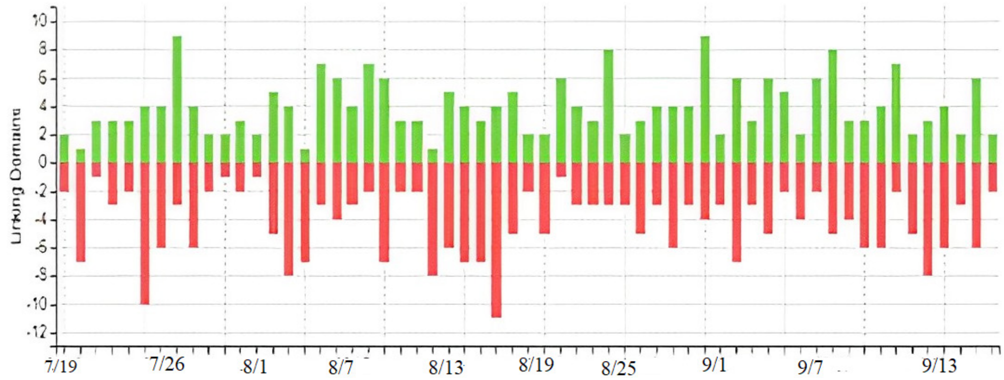

Figure 1. Diagram of discovered and lost linking domain of Calcutta University.

Table 6. MoZ DA for Jawaharlal Nehru University.

No.	1	2	3	4	5	6	7	8	9	10
MoZ DA	66.65	64.52	65.88	63.17	68.72	60.94	69.24	64.6	68.22	69.39

Table 7. Off-page SEO, On-page SEO and SEO Difficulty for Jawaharlal Nehru University.

WEBSITE	Off-page SEO	On-page SEO	SEO Difficulty
www.jnu.ac.in	61.28	98.84	74.42
	59.68	95.42	72.18
	60.21	95.73	72.71
	59.82	95.15	72.47
	60.34	98.12	74.25
	60.95	99.15	72.37
	60.72	98.91	73.86
	61.03	99.67	73.46
	61.09	98.02	73.95
	50.81	97.10	72.55

Table 8. Domain Authority (DA) of Jawaharlal Nehru University in different search engine.

Domain Name	Domain Authority (DA)
https://microsoft.com/	99
https://docs.google.com/	98
https://en.wikipedia.org/	98
https://sites.google.com/	97
https://plus.google.com/	97
https://europa.eu/	97
https://github.com/	96

Table 9. Top pages by links of Jawaharlal Nehru University.

Page/URL	Page Authority (PA)
https://www.jnu.ac.in/	60
https://jnu.ac.in/sites/default/files/Court.pdf	56
https://www.jnu.ac.in/main/	53
https://jnu.ac.in/	52
https://www.jnu.ac.in/career	51
https://www.jnu.ac.in/Career/currentjobs.htm	51
https://admissions.jnu.ac.in/	50

Figure 2 displays a graphical representation of Jawaharlal Nehru University's discovered and lost linking domain. Red for lost linking and green for discovered linking.

3.3 For Indian Institute of Management, Ahmadabad (IIM-A)

The MoZ DA lower and upper limits for IIM-A are 54.00 and 61.00 respectively. We took into consideration the data during a 15-day timeframe, computing 10 values with a uniform distribution over the range [54.00, 61.00]. **Table 10** contains the computed 10 MoZ DA values. Details on Off-page SEO, On-page SEO, and SEO Difficulty for IIM-A are provided in **Table 11**.

The Open Page Rank of IIM-A is 4.26 based on live data from Google Page Rank Checker (www.sitecheckers.pro/page-rank/). **Table 12** displays the Domain Authority (DA) of IIM-A across several

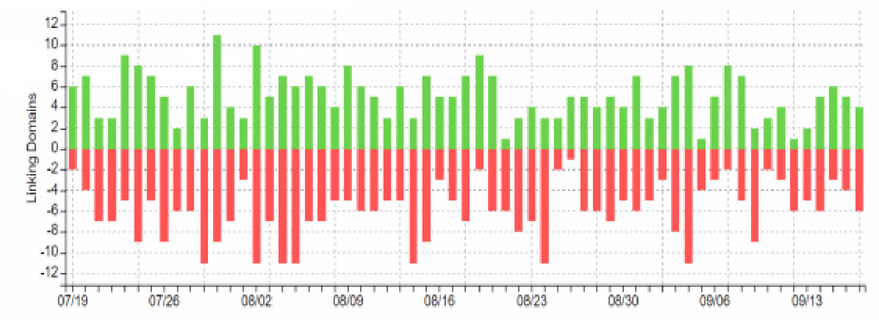

Figure 2. Diagram of discovered and lost linking domain of Jawaharlal Nehru University.

Table 10. 10 MoZ DA values of IIM-A.

No.	1	2	3	4	5	6	7	8	9	10
MoZ DA	55.51	54.98	60.63	56.99	60.22	59.8	59.82	55.78	55.81	59.83

Table 11. Off-page SEO, On-page SEO and SEO Difficulty for IIM-A.

WEBSITE	Off-page SEO	On-page SEO	SEO Difficulty
www.iima.ac.in	52.28	99.48	68.79
	51.88	99.26	68.46
	52.28	99.59	68.48
	52.32	97.67	68.40
	52.59	98.67	68.22
	52.36	97.33	68.98
	52.28	97.10	68.40
	52.31	98.71	68.44
	52.34	98.72	68.91
	52.44	98.49	68.09

search engines. **Table 13** lists the top pages of this university that have links to it.

Table 12. Domain Authority (DA) of IIM-A in different search engine.

Domain Name	Domain Authority (DA)
https://en.wikipedia.org/	99
https://sites.google.com/	97
https://adobe.com/	97
https://cnn.com/	95
https://bbc.co.uk/	95
https://fr.wikipedia.org/	95
https://wikimedia.org/	95

In **Figure 3**, the discovered and lost linking domains of IIM-A are represented graphically. Green indicates a discovered link, whereas red indicates a lost link.

3.4 For Indian Institute of Technology Bombay (IIT-B)

The lower and upper limits of the MoZ DA are 55.00 and 63.00 respectively for IIT-B. We also included the data throughout a period of 15 days, and we estimated 10 values using a uniform distribution mostly in spectrum [55.00, 63.00]. **Table 14** contains the computed 10 MoZ DA values. Details on Off-page SEO, On-page SEO, and SEO Difficulty for IIT-B are provided in **Table 15**. Domain Authority (DA) of IIT-B in the different search engines has been listed in **Table 16**. The top Pages by Links of IIT-B have been presented in **Table 17**.

Table 13. Top pages by links of IIM-A.

Page/URL	Page Authority (PA)
https://www.iima.ac.in/	50
https://www.iima.ac.in/web/iima	48
https://iima.ac.in/	47
https://www.iima.ac.in/web/iima/working-for-us/current-openings	44
https://www.iima.ac.in/web/pgp/apply/domestic/admission/selection-process	42
https://wimwian.iima.ac.in/wp-content/uploads/2019/07/Started-by-Shivendra-Singh-in-2016-in-Dubai-UAE-with-a-mission-to-bring-technology-innovation-in-the-farming-sector-Barton-Breeze-focuses-on-Hydroponics.jpg	41
https://web.iima.ac.in/assets/snippets/workingpaperpdf/7258816322015-03-07.pdf	41

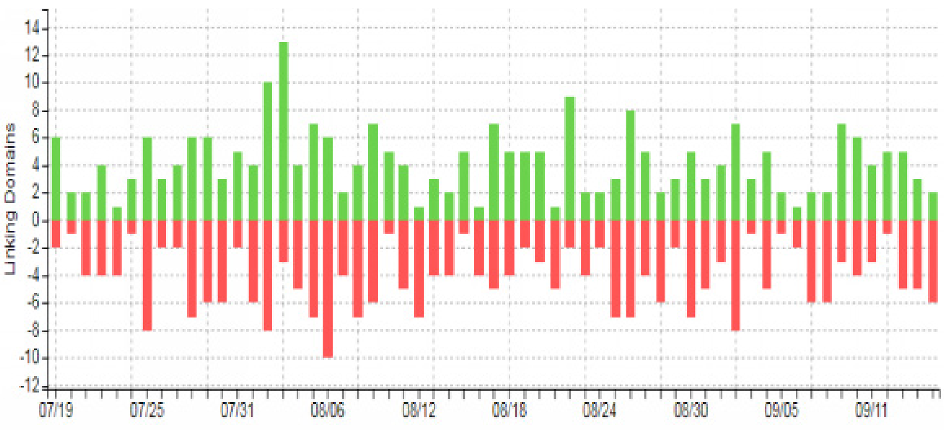

Figure 3. Diagram of discovered and lost linking domain of IIM-A.

Table 14. 10 MoZ DA values for IIT-B.

No.	1	2	3	4	5	6	7	8	9	10
MoZ DA	56.51	55.98	61.63	52.99	59.22	58.8	60.82	61.78	63.81	58.83

Table 15. Off-page SEO, On-page SEO and SEO Difficulty for IIT-B.

WEBSITE	Off-page SEO	On-page SEO	SEO Difficulty
www.iitb.ac.in	52.28	99.76	68.79
	51.88	99.55	68.46
	52.28	99.41	68.48
	52.32	97.42	68.40
	52.59	98.89	68.22
	52.36	97.35	68.98
	52.28	97.75	68.40
	52.31	98.72	68.44
	52.34	98.77	68.91
	52.44	98.40	68.09

Table 16. Domain Authority (DA) of IIT-B in different search engine.

Domain Name	Domain Authority (DA)
https://www.google.com/	100
https://youtube.com/	100
https://microsoft.com/	99
https://docs.google.com/	98
https://mozilla.org/	98
https://en.wikipedia.org/	98
https://sites.google.com/	97

Table 17. Top pages by links of IIT-B.

Page/URL	Page Authority (PA)
https://www.iitb.ac.in/	64
https://www.iitb.ac.in/~pge	57
https://www.gymkhana.iitb.ac.in/~smp	57
https://www.civil.iitb.ac.in/~gpatil	57
https://www.ircc.iitb.ac.in/IRCC-Webpage/rnd/HRMSLoginPage.jsp	56
https://www.idc.iitb.ac.in/	56
https://www.gate.iitb.ac.in/	56

In **Figure 4**, a graphical representation of the IIT-B's discovered and lost linking domains is displayed. Red for a lost link and green for a link that has been discovered.

3.5 Expected values of SEO parameters

For the four Indian educational institutions listed here, the University of Calcutta, Jawaharlal Nehru University, the Indian Institute of Management, Ahmadabad, and the Indian Institute of Technology, Bombay; we have presented (see **Table 18**) expected/average parametric values in terms of next integer for Off-page SEO, On-page SEO, and SEO Difficulty out of 100. A graphical representation has been depicted in **Figure 5**.

From **Figure 5** it has been observed that the Off-page SEO of CU, IIM-A and IIT-B are 51.00, 53.00 and 53.00 respectively. While JNU's Off-page SEO score is 60. Simply said, Off-page SEO tells Google or other search engines how other people feel about their website. Search engines will infer, for instance, that they have excellent information that offers users value if they have provided a lot of quality links connecting to the websites. If configured effectively, On-page SEO ranking indicators can have a significant impact on a web page's potential to rank. The higher On-page SEO factors, such as a content page's quality, good content, etc., have an impact on search engine rankings. It is evident from **Figure 5** that four institutes have a higher impact on society. SEO Difficulty is an SEO parameter that determines how challenging it would be to appear on Google's first page for a specific search. On a scale from 0 to 100, with 100 being the most difficult to rank for,

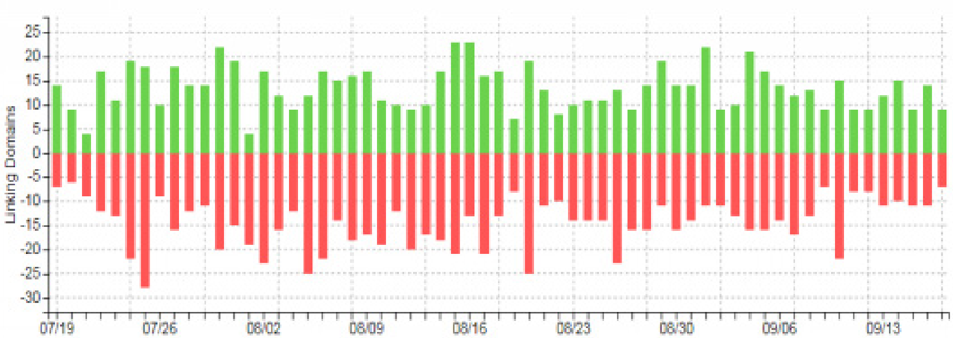

Figure 4. Diagram of discovered and lost linking domain of IIT-B.

Table 18. Expected values of SEO parameters.

Name of the University/Institute	Off-page SEO	On-page SEO	SEO Difficulty	Brand Query
University of Calcutta (www.caluniv.ac.in)	51.00	94.00	62.00	Yes
Jawaharlal Nehru University (www.jnu.ac.in)	60.00	98.00	74.00	Yes
Indian Institute of Management Ahmadabad (www.iima.ac.in)	53.00	99.00	69.00	Yes
Indian Institute of Technology Bombay (www.iitb.ac.in)	53.00	99.00	69.00	Yes

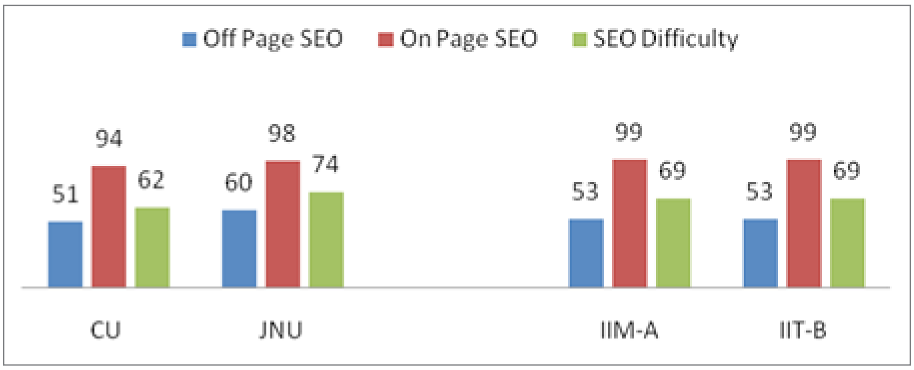

Figure 5. A graphical representation of Off-page SEO, On-page SEO, and SEO Difficulty.

it is evaluated. From **Figure 5** it has been seen that IIM-A and IIT-B have the same values. On the other hand CU has lesser value compared to JNU. But all the institutes have higher SEO Difficulty values.

4. Concluding remarks

In this article, we have examined websites that take live data into account through search engine optimization (SEO). A set of measures considered search engine optimization that can help a website rank highly in search engine results. Here, we have investigated several SEO factors, including MoZ DA, Page Authority (PA), Off-page SEO, On-page SEO, SEO Difficulty, etc. The main problem for all web developers/website owners is their website's poor page rank, congestion, usage, poor look on search engines. As real-time data would show how the SEO strategy may be applied to website page rank, page difficulty removal, and brand query, among other things, we have investigated live data of four websites under this instance. In order to calculate Off-page SEO, On-page SEO, and SEO Difficulty, we relied on live data in this study. For the sake of explanation, we have considered websites of four reputable Indian universities and institutes. Using live data and SEO, we determined the Off-page SEO, On-page SEO, and SEO Difficulty. The estimated outcomes have finally been shown and compared.

Here, we have performed a comparative analysis of websites employing search engine optimization while considering real data and some existing parameters and their relationships. For the calculation of various SEO factors, we have additionally proposed several formulas. Such techniques can be used to explore various websites for further study.

Author Contributions

S.M., L.S., S.S. and K.T. formulate and studied the problem. S.M., L.S., S.S. and K.T. wrote the first draft of the manuscript. All authors have read and agreed to the final version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Belsare, S., Patil, S., 2012. Study and evaluation of user's behavior in e-commerce using data. Research Journal of Recent Sciences. 1, 375-387.

[2] Cho, J., Roy, S., 2004. Impact of search engines on page popularity. Proceedings of the 13th International Conference on World Wide Web; 2004 May 17-22; New York. p. 20-29.

[3] Knezeric, B., Vidas-Bubanja, M. (editors), 2010. Search engine marketing as key factor for generating quality online visitors. MIPRO, 2010 Proceedings of the 33rd International Convention; 2010 May 24-28; Opatija, Croatia. USA: IEEE. p. 1193-1196.

[4] Jain, A., 2013. The role and importance of search engine and search engine optimization. International Journal of Emerging Trends & Technology in Computer Science. 2(3), 99-102.

[5] Raorane, A.A., Kulkarni, R.V., 2012. Association rule—Extracting knowledge using market basket analysis. Research Journal of Recent Sciences. 1(2), 19-27.

[6] Bhandari, R.S., Bansal, A., 2018. Impact of search engine optimization as a marketing tool. Jindal Journal of Business Research. 7(1), 24-36.

[7] Poongkode, J.P.S., Nirosha, V., 2014. A study on various search engine optimization techniques. International Journal of Innovative Research in Computer and Communication Engineering. 2(11), 6738-6742.

[8] Zhang, S., Cabage, N., 2016. Search engine optimization: Comparison of link building and social sharing. Journal of Computer Information Systems. 57(2), 148-159.

[9] Page, L., Brin, S., Motwani, R., et al., 1999. The page rank citation ranking: Bringing order to the web. The web conference. Stanford Info. Lab: USA.

[10] Sharma, D., 2010. A comparative analysis of web page ranking algorithms. International Journal on Computer Science and Engineering. 2(8), 2670-2676.

[11] Shahzad, A., Nawi, N.M., Hamid, N.A., et al., 2017. The impact of search engine optimization on the visibility of research paper and citations. International Journal of Informatics Visualization. 4(2), 195-198.

[12] Giomelakis, D., Veglis, A.A., 2019. Search engine optimization. Advanced methodologies and technologies in network architecture, mobile computing, and data analytics. IGI Global: Hershey. pp. 1789-1800.

[13] Green, E.A., Markey, K. L., Kreider, M. (inventors), 2016. Subject Matter Context Search Engine. US Patent. 8,832,075,B2. 2016 Apr 12.

[14] Jin, X., Wah, B.W., Cheng, X., et al., 2015. Significance and challenges of big data research. Big Data Research. 2(2), 59-64.

[15] Davenport, T.H., Dyche, J., 2016. Big Data in Big Companies [Internet]. Available from: https://www.iqpc.com/media/7863/11710.pdf

[16] Seymour, T., Frantsvog, D., Kumar, S., 2011. History of search engines. International Journal of Management & Information Systems. 15(4), 47-58.

[17] Amazon e-Market Place [Internet]. Available from: www.amazon.com

[18] Robertson, S.A., 2019. Brief history of search results ranking. IEEE Annals of the History of Computing. 41, 22-28.

[19] Tekiner, F.J., Keane, A., 2014. Big data framework. IEEE International Conference on Systems, Man and Cybernetics; 2013 Oct 3-16. Manchester. New York: IEEE. p. 1494-1499.

[20] Luh, C.J., Yang, S.A., Huang, T.L.D., 2016. Estimating Google's search engine ranking function from a search engine optimization perspective. Online Information Review. 40(2), 1-29.

[21] Thatcher, A., 2008. Web search strategies: The influence of Web experience and task type. Information Processing & Management. 44(3), 1308-1329.

[22] Monchaux, S., Amadieu, F., Chevalier, A., et al., 2015. Query strategies during information searching: Effects of prior domain knowledge and complexity of the information problems to be solved. Information Processing & Management. 51(5), 557-569.

[23] Kutlwano, K.K.M., Ramaboa, P.F., 2018. Keyword length and matching options as indicators of search intent in sponsored search. Information Processing & Management. 54(2), 175-183.

[24] Vyas, C., 2019. Evaluating state tourism websites using search engine optimization tools. Tourism Management. 73, 64-70.

[25] Matta, H., Gupta, R., Agarwal, S. (editors), 2020. Search engine optimization in digital marketing: Present scenario and future scope. 2020 International Conference on Intelligent Engineering and Management (ICIEM); 2020 June 17-19; London, UK. New York: IEEE. p. 530-534.
DOI: https://doi.org/10.1109/ICIEM48762.2020.9160016

[26] Nadeem, A., Hussain, M., Iftikhar, A. (editors), 2020. New Technique to Rank Without Off Page Search Engine Optimization, 2020 IEEE 23rd International Multitopic Conference (INMIC); 2020 Nov. 5-7; Bahawalpur. New York: IEEE. p. 1-6.

[27] Grover, P.S., Ahuja, L. (editors), 2021. An overview of search engine optimization. 2021 9th International Conference on Reliability. Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO); 2021 Sep 03-04; Noida. New York: IEEE. p. 1-6.

[28] Saura, J.R., 2021. Using data sciences in digital marketing: Framework, methods, and performance metrics. Journal of Innovation & Knowledge. 6(2), 92-102.

[29] Lambrecht, P., Peter, M.K., 2022. The influence of digital assistants on search engine strategies: Recommendations for voice search optimization. Marketing and smart technologies, smart innovation, systems and technologies. Springer: Singapore. pp. 280.
DOI: https://doi.org/10.1007/978-981-16-9272-7_55

[30] Erdmann, A., Arilla, R., Ponzoa, J.M., 2022. Search engine optimization: The long-term strategy of keyword choice. Journal of Business Research. 144, 650-662.

[31] Maitra, S., Sahoo, L., Tiwary, K.S., 2022. Study, analysis and comparison between Amazon A10 and A11 search algorithm. Journal of Computer Science Research. 4(4), 1-6.

[32] Maitra, S., Sahoo, L., Tiwary, K.S., 2022. Methods and strategies for search engine optimization. COJ Robotics & Artificial Intelligence. 2(2), 1-7.

[33] Maitra, S., Sahoo, L., Lahiri Dey, J., et al., 2023. Multi-criteria decision making and its application to online learning platform selection during the COVID-19 pandemic based on TOPSIS method. Real life applications of multiple criteria decision-making techniques in fuzzy domain, studies in fuzziness and soft computing. Springer: Singapore. pp. 420.
DOI: https://doi.org/10.1007/978-981-19-4929-6_23

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ARTICLE

Inquiring Natural Language Processing Capabilities on Robotic Systems through Virtual Assistants: A Systemic Approach

Ioannis Giachos[1], *Evangelos C. Papakitsos*[1*], *Petros Savvidis*[1,2], *Nikolaos Laskaris*[1]

[1] *Department of Industrial Design & Production Engineering, University of West Attica, Egaleo, Athens, 12241, Greece*
[2] *Research Laboratory of Electronic Automation, Telematics and Cyber-Physical Systems, University of West Attica, Egaleo, Athens, 12241, Greece*

ABSTRACT

This paper attempts to approach the interface of a robot from the perspective of virtual assistants. Virtual assistants can also be characterized as the mind of a robot, since they manage communication and action with the rest of the world they exist in. Therefore, virtual assistants can also be described as the brain of a robot and they include a Natural Language Processing (NLP) module for conducting communication in their human-robot interface. This work is focused on inquiring and enhancing the capabilities of this module. The problem is that nothing much is revealed about the nature of the human-robot interface of commercial virtual assistants. Therefore, any new attempt of developing such a capability has to start from scratch. Accordingly, to include corresponding capabilities to a developing NLP system of a virtual assistant, a method of systemic semantic modelling is proposed and applied. For this purpose, the paper briefly reviews the evolution of virtual assistants from the first assistant, in the form of a game, to the latest assistant that has significantly elevated their standards. Then there is a reference to the evolution of their services and their continued offerings, as well as future expectations. The paper presents their structure and the technologies used, according to the data provided by the development companies to the public, while an attempt is made to classify virtual assistants, based on their characteristics and capabilities. Consequently, a robotic NLP interface is being developed, based on the communicative power of a proposed systemic conceptual model that may enhance the NLP capabilities of virtual assistants, being tested through a small natural language dictionary in Greek.

Keywords: Natural language processing; Robotic systems; Virtual assistant; Human-robot interface

*CORRESPONDING AUTHOR:
Evangelos C. Papakitsos, Department of Industrial Design & Production Engineering, University of West Attica, Egaleo, Athens, 12241, Greece; Email: papakitsev@uniwa.gr

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1. Introduction

One of the most important parts of an advanced humanoid robot is the communication function. More specifically, the way that it receives orders from a person, or an interlocutor, as well as the means by which it returns information to him/her. The Human-Robot Interface (HRI) of an advanced humanoid robot consists of a unit to collect the natural language input, a unit to process the received sentences and a unit for the semantic representation of these sentences [1]. This is exactly what the robotic system needs to be able to process for understanding commands in natural language. So, there is a Natural Language Processing (NLP) unit that aims to analyze incoming sentences/commands and a Natural Language Understanding (NLU) unit for understanding these sentences. The recognized request is forwarded to subsequent units to begin the response process. This part of the machine that is described above is found autonomously in many applications for many years, such as an Intelligent Virtual Assistant (IVA) or Intelligent Personal Assistant (IPA). The subtle difference between them is that an IVA is an artificial intelligence (AI) software that can provide interactive and personalized services to users through voice and text-based interactions. It is designed to assist users in performing tasks, answering questions, providing recommendations, and facilitating transactions. An IVA can be integrated into various devices and applications, such as smart phones, smart home devices, chat-bots, and customer service platforms. On the other hand, an IPA is a type of virtual assistant that is designed to provide personalized assistance to individual users, based on their preferences, habits, and history. It can be integrated into various devices, such as smart phones, smart watches, and smart speakers, to help users perform tasks, manage information, and control their environments by using voice or text commands.

The first system known that responded to a voice command was a commercial children's toy produced in 1922 by Elmwood Button Co [2], "Radio Rex". It was a toy dog and was responding to its name called. In fact, the toy's system was designed to be triggered when the vowel in "Rex" was sounded. A more complicated system that could be considered as an ancestor of IVA systems was a device called "Voder", which was developed by the Bell Telephone Laboratories in 1939 [3,4]. Voder was not a virtual assistant in the modern sense, but rather a machine that could synthesize human speech. It was one of the earliest examples of a speech synthesizer and was demonstrated at the 1939 World's Fair in New York. Voder consisted of a console with a keyboard and foot pedals, which were used to produce speech sounds by manipulating various controls. An operator could type out a message on the keyboard, and Voder would produce a synthetic speech output based on the input. While Voder was not an intelligent machine, like modern virtual assistants, it was a significant step forward, in the development of speech technology and paved the way for the future advanced speech synthesis and recognition systems. It's worth noting that there were also earlier attempts at speech synthesis, such as the "talking machines", invented in the late 1800s [5,6], but these were not electronic devices like Voder.

In the following decades, there were several recorded efforts, but also important steps towards evolution. The birth decade of virtual assistants was the 90s. The first virtual assistant, known as "Dr. Sbaitso", was released by Creative Labs in 1991 [7,8]. However, the term "virtual assistant" did not come into widespread use until the mid-2000s, with the introduction of Apple's Siri in 2011 and other similar voice assistants. Since then, there have been many virtual assistants, developed for various devices and platforms.

So, while the concept of a virtual assistant has been around since the early 1990s, the specific term "virtual assistant" refers to more recent developments in the field of AI and speech recognition. Nevertheless, nothing much is revealed about the nature of the human-robot interface of commercial IVAs, therefore, any new attempt of developing such a capability has to start from scratch. Accordingly, to include corresponding capabilities to a developing NLP system of a virtual assistant, a methodology of inquiring and development is required.

2. Methodology

Initially, in order to manage the necessary information on the NLP capabilities of an IVA, the systemic methodology in information management through the Organizational Method for Analyzing Systems technique (OMAS-III) [9] was utilized in this inquiry. The following subsections present the analysis and application of this methodology for the selection of literature references.

2.1 Systemic information management

Information management is the most critical activity of any research work. The concepts of systemic information management are shown in **Table 1** and discussed below.

The information cycle includes the collection of primary data ("input"), its processing and finally its dissemination ("output"). In each of these three phases, information is stored as a necessary activity of any information system. The three phases follow the General Systems Model (GSM) [10], since the collection phase corresponds to the input of the information system, while the dissemination phase corresponds to its output. Moreover, each phase has its own particular features.

The primary data are collected from their sources, which can be divided into primary, secondary and tertiary sources (see also Section 2.2, with regard to literature sources). The typology of the data refers to the form of their origin and is divided into oral, printed, electronic/digital and audiovisual (in the respective analogue media). The processing of data involves, in order, their evaluation, their structuring into categories (classification) and their correlation, both with each other and with other pre-existing data. This is followed by information generation, where conclusions (secondary information) are drawn from the primary data. Finally, information dissemination is carried out by the same means as in the typology of data collection. Data evaluation is discussed in more detail in the next section.

2.2 Systemic information assessment

Useful information should be valid, timely, specific, clear and complete (**Table 1**). Validity is investigated in terms of sources and requires cross-checking when there is a multiplicity of sources. It is assessed for its reliability and accuracy. Reliability increases, the more the data are collected from primary sources, their subject matter is known, the method of collection and the purpose of their display, as well. The timeliness of the information refers both to its short distance in time from the events under consideration (Recent) and to its collection at the time it is needed (Prompt). The relevant assessment questions are:

- How recent the data are?
- Are data out of date?
- Information specificity is about sorting out relevant information from irrelevant ("noise"). In research methodology, it also appears in the properties of Relevance and Significance [12]. In terms of relevance, the followings are considered:
- Are the research questions/objectives relevant to ours and therefore relevant to our research?
- Is the research context different and far removed from our research questions and objectives?
- Are there references to this item or its author in other useful data?
- Does the item support or contradict our arguments? (Both are useful.)

In terms of relevance, the following are considered:

- Do the data appear to be biased? Do they use irrational arguments, emotionally charged words, or do they only choose cases that support the conclusion drawn? Even so, it may be relevant to our critical review.
- Are there any methodological omissions in the work (e.g., sample selection, data collection, data analysis)? Even if there are, this may be relevant to our project.
- Is the accuracy sufficient? Even if it is not, it may be the only relevant evidence that can be found.

Table 1. Systemic information management [11].

<table>
<tr><td rowspan="7">Collection (Input)</td><td rowspan="3">Sources</td><td>Primary</td><td colspan="2" rowspan="3">Cross-checking</td></tr>
<tr><td>Secondary</td></tr>
<tr><td>Tertiary</td></tr>
<tr><td rowspan="4">Typology</td><td>Oral</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>Printed</td></tr>
<tr><td>Digital</td></tr>
<tr><td>Audio-visual</td></tr>
<tr><td rowspan="10">Processing</td><td rowspan="7">Evaluation</td><td rowspan="2">Valid</td><td>Credible</td><td rowspan="2">Cross-checking</td></tr>
<tr><td>Precise</td></tr>
<tr><td rowspan="2">Timely</td><td>Prompt</td><td rowspan="2"></td></tr>
<tr><td>Recent</td></tr>
<tr><td>Relevant</td><td colspan="2" rowspan="5"></td></tr>
<tr><td>Clear</td></tr>
<tr><td>Complete</td></tr>
<tr><td rowspan="2">Structuring</td><td>Classification</td></tr>
<tr><td>Correlation</td></tr>
<tr><td>Creation</td><td colspan="3">From Primary to Secondary</td></tr>
<tr><td>Dissemination</td><td colspan="4">(Output)</td></tr>
</table>

- Does the data provide suggestions for future research?

The clarity of the information is assessed in terms of the comprehensibility of the wording, while completeness can be tested in terms of communicative adequacy. This is where Systems Methodology makes a decisive contribution, by using the OMAS-III as a tool for assessing the completeness of information, by checking the following (through answering the "journalists' questions", shown below enclosed in parentheses):

- The purpose served ("Why?").
- The results/conclusions described ("Output/What?").
- The quantitative factors (means/resources) needed ("Input/How much?").
- The rules/conditions governing the research context ("How?").
- The human factor traits involved ("Who?").
- The characteristics of the location of the subject under investigation ("Where?").
- The temporal elements of the subject under consideration ("When?").

2.3 Application of systems methodology

The bibliographic references of the inquiry were selected according to the question: "How a virtual assistant understands?" The purpose is to investigate the techniques on the basis of which a virtual assistant nowadays can understand meanings from the sentences that reach it.

The search criteria applied are:

- Search engine: Scopus.
- Recent years: From 2019 to 2023.
- Keywords: Virtual assistant, natural language, NLP, machine learning, deep learning, language understanding, NLU, voice assistant, voice-controlled, smart devices, dialogue systems, deep neural networks, voice command, virtual agent, Human-Computer Interaction, speech recognition.
- Document type: Articles and reviews.
- Subject area: Computer science.
- Access: Open.

3. Inquiry

The conducted inquiry resulted in the following:

A search on virtual assistants returns more than a thousand articles. This number was reduced to 316, when the search was made more specific, by using the term "how they understand". Then, there was a further limitation, when the time span of the articles, within the last five years, was made more specific. The new number is 221 articles. By applying restrictions to the keywords (see Section 2.3), the number of articles became 137. Of these, by choosing to keep only articles and reviews, 39 remained. Then, when only those hosted in Open Access journals were kept, only 19 articles remained. The last criterion applied was computer science in the subject area. After this, the 12 articles below remained for discussion.

The 1st article [12] discusses parents' motivations for using virtual assistants (such as Amazon's Alexa or Google Assistant) with their children at home. The authors conducted interviews with parents, to understand how they use virtual assistants to support their children's learning and development.

In the 2nd study [13], the method used is Red Deer Optimization with AI-enabled image captioning system. The virtual assistant is designed to assist visually impaired people, by providing image captions that are generated using an AI algorithm. The Red Deer Optimization algorithm is used to optimize the performance of the AI model, for generating accurate and relevant image captions. The system uses deep learning techniques, such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), to process and analyze images and generate captions based on the content of the images. The virtual assistant is designed to be user-friendly and can be accessed through a mobile application or a web interface.

The 3rd article [14] discusses different methods for measuring the similarity between questions in Arabic. It does not mention any specific method used for virtual assistants to understand the questions. However, measuring the similarity between questions can be a useful component of NLP.

The 4th article [15] discusses various approaches to dialogue management in conversational systems. The article reviews different methods and techniques for dialogue management, such as rule-based, model-based, and reinforcement learning-based approaches.

The 5th article [16] does not focus on any specific virtual assistant or conversational system, but rather provides a broad overview of different approaches and challenges in dialogue management. Therefore, it does not describe a specific method used by a virtual assistant to understand user input. Instead, it provides a comprehensive review of different approaches that conversational systems can use to manage the dialogue.

In the 6th article [17], the issues discussed are faced by IVAs, such as Siri, Google Assistant, Cortana, and Alexa. These issues include voice recognition, contextual understanding, and human interaction. The authors conducted a survey of 100 users to understand their experiences with IVAs. The survey found that while IVAs offer many services, there are still improvements needed in voice recognition, contextual understanding, and hands-free interaction. The article aims to address these improvements, so that the use of IVAs can be increased. The main objective of the survey was to validate the real potential of IVAs and to guide users in choosing the best personal assistant for real-life scenarios. According to the 6th article [18], the method used for the virtual assistant to understand is a "semantic web framework". This framework involves the usage of ontologies, which are structured vocabularies that define relationships between concepts, to enable the virtual assistant to understand and respond to natural language queries, related to public health. The authors describe a case study where they applied this framework to develop a smart assistant for public health, which was able to accurately answer questions related to diseases, symptoms, and treatments.

In the 7th article [19], the Capsule Net architectures are used, for Intent detection and slot filling for a Romanian home assistant. The Capsule Net architecture is a type of deep learning neural network that aims to overcome the limitations of the traditional Convolutional Neural Network (CNN), by capturing the hierarchical relationships between features. The authors used this architecture for both intent detection and slot filling, in order to improve the accuracy of the Romanian home assistant's understanding of user queries. Intent detection involves identifying the user's intention or goal behind the query, while slot filling involves identifying specific pieces of information that are relevant to fulfilling that intention or goal. The authors demonstrated that their approach using Capsule Net architectures achieved higher accuracy, compared to other state-of-the-art methods in intent detection and slot filling for the Romanian home assistant.

The 8th article [20] does not appear to describe a specific method used by virtual assistants to understand natural language. Instead, the article focuses on the role of social identity and the extended self in collaboration with virtual assistants. It explores how users perceive and interact with virtual assistants and how the assistants can be designed to enhance collaboration with users. Therefore, the article does not describe a technical method of virtual assistants for understanding natural language, but rather a theoretical framework for understanding users' behaviour and preferences related to virtual assistants.

In the 9th article [21], the authors are investigating the factors that influence users' continued use of smart voice assistants.

The 10th article [22] discusses how NLP and other supporting technologies such as IoT and AI are used to enable virtual assistants to work as real-time assistants, providing technical and social assistance to users in various modes, such as secretarial work, customer service support, and web editing tasks. The authors also designed an intelligent virtual assistant that could be integrated with Google virtual services and work with the Google virtual assistant interface, using speech recognition, a knowledge base, and machine learning techniques to make the conversation between humans and software more natural.

The 11th article [23] explores the question of why it is helpful to have a digital assistant, specifically in the context of manufacturing. The article describes the components and benefits of digital assistants, such as mobility, voice interaction, a delegation of tasks, and rapid data analysis. The article notes that developing a digital assistant can be challenging, as customers may not benefit from all of its components immediately. Additionally, it argues that digital assistants have significant potential in manufacturing, where they can help to enhance the skills and capabilities of the remaining workforce, save employees' time, and contribute to increasing work efficiency.

The last article (12th) [24] discusses a method for building scalable multi-domain conversational agents, by using the Schema-Guided Dialogue Dataset. This dataset provides a schema that defines the possible intents, slots, and dialogue actions that a virtual assistant can recognize and generate, making it easier to train and evaluate virtual assistants across multiple domains. The method used involves fine-tuning pre-trained language models, such as BERT, and training dialogue models using supervised learning techniques on the dataset. The virtual assistant can then understand user input and generate appropriate responses, based on the defined schema.

4. Discussion

According to the above inquiry and studies, it is found that, while there is extensive discussion on the use of IVAs to address various problems and proposals for increased use, few words are said about how they operate. Specifically, it is known that an IVA typically works as shown below:

1) Input: The IVA receives input from the user, usually in the form of text or voice commands.

2) NLP: The IVA uses NLP algorithms to understand the user's input and extract the relevant information.

3) Knowledge Base: The IVA accesses a knowledge base, which contains information that the IVA can use to answer the user's questions or perform a task.

4) Decision Making: Based on the user's input and the information available in the knowledge base, the IVA makes a decision about how to respond to the user's request.

5) Output: The IVA generates a response to the

user, which can be in the form of text, voice, or other types of media.

6) Machine Learning: IVAs can also use machine learning techniques to improve their performance over time. As they interact with users, they can learn from their mistakes and become better at understanding and responding to users' requests.

Overall, the goal of an IVA is to provide a personalized, efficient, and intuitive user experience, similar to interacting with a human assistant. IVAs can be used in a variety of applications. However, because IVAs are commercial products, there is not much emphasis on how they work and how they understand natural language. As a result, research mostly focuses on how these products are used. This lack of information opens up a chapter on how to apply similar capabilities to those of commercial products on newly developing robotic systems.

Such a robotic system, being developed by the authors [25-27], is based on the communicative power of the OMAS-III systemic conceptual model and uses experimentally a small natural language dictionary in Greek. Special emphasis is given to the understanding aspect, with an NLU unit based on Hole Semantics [28,29], which recognizes gaps in expressions and tries to initially fill them, either with existing knowledge it possesses, or with questions to its interlocutor. This gap recognition ability is implemented through the journalists' questions of OMAS-III (see Section 2.2). Each question corresponds both to a part-of-speech (i.e. subject, object, verb, adverb, etc.) and simultaneously to a relevant semantic slot. If a slot is empty, which means an absence of information, then a semantic hole is created that has to be filled.

Special attention is given to how the system understands time through the sentences it receives and in combination with its existing developing knowledge. Such a system could be very important in many areas of application, such as healthcare, where it can sequence events that have occurred, as well as those that need to be implemented. The evaluation of the system's performance is undergoing, and relevant data are gathered to be presented in the near future. This inquiry also highlights a significant research gap in sequencing actions, given in random order.

5. Conclusions

Through the present study, it is understood that current virtual assistants are commercial products that the information revealed a focus on their functionality and not on the technical part of achieving their functionality. They include an NLP module to manage the human-robot interaction, yet, a gap was found in the description of IVAs comprehension techniques. Additionally, a research gap remains in arranging the temporal sequence of actions that such a system has to think about; not just time management but understanding time. On this gap, the authors are going to continue and expand their previous work [26,27], which is based on the communicative power of the OMAS-III systemic conceptual model. This conceptual model is being tested along with the framework of Hole Semantics, in order to allow a robot to handle missing information. The experimental use of conceptual modelling is currently under trials.

Author Contributions

I. Giachos conducted the inquiry, classified the results and edited the text. E.C. Papakitsos monitored the usage of systemic methodology and assessed the compatibility of the research criteria to the conceptual framework of Systems Science and OMAS-III; he also supervised the usage of NLP techniques. P. Savvidis evaluated the technical part of the virtual assistants and selected the suitable ones for further investigation. N. Laskaris supervised this research project, set the assessment criteria and evaluated the methodology, as well as the overall outcome.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Giachos, I., Piromalis, D., Papoutsidakis, M., et al., 2020. A contemporary survey on intelligent human-robot interfaces focused on natural language processing. International Journal of Research in Computer Applications and Robotics. 8(7), 1-20.

[2] Markowitz, J., 2003. Toys that Have a Voice. Speech Technology Magazine [Internet]. Available from: https://www.speechtechmag.com/Articles/ReadArticle.aspx?ArticleID=30031

[3] Juang, B.H., Rabiner, L.R., 2005. Automatic speech recognition—a brief history of the technology development. Rutgers University and the University of California, Santa Barbara. 1, 67.

[4] Gold, B., 1990. A history of Vocoder research at Lincoln Laboratory. The Lincoln Laboratory Journal. 3(2), 163-202.

[5] Lindsay, D., 1997. Talking head. American Heritage of Invention & Technology. 13(1).

[6] Suryadi, S., 2006. The "talking machine" comes to the Dutch East Indies: The arrival of Western media technology in Southeast Asia. Bijdragen Tot de Taal-,Land-En Volkenkunde/Journal of the Humanities and Social Sciences of Southeast Asia and Oceania. 162(2/3), 269-305.
DOI: https://doi.org/10.1163/22134379-90003668

[7] Deryugina, O.V., 2010. Chatterbots. Scientific and Technical Information Processing. 37(2), 143-147.
DOI: https://doi.org/10.3103/S0147688210020097

[8] Ahirwar, G.K., 2020. Chatterbot: Technologies, tools and applications. High Performance Vision Intelligence: Recent Advances. 913, 203-213.
DOI: https://doi.org/10.1007/978-981-15-6844-2_1

[9] Papakitsos, E., 2013. The systemic modeling via military practice at the service of any operational planning. International Journal of Academic Research in Business and Social Science. 3(9), 176-190.

[10] Sanders, M., 1991. Communication technology today and tomorrow. Glencoe/McGraw-Hill: New York.

[11] Παπακίτσος, Ε.Χ., 2008. Θέματα Σεμιναρίων Σχολικού Επαγγελματικού Προσανατολισμού (Greek) [Seminar Topics in School Vocational Guidance]. Αθήνα: Μ.-Χ.Χ. Χριστοδουλάτου.

[12] Saunders, M., Lewis, P., Thornhill, A., 2015. Research methods for business students (7th edition). Pearson Publication: Dallas.

[13] Wald, R., Piotrowski, J. T., Araujo, T., et al., 2023. Virtual assistants in the family home. Understanding parents' motivations to use virtual assistants with their Child(dren). Computers in Human Behavior. 139, 107526.
DOI: https://doi.org/10.1016/j.chb.2022.107526

[14] Hilal, A.M., Alrowais, F., Al-Wesabi, F.N., et al., 2023. Red deer optimization with artificial intelligence enabled image captioning system for visually impaired people. Computer Systems Science and Engineering. 46(2), 1929-1945.
DOI: https://doi.org/10.32604/csse.2023.035529

[15] Daoud, M., 2022. Topical and non-topical approaches to measure similarity between arabic questions. Big Data and Cognitive Computing. 6(3), 87.
DOI: https://doi.org/10.3390/bdcc6030087

[16] Brabra, H., Báez, M., Benatallah, B., et al., 2021. Dialogue management in conversational systems: A review of approaches, challenges, and opportunities. IEEE Transactions on Cognitive and Developmental Systems. 14(3), 783-798.
DOI: https://doi.org/10.1109/TCDS.2021.3086565

[17] Tulshan, A.S., Dhage, S.N., 2019. Survey on virtual assistant: Google Assistant, Siri, Cortana, Alexa. Advances in Signal Processing and Intelligent Recognition Systems, SIRS 2018. Communications in Computer and Information Science. 968, 190-201.
DOI: https://doi.org/10.1007/978-981-13-5758-9_17

[18] Sermet, Y., Demir, I., 2021. A semantic web framework for automated smart assistants: A case study for public health. Big Data and Cognitive Computing. 5(4), 57.
DOI: https://doi.org/10.3390/bdcc5040057

[19] Stoica, A., Kadar, T., Lemnaru, C., et al., 2021.

Intent detection and slot filling with capsule net architectures for a romanian home assistant. Sensors (Switzerland). 21(4), 1-28.
DOI: https://doi.org/10.3390/s21041230

[20] Mirbabaie, M., Stieglitz, S., Brünker, F., et al., 2021. Understanding collaboration with virtual assistants—The role of social identity and the extended self. Business and Information Systems Engineering. 63(1), 21-37.
DOI: https://doi.org/10.1007/s12599-020-00672-x

[21] Pal, D., Babakerkhell, M.D., Zhang, X., 2021. Exploring the determinants of users' continuance usage intention of smart voice assistants. IEEE Access. 9, 162259-162275.
DOI: https://doi.org/10.1109/ACCESS.2021.3132399

[22] Arora, S., Athavale, V.A., Maggu, H., et al., 2020. Artificial intelligence and virtual assistant—working model. Mobile radio communications and 5G networks: Proceedings of MRCN 2020. Springer Singapore: Singapore. pp. 163-171.
DOI: https://doi.org/10.1007/978-981-15-7130-5_12

[23] Wellsandt, S., Hribernik, K., Thoben, K.D., 2021. Anatomy of a digital assistant. Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems. IFIP Advances in Information and Communication Technology. 633, 321-330.
DOI: https://doi.org/10.1007/978-3-030-85910-7_34

[24] Rastogi, A., Zang, X., Sunkara, S., et al., 2020. Towards scalable multi-domain conversational agents: The schema-guided dialogue dataset. Proceedings of the AAAI Conference on Artificial Intelligence. 34(5), 8689-8696.

[25] Papakitsos, E.C., Giachos, I., 2016. The study of machine translation aspects through constructed languages. International Journal of Electronic Engineering and Computer Science. 1(1), 28-34.

[26] Γιάχος, Ι., Παπακίτσος, Ε.Χ., Μακρυγιάννης, Π.Σ., 2017. Ένα Πείραμα Εκμάθησης Γλωσσικής Επικοινωνίας σε ένα Ρομποτικό Σύστημα (Greek) [An Experiment in Learning Language Communication in a Robotic System]. The 9th Conference on Informatics in Education—Piraeus. p. 46-56. Available from: http://events.di.ionio.gr/cie/images/documents17/cie2017_Proc_OnLine/new/custom/pdf/CIE2017_proceedings_all.pdf

[27] Giachos, I., Papakitsos, E.C., Chorozoglou, G., 2017. Exploring natural language understanding in robotic interfaces. International Journal of Advances in Intelligent Informatics. 3(1), 10-19.
DOI: http://dx.doi.org/10.12928/ijain.v3i1.81

[28] Bunt, H., 2008. Semantic underspecification: Which Technique for what purpose? Computing Meaning. 3, 55-85.

[29] Bos, J., 2002. Underspecification and resolution in discourse semantics [PhD thesis]. Saarland: Saarland University.

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ARTICLE

SGT: Session-based Recommendation with GRU and Transformer

Lingmei Wu, Liqiang Zhang, Xing Zhang, Linli Jiang, Chunmei Wu*

School of Mathematics & Computer Science, Guangxi Science & Technology Normal University, Laibin, Guangxi, 546199, China

ABSTRACT

Session-based recommendation aims to predict user preferences based on anonymous behavior sequences. Recent research on session-based recommendation systems has mainly focused on utilizing attention mechanisms on sequential patterns, which has achieved significant results. However, most existing studies only consider individual items in a session and do not extract information from continuous items, which can easily lead to the loss of information on item transition relationships. Therefore, this paper proposes a session-based recommendation algorithm (SGT) based on Gated Recurrent Unit (GRU) and Transformer, which captures user interests by learning continuous items in the current session and utilizes all item transitions on sessions in a more refined way. By combining short-term sessions and long-term behavior, user dynamic preferences are captured. Extensive experiments were conducted on three session-based recommendation datasets, and compared to the baseline methods, both the recall rate Recall@20 and the mean reciprocal rank MRR@20 of the SGT algorithm were improved, demonstrating the effectiveness of the SGT method.

Keywords: Recommender system; Gated recurrent unit; Transformer; Session-based recommendation; Graph neural networks

1. Introduction

Recommendation systems have become increasingly important in filtering and recommending potentially interesting items to target users, as well as promoting product marketing and generating significant commercial benefits, particularly in multimedia websites and e-commerce. Traditional recommenda-

*CORRESPONDING AUTHOR:
Liqiang Zhang, School of Mathematics & Computer Science, Guangxi Science & Technology Normal University, Laibin, Guangxi, 546199, China; Email: cute_2023@163.com

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tion systems are based on users' historical interaction information, which is not always suitable for many applications.

For instance, in cases where a user browses a set of items without logging in, their identity might be anonymous, and within the current session, only the user's historical actions are available. In addition, traditional recommendation systems mostly focus on static settings, which are also unsuitable in real life, as user preferences are often dynamic. Therefore, short-term histories can capture more accurate user intentions. To address this issue, a recommendation system based on sessions has been proposed, which predicts the likelihood of the next item being clicked based on the current session's sequence [1].

The recommendation system can be broadly divided into feature-based recommendation [2], social recommendation [3,4], and sequential recommendation [5]. The feature-based method combines user information and product features to model the user-product interaction behavior and predicts the probability of users selecting products [2]. Although it is effective in learning the embedding vectors of products in the user-product interaction network, it requires significant computational resources to obtain user preferences. Social recommendation [3,6], which is based on social information [7] can alleviate data sparsity and cold-start problems,but these methods assume that users with all social links have similar preferences. As users' interests are dynamic and subject to change, they depend not only on user preferences but also on understanding the change of user interests [8].

Session-based recommendation is mainly relies on user behavior logs within a session to predict the next item of interest. Previous research on session recommendation has mainly focused on the sequential features of sessions. Based on Markov chain methods, sequential behavior data is used to predict the next behavior of users based on their prior behavior [9-11]. Recently, deep learning methods have been introduced to session-based recommendation scenarios. Recurrent Neural Networks (RNNs) have achieved significant results due to their exceptional sequence modeling ability [12-15]. However, RNN-based models often only simulate the transitions between continuously interacting items, ignoring the rich information between contexts. Graph Neural Network (GNN) methods convert session sequences into graph structures and utilize them as input to learn the complex transformation dependencies between item nodes to explore complex item transitions [16-20].

Despite the promising performance and potential of GNN-based methods in session-based recommendation, there are still limitations that need to be addressed, such as the challenges of effectively modeling long-range dependencies and the risk of over-smoothing [21]. Over-smoothing refers to the convergence of all node representations to a constant after a sufficient number of layers. Therefore, designing new architectures is crucial for addressing these issues.

In recent years, transformers have been shown to be successful in natural language understanding [22], computer vision [23], and biological sequence modeling [24]. They can capture the interaction information between nodes through self-attention layers, rather than just aggregating local neighbor information in the message passing mechanism.

However, most of the current approaches only consider a single item as the basic unit for extracting user preferences, ignoring the user intent implied by a set of contiguous and adjacent items. The user intent may change over time, and the items that have been clicked, saved, or purchased in the past may affect the subsequent items. Different numbers or levels of continuous items contain different user intentions, which can aid in providing multiple candidate recommendation items and accurate session intent information. In this paper, we extract user intent from both single items and combinations of contiguous items. Firstly, we use a gated graph neural network to model the session sequence and obtain aggregated embedding representations of the items in the session, followed by self-attention mechanism to obtain the global embedding representation of the session, and finally, the recommendation decision is made.

2. Related work

The most basic approach based on Markov chains is to estimate the transition matrix heuristically by using the frequency of transitions in the training set. However, this method is not able to deal with unobserved transitions. For example, Rendle et al. [9] proposed the personalized Markov chain (FPMC) which combines matrix factorization with a first-order Markov chain to capture continuous user behavior and short-term interests. Wang et al. [25] proposed a hierarchical representation model (HRM) that improves FPMC with a hierarchical structure. Nevertheless, Markov chain-based methods typically cannot capture more complex higher-order sequence patterns. As considering more previous items quickly makes the state size difficult to manage, most Markov chain-based models only use first-order transitions to construct the transition matrix, resulting in their inability to capture more complex higher-order sequential patterns.

With the great success of deep learning in various fields, more and more neural network-based methods have been applied to session-based recommendation tasks. Hidasi et al. [12] modeled session data using multiple gated recurrent units (GRUs) [26] layers. Tan et al. [14] then further improved its performance by using data augmentation, pre-training, and privileged information. Li et al. [13] proposed the NARM model, combines the attention mechanism with GRU to encode the user's behavioral sequence and emphasize its main intention in the current session. Liu et al. [27] created STAMP, a short-term memory priority model based on multi-layer perceptron and attention mechanism, which effectively captures users' global preferences and local interests. Wu et al. [28] converted contextual information into low-dimensional real vector features, and subsequently integrated them into a session-based recursive neural network recommendation model using three merging methods: Add, Stack, and Multilayer Perceptron.

Given the impressive results of deep learning in various domains, an increasing number of neural network-based techniques have been applied to session-based recommendation tasks. However, Wu et al. [16] argued that RNN-based models can only simulate one-way transitions between adjacent items, failing to capture context transitions between entire session sequences. They proposed an SR-GNN model that introduced graph neural networks to achieve stronger performance. In addition, Xu et al. [17] combined GNNs and self-attention networks (SANs) to capture long-range dependencies within sessions. Qiu et al. [18] used a weighted graph attention network to obtain item representations and then used a readout function to generate recommended session representations. Yu et al. [29] proposed a novel target attention graph neural network that considers candidate items when generating session representations. As most of the aforementioned works rely only on anonymous sessions with a lack of user long-term profiles, Zhang et al. [30] proposed a user behavior graph construction method based on long-term and short-term user interactions. Chen et al. [19] proposed a LESSR model to tackle the problem of inadequate long-term dependency capture and lossy session encoding in prior GNN-based approaches.

Most of the above approaches mainly focus on the item transition information within the ongoing session or directly employ all sessions to construct the model, neglecting the influence of the sequential items at distinct levels on the recommendation performance.

3. The proposed method

In this section, we first introduce the formal definition of the general session-based recommendation problem (Section 3.1). Then we explain the session graph construction (Section 3.2). Afterwards, we elaborate the proposed model i.e. session representation layer (Section 3.3), and prediction layer (Section 3.4).

In this paper we propose the SGT model, which utilizes both GRU and Transformer, for session based recommendation. Which consists of four main components: Input layer, embedding layer, session representation layer, and prediction layer. The structure of the SGT model is shown in **Figure 1**, and the structure of the Transformer layer is shown in **Figure 2**. In **Figure 1**, first construct a heterogeneous session graph of continuous intent units for the user. Then these input features are embedded into low-dimensional vectors. The Gated Recurrent Unit is applied to obtain all node vectors involved in the session graph. Next, the Transformer layer is used to capture the long-range dependencies between items in the session and assign different weights to the different items. The session representation layer integrates the user's long-term and short-term interests using a long and short interest gate fusion module. In the prediction layer, the score of each candidate item is calculated by multiplying its embedding with the session representation linearly transformed, and

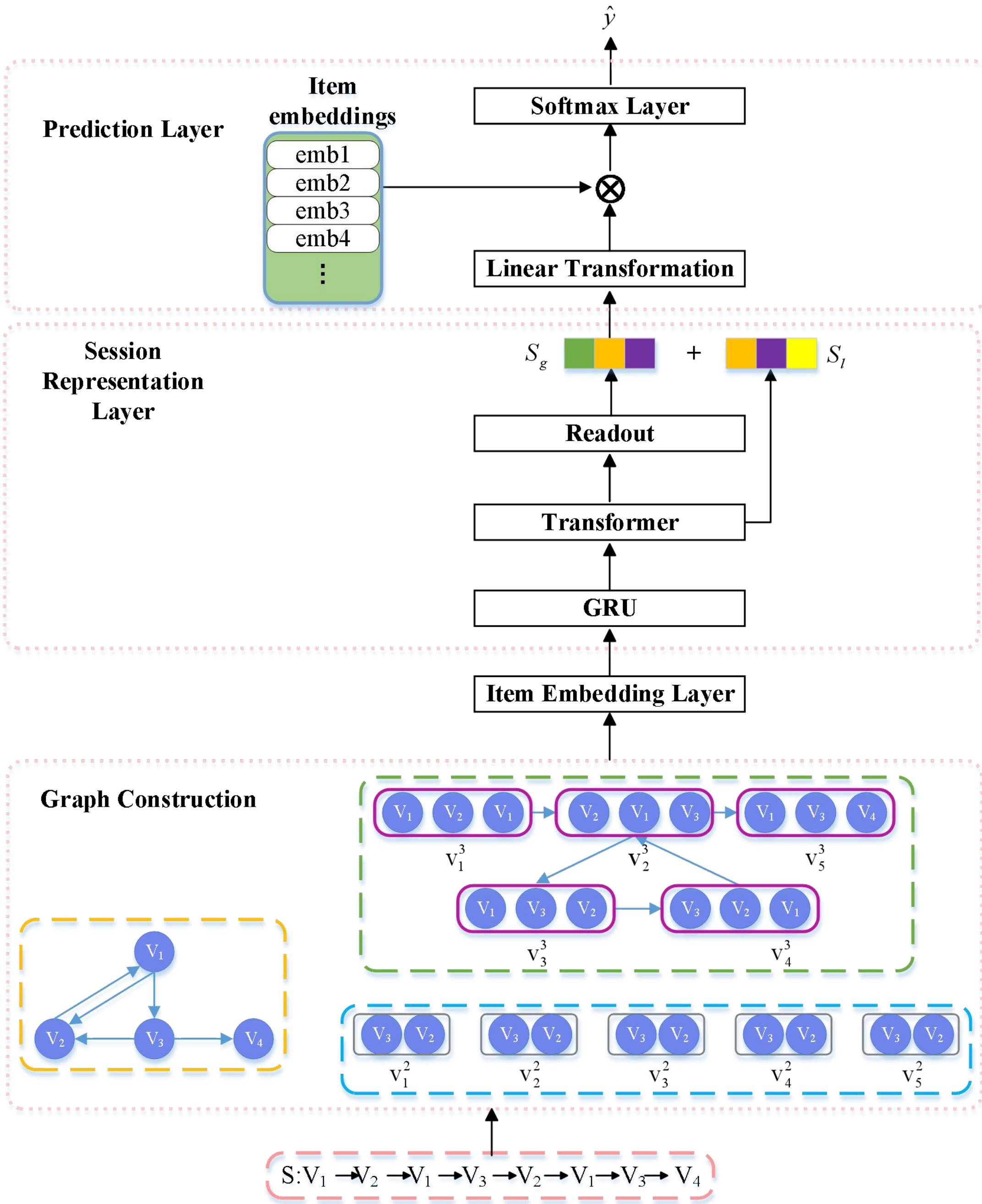

Figure 1. The overall framework of the proposed model.

recommends the top-ranked items.

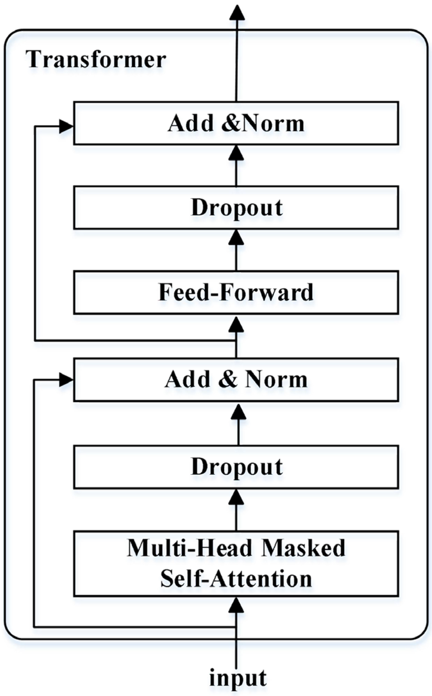

Figure 2. Transformer layer.

3.1 Problem definition

The task of session-based recommendation is to predict the user's next action based on their behavior within the current session. Here we present a formal definition of the session-based recommendation problem.

Let $S=\{S_i\}_{|S|}$ be a set of sessions and $V = \{v_1, v_2,...v_m\}$ be a set of candidate items that appear in all sessions, m indicates the number of items. Each session, ordered by timestamps, can be represented as $S_i=\{v_1^s,v_2^s,...v_l^s\}$, where l is the session length, v_i^s indicates the item that the user clicked at the location i in the session S_i.

The goal of session-based recommendation is to predict the next click, i.e. the sequence label, v_{l+1} for a session S_i. Given a session S_i, a session-based recommendation model outputs probabilities for all possible items, where the element value of the vector $\hat{y}$ represents the recommendation score of the corresponding item. The top-K values in the vector are considered as the recommended candidate items.

3.2 Session graph construction

The current session-based recommendation mainly focuses on individual items. This paper predicts users' interests by combining continuous sequences of different granularities to provide better recommendations. $v_j^k=(v_j,...v_{j+k-1})$ is defined as a continuous segment with a length of k starting from j, $k$represents the granularity level of continuous projects. Taking the session $s=\{v_1,v_2,v_1,v_3,v_2,v_1,v_3,v_4\}$ as an example, $v_1^1,...,v_4^1$ represent the first-level continuous intent unit, $(v_1,v_2),...,(v_3,v_4)$ represent the second-level continuous intent unit, denoted as $v_1^2,...v_5^2$, $(v_1,v_2,v_1),...,(v_1,v_3,v_4)$ represent the third-level continuous intent unit, denoted as $v_1^3,...v_5^3$.

Each input item $v_i \in S$ is transformed into a dense vector $e_i \in \mathrm{R}^d$ through the embedding layer, which allows them to be directly inputted into the deep neural network. d is dimension of the representation e_i. For 1-level continuous items, they are initialized to generate learnable embedding vectors e_j^1. For higher-level continuous items, the initialization uses GRU to extract sequence-sensitive intents. The initialization of k-level continuous items is represented as e_j^k, which can be defined as:

$$e_j^k=\delta(\{e_j^1,\cdots,e_{j+k-1}^1\}) \tag{1}$$

$$e_j^k=e_j^{k,set}+e_j^{k,seq} \tag{2}$$

The session graph is mainly composed of multiple subgraphs of different granularities, using different levels of subgraphs to capture the relationships between items. For example, for a session $s=\{v_1,v_2,v_1,v_3,v_2,v_1,v_3,v_4\}$, 5 groups of level-2 continuous intent units can be constructed to model the relationships between items at the level-2. In order to combine subgraphs of different granularities into a complete session graph, special edges are used to connect the high-order session graph and the first-order session graph. Intra-granular edges $(v^k,\text{intra}-k,v^k)$ are used for items at the same level, while inter-granular edges (v^1,intra,v^k) and (v^k,intra,v^1) are used for higher-order and first-order items.

3.3 Session representation layer

Gated recurrent unit layer

Capturing sequence information is a critical aspect of session-based recommendation. Wu et al. [7] have demonstrated that RNN is effective in this regard. Among RNN variants, GRU mitigate the vanishing gradient problem that plagues RNNs, and has fewer parameters and faster training speed than LSTM, another variant of RNN. Hence, in this paper, we employ GRU to capture sequence information.

We use GRU to model item embedding representations, and update the current node's feature representation as follows:

$$r_t = \sigma(W_r e_t + U_r h_{t-1}) \tag{3}$$

The update gate determines whether to update the hidden state, and the formula is as follows:

$$z_t = \sigma(W_z e_t + U_z h_{t-1}) \tag{4}$$

The calculation formula for the hidden state $\hat{h}_t$ based on the reset gate is as follows:

$$\hat{h}_t = \tanh[W_h e_t + U_h (r_t \odot h_{t-1})] \tag{5}$$

The equation for updating the hidden state using the update gate can be expressed as:

$$h_t = (1 - z_t) h_{t-1} + z_t \hat{h}_t \tag{6}$$

In the above equations, r_t and z_t represent reset and update gates, respectively. $\sigma(\cdot)$ represents the sigmoid function. e_t represents the input at time step t. h_{t-1} represents the previous hidden state of the GRU. These two parts explore the correlation between e_t and the current state of the GRU. W_r, W_z, W_h, U_r, U_z, U_h are parameter matrices and $\odot$ represents matrix dot products. When all nodes in the graph are updated and converge, the final representation of each node can be obtained.

Then using the last hidden state of the GRU layer represents the sequential behavior of the user in the current session.

$$c_t^g = h_t \tag{7}$$

Transformer layer

The core of the transformer model lies in the design of the self-attention layer, which uses multi-head attention to map the sequence to different semantic subspaces and internally extract sequence features for each subspace. This ultimately completes the feature extraction of the original sequence information, as shown in **Figure 2**.

Users often have multiple interests,and a single attention network may not be enough to capture all the relevant information. For example, when browsing for a new smartphone, the user may consider aspects such as camera quality, battery life, and screen size. Multi-head attention is a technique that allows the model to attend to multiple aspects of the input simultaneously, by constructing several parallel attention modules [22]. This technique can effectively capture the user's interests and preferences from their session click sequence, enabling better recommendations.

To predict the next item that a user may click in a session, it is necessary to model the user's interests from the user's session click sequence and capture the user's main intent. In this paper, multi-head attention is used to learn the representation of each continuous intent unit by constructing multiple parallel attention modules. It learns a deeper representation of each item by capturing its relationship with other items in the behavior sequence, thus improving the recommendation effectiveness of the model.

The multi-head attention layer aggregates the self-attention output vectors $\mathrm{H} = [h_1, ..., h_t]$ from the previous hidden outputs of the GRU. By constructing multiple parallel attention modules, the model can learn user interests from different semantic subspaces, thus modeling the user session sequence and learning a session feature vector that can express user intent. The calculation formula is as follows:

$$\mathrm{S} = \mathrm{MultiHead}(\mathrm{H}) = \mathrm{Concat}(head_1, head_2, ...head_h) W^O \tag{8}$$

Define $Q = \mathrm{H}W_i^Q, K = \mathrm{H}W_i^K, V = \mathrm{H}W_i^V$,

$$head_i = \mathrm{Attention}(Q\mathrm{W}_i^Q, K\mathrm{W}_i^K, V\mathrm{W}_i^V) \tag{9}$$

$$\text{Attention}(\mathbf{Q},\mathbf{K},\mathbf{V}) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)\mathbf{V} \tag{10}$$

Here, Q,K,V represent the query, key, and value matrices, respectively, and W_i^Q, W_i^K, W_i^V and W^O are learnable parameter matrices. h is the number of heads. The function $head_i = Attention\,(Q\boldsymbol{W}_i^Q, K\boldsymbol{W}_i^K, V\boldsymbol{W}_i^V)$ is the scaled dot-product attention with softmax activation. $\sqrt{d_k}$ is the dimension of the key vector. The multi-head attention layer produces an output by concatenating the outputs from all attention heads and applying a linear transformation with a weight matrix.

The self-attention mechanism is enhanced by the residual normalization layer and the point-wise feed-forward network (FFN). The former employs the idea of residual networks by adding the original input and output before normalization, thereby enhancing the memory capacity of the original sequence information. The latter performs a corresponding linear transformation on the output of the multi-head attention. The calculation can be expressed as:

$$\text{F} = FFN(\text{S}) = \max(0, \text{S}W_1 + b_1)W_2 + b_2 \tag{11}$$

where W_1 and W_2 are parameter matrices, b_1 and b_2 are multi-dimensional bias vectors, and F is the output of multi-head attention. Different layers capture different types of features. After the first self-attention network module, it aggregates all the previous item embeddings. To further simulate the complex relationships behind the item sequence, self-attention network modules are stacked together. The $m(m>1)$ layer is defined as:

$$\mathbf{S}^m = SA(F^{(m-1)}) \tag{12}$$

$$\mathbf{F}^m = FFN(\text{S}^m), \forall i \in 1,2\cdots,n \tag{13}$$

$\mathbf{F}^m \in R^{n\times d}$ is the final output of the multi-layer attention.

Generating session embedding vectors

For each level of continuous intent units, a local representation z_l^k is generated, as well as a global representation z_g^k to capture user preferences. As shown in **Figure 2**, given a session s_i and corresponding embeddings of continuous intent units $h_i^k \in \boldsymbol{R}^d, i=1,\ldots,n_k, k=1,\ldots,K$, n_k is the number of intent units per k level, and K is the number of levels of intent. The last intent unit $h_{n_k}^k$ is taken as the local representation z_l^k, and a soft attention mechanism is used to obtain the global representation z_g^k. The calculation is as follows:

$$z_g^k = \sum_{c=1}^{|C|} \text{Softmax}_c(\gamma_c^k)h_c \tag{14}$$

$$\gamma_c^k = W_0^{k^T}\sigma(W_1^k h_c + W_2^k z_l^k + b^k) \tag{15}$$

Aggregating all the embedded intent units to generate the context representation, i.e., $C = \{h_i^k | i = 1,\ldots,n_k, k=1,\ldots,K\}$, where $h_c \in C$ as one of the context embeddings. $W_0^k \in \boldsymbol{R}^d, W_1^k \in \boldsymbol{R}^{d\times d}, W_2^k \in \boldsymbol{R}^{d\times d}$ are trainable parameters, $b^k \in \text{R}^d$ is bias. $\sigma(\cdot)$ is sigmoid function. Finally, we compute the hybrid embedding z_s^k by taking transformation over the concatenation of the local and global embedding vectors:

$$z_s^k = W_3^k[z_g^k; z_l^k] \tag{16}$$

where $[;]$ is concatenation operation and matrix $W_3^k \in \text{R}^{2d}$ compresses two combined embedding vectors into the latent space.

3.4 Prediction layer

After obtained the embedding of each session from different levels of granularity, we further calculate the recommendation score y_i^k for each candidate item over the whole item set V by multiplying their initial embeddings e_i, which can be defined as:

$$y_i^k = z_s^k e_i \tag{17}$$

Then, we apply a softmax function over y_i^k to transform it into probability distribution form $\hat{y}$:

$$\hat{y} = soft\max(y_i^k) \tag{18}$$

Finally, we select the K items with the highest recommendation scores based on $\hat{y}$ for top-K recommendation.

To optimize the model, backpropagation is used for neural network by minimizing the cross-entropy loss between the predictions and the ground truth. The loss function is defined as follows:

$$L(\hat{y}) = -\sum_{i=1}^{|I|} y_i \log(\hat{y}_i) + (1 - y_i)\log(1 - \hat{y}_i) \quad (19)$$

where y represents the one-hot encoded vector of the ground truth item.

4. Experiments and analysis

In this section, we provide an overview of the experimental setup. Firstly, we introduce the Datasets, evaluation metrics and compared methods used in our experiments. Next, we compare the performance of our proposed SGT with other state-of-the-art methods. Finally, we conduct a comprehensive analysis of SGT under different experimental settings to provide insights into its effectiveness.

4.1 Datasets

We evaluate the effectiveness of our proposed method on three widely used real-world datasets, i.e. *Diginetica*①*,Gowalla*② *and Last.fm*③.

- *Diginetica* is an anonymous user browsing and transaction record dataset provided in CIKM Cup 2016, which includes transaction logs and user browsing histories suitable for session-based recommendation.
- *Gowalla* is a check-in behavior dataset widely used for interest recommendation. In this experiment, the top 30,000 popular locations are retained, and the user's check-in records are grouped into unrelated time periods by splitting intervals exceeding 1 day between adjacent records. The last 20% of the sessions are used as the test set.
- *Last.fm* is a music dataset that includes a list of the user's most popular artists, album and track names as features, as well as timestamps and play counts, and user application tags that can be used to build content vectors. In this experiment, the top 40,000 popular artists are retained, and the interval is set to 8 hours for segmentation. The most recent 20% of sessions are used as the test set.

Following other works [13,16,19,26,28], we applied filtering to remove sessions with a length of 1 and items that appeared less than 5 times. Additionally, same as the studies [13,26], we utilized the data augmentation techniques to process the datasets. Furthermore, for session-based recommendation, we designated the sessions from the last week as the test data and used the remaining data for training. The resulting statistics of the datasets are presented in **Table 1**.

Table 1. Statistics of datasets used in the experiments.

Datasets	Diginetica	Gowalla	Last.fm
# of clicks	982961	1122788	3835706
# of training sessions	719470	675561	2837644
# of test sessions	60858	155332	672519
# of items	43097	29510	38615
#length<=5	537546	627100	1136909
#length>5	239483	203793	2373254
Average length	5.12	4.32	9.16

4.2 Evaluation metrics

To assess the recommendation performance of all models, we utilize the following two commonly used metrics.

Recall@ ***K*** (Recall calculated over top-K items) is commonly used to measure predictive accuracy. It represents the proportion of correctly recommended items among the top-K items. It is calculated as:

$$\text{Recall}@K = \frac{n_{hit}}{N} \quad (20)$$

where n_{hit} represents the number of sessions with desired items in top-K recommended items and N denotes the number of test data. The Recall measure is order-insensitive in the recommendation list, where large Recall value indicates better recommendation performance of the model.

MRR@K (Mean Reciprocal Rank calculated over top-K items) is the average of reciprocal ranks

① http://cikm2016.cs.iupui.edu/cikm-cup
② https://snap.stanford.edu/data/loc-gowalla.html
③ http://ocelma.net/MusicRecommendationDataset/lastfm-1K.html

of the correctly-recommended items. $\frac{1}{Rank(i)}$ is set to zero when the rank is large than K. The MRR measure considers the order of recommendation ranking and higher value indicates that correct recommendations are at the top of the ranking list. It is calculated as:

$$MRR@K = \frac{1}{Q}\sum_{i}^{|Q|}\frac{1}{Rank(i)} \tag{21}$$

$|Q|$ denotes the number of users, $Rank(i)$ represents the position of the first correct recommendation in the item list recommended by the model for the $i-\text{th}$ user.

In our experiment, we consider Top-K (K = 20) for recommendation.

4.3 Baselines

To evaluate the effectiveness of our proposed method, we compare it with the following representative baselines:

- **Item-KNN** [31] uses the nearest neighbor idea to recommend items similar to the last clicked item in the session.
- **FPMC** model [9] combines Markov chain and matrix factorization models, using a pairwise interaction model to perform matrix factorization on the personalized transition matrix of items, thus solving the Next Basket recommendation problem.
- **GRU4Rec** [12] is an RNN-based model that uses gated recurrent units (GRU) to model user sequences.
- **NARM** [13] uses GRU to extract sequence information and improves recommendation performance by adding attention mechanisms.
- **SR-GNN** [16] uses graph neural networks to model the order relationship between items, learns user interests in the session using attention mechanisms, and self-attends to the last item to predict the next item that the user is likely to click on.
- **GC-SAN** [17] is an improvement on SR-GNN, capturing local dependencies through graph neural networks and applying self-attention mechanisms to learn long-range dependencies.
- **LESSR** [19] introduces two session graphs to solve the problem of lost order information and long-term dependency.

4.4 Comparison with baseline methods

To evaluate the overall performance of the proposed model, we compare it with other state-of-art session-based recommendation methods. We randomly split 10% of the samples from the training set as the validation set, and the intention unit granularity level was set to {1, 2, 3, 4, 5, 6} to obtain the optimal value using the Adam optimizer. The batch size was set to 512, the embedding dimension was 256, and the number of heads in the multi-head attention was set to 2. The learning rate was set to 0.001, and the model's learning rate decayed to 0.1 times the previous value every 3 iterations. The overall performance in terms of Recall@20 and MRR@20 is shown in **Table 2**, with the best results highlighted in boldface.

The performance of the traditional Item-KNN and FPMC methods is relatively poor on the datasets used in the experiment, as these methods cannot well capture the complex temporal relationships between items in the session sequence.

All neural network algorithms have better performance in Recall@20 and MRR@20. The experimental results demonstrate the powerful ability of these algorithms to extract features, including sequence features. The NARM model uses attention mechanisms and the collaborative effect of user long-term and short-term features, which performs better than GRU4Rec in terms of indicators. This indicates that different items in a user session have different effects on user interests. The SR-GNN uses graph neural networks to model the complex dependency relationships between items and extracts node features using attention mechanisms, improving the recommendation performance. The GC-SAN improves upon SR-GNN by using self-attention networks to capture the global dependency relationships between items. The LESSR performs better than SR-GNN by solving the problem of losing sequence information when converting session sequences into graph networks, indicating the effectiveness of retaining sequence information in sessions.

The proposed SGT model performs well on all datasets, which suggests that intent can be utilized at various granularity levels for modeling intricate transitions between user intents. The multi-head attention layer can effectively extract deep features of user sessions, capturing more comprehensive and precise user preferences, thereby predicting the next item that the user is likely to click on with greater accuracy.

4.5 Comparison with different connection schemes

In this section, we propose a set of comparative models to validate the effectiveness of incorporating last-click information into session context for session-based recommendations:

SGT-L: Local embedding only.

SGT-G: Global embedding with the attention mechanism.

The results of methods with two different embedding strategies are given in **Table 3**.

According to the table, it can be seen that SGT model with hybrid embedding method achieves the best results on all three datasets, indicating the significance of explicitly integrating current session interests with long-term preferences. For example, taking the Diginetica dataset as an example, the SGT model improved the performance of hit rate evaluation metric by 0.35% and 3.13% compared to SGT-L and SGT-G, respectively, while the performance improvement of mean reciprocal rank evaluation metric was 1.28% and 3.08%, respectively. These results indicate that the SR-BE model with both local and global encoders provides a more accurate and comprehensive recommendation system, effectively capturing the relevant features of current and nearby items. Furthermore, the **Table 3** shows that SGT-L performs better than SGT-G on three datasets. This indicates that focusing on the item features in the current session is more important than focusing on the items in its neighborhood.

In conclusion, the ablation experiments and analyses presented in this paper demonstrate the effectiveness of different modules in the proposed SGT model, and the performance of the model can be further improved when multiple modules work together. The results of this study provide insights into the importance of incorporating local and global encoders for achieving optimal performance in session-based recommendation systems.

Table 2. The performance of SR-GNN with other baseline methods over three datasets.

Algorithm	Diginetica		Gowalla		Last.fm	
	Recall@20	MRR@20	Recall@20	MRR@20	Recall@20	MRR@20
Item-KNN	39.51	11.22	38.60	16.66	14.90	4.04
FPMC	28.50	7.67	29.91	11.45	12.86	3.78
GRU4REC	42.55	12.67	39.55	16.99	22.13	7.15
NARM	52.89	16.84	52.24	25.13	23.09	7.90
SRGNN	53.44	17.31	53.24	26.03	23.85	8.23
GC-SAN	54.78	18.57	53.66	25.69	22.64	8.42
LESSR	51.71	18.15	51.34	25.49	23.37	9.01
SGT	56.95	19.74	56.59	28.03	27.92	9.70

Table 3. The performance of different session representations.

Algorithm	Diginetica		Gowalla		Last.fm	
	Recall@20	MRR@20	Recall@20	MRR@20	Recall@20	MRR@20
SGT-L	56.75	19.49	54.17	26.02	28.35	9.45
SGT-G	55.22	19.15	53.13	25.21	15.19	8.63
SGT	56.95	19.74	56.59	28.03	27.92	9.70

4.6 Model analysis and discussion

Impact of the dimension size

From **Figures 3 and 4**, these results are evident that an appropriate increase in the dimension of embedding vectors results in a significant improvement in the model's recommendation performance. This is because a higher embedding dimension can accommodate more latent information, thereby enhancing the model's expression ability. Specifically, for the Diginetica dataset, the model's recommendation performance is optimal when using embedding vectors of around 250 dimensions, and any further increase in dimensionality would lead to a decrease in performance. For the Gowalla dataset, the model's recommendation performance is relatively better at an embedding dimension of 200. Finally, for the Last.fm dataset, the model's recommendation performance is relatively better at an embedding dimension of 150. It is crucial to note that excessively high dimensions can cause the model to have too many parameters, leading to overfitting.

Results on different intent unit granularity

We evaluate the impact of intent granularity level on the performance of our proposed model on three datasets. The corresponding results are illustrated in **Figure 5** and **Figure 6**. These results indicate that for the Diginetica dataset, performance initially improved with increasing granularity, decreased at granularity 5, increased again at granularity 6, and then stabilized with further granularity increase. For the Gowalla dataset, performance decreased at granularity 4, increased at granularity 5, and then decreased again with further granularity increase. Last.fm showed better performance at granularity 3, with a decrease in performance at higher granularity levels. The study suggests that incorporating higher-level granularity is useful for datasets with long session lengths, but performance will become stable with coarser granularity, as longer sessions may not necessarily provide more useful information.

Impact of self-attention layer

Figures 7 and 8 depict the impact of the number of self-attention layers on evaluation metrics. The results indicate that increasing the number of layers does not always lead to better performance for the Diginetica and Gowalla datasets. The optimal number of layers for these datasets is 1, and when the number of layers exceeds this value, the model tends to overfit, resulting in a rapid decline in performance. In contrast, for the Last.fm dataset, performance gradually improves with an increase in the number of layers, but then decreases at layer 4. This is because the model's learning ability increases with more layers, but having too many layers can lead to over-smoothing even when the model is not overfitting. Therefore, adding more layers is not an effective approach for capturing long-range dependencies.

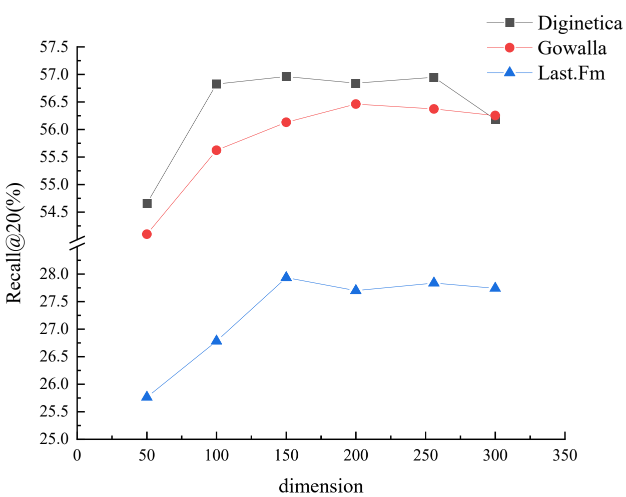

Figure 3. Effects of different embedding dimension on recall.

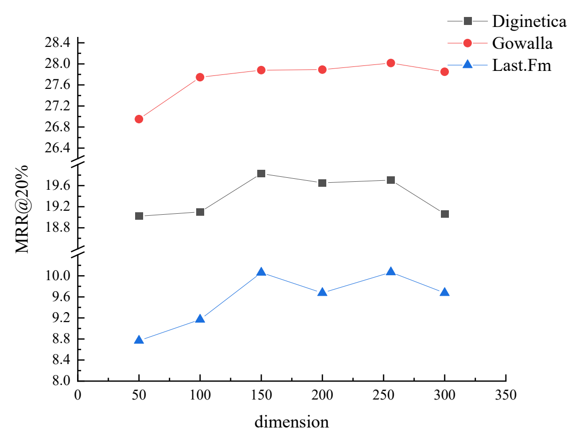

Figure 4. Effects of different embedding dimension on MRR.

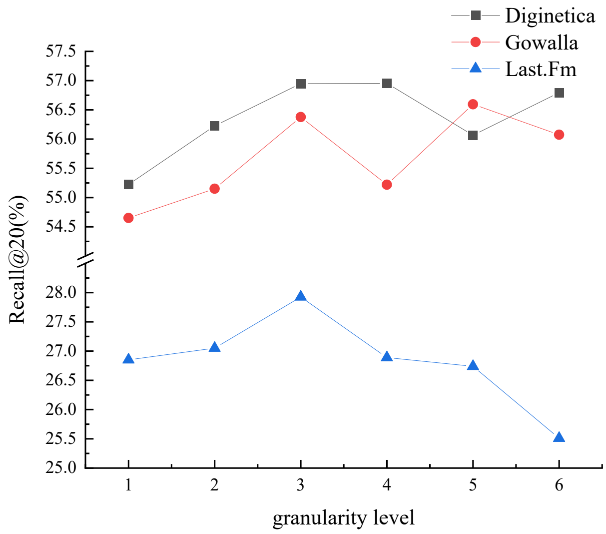

Figure 5. Impact of intent unit granularity levels on recall.

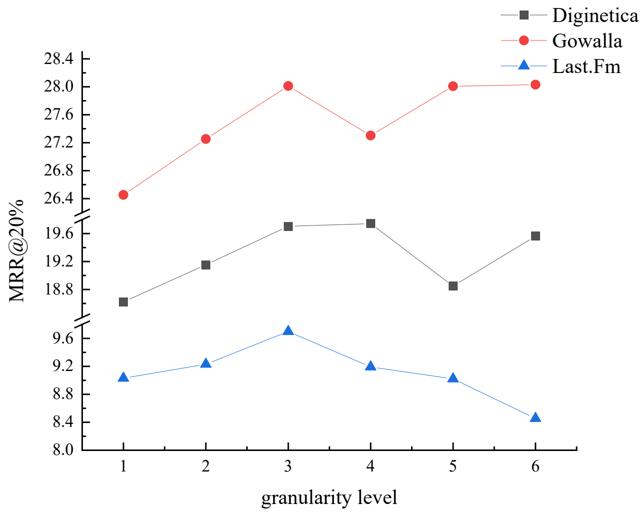

Figure 6. Impact of intent unit granularity levels on MRR.

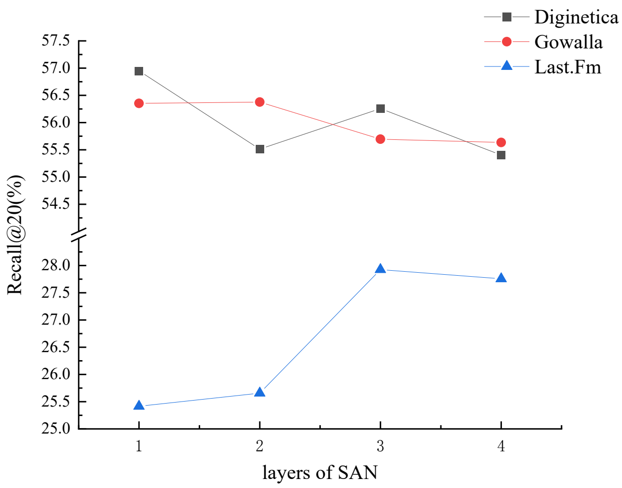

Figure 7. Impact of self-attention layer on recall.

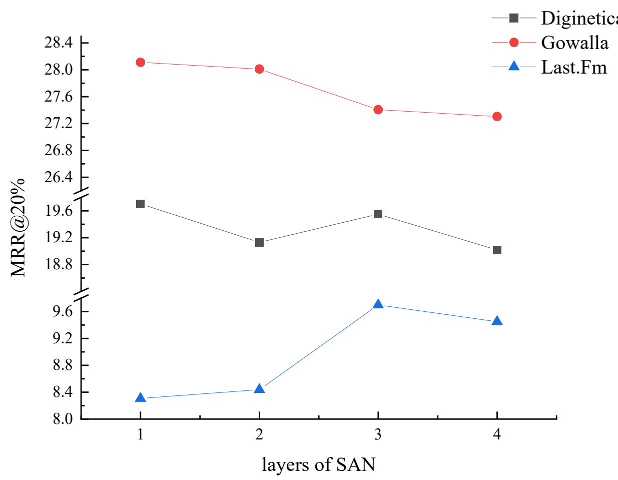

Figure 8. Impact of self-attention layer on MRR.

5. Conclusions

This paper proposes the SGT model based on GRU and Transformer for session-based recommendation. Specifically. We first construct session graphs from anonymous session records by establishing intra-granular and inter-granular edges to represent continuous item units at the same and different levels, respectively. This allows us to capture the complex preference transition relationships and long-term dependencies among multi-level continuous intent units. We then apply GRU to generate new latent vectors for all items, followed by employing transformer to capture multiple interests and assign different weights to different items. The attention network is used to capture global dependencies. Finally, we combine the local short-term dynamics and global dependencies to represent session sequences. Our experiments on three real-world datasets demonstrate that SGT outperforms other baseline methods. In future work, we plan to integrate some available auxiliary information, such as item attributes, to obtain more informative item representations, and explore various types of user behaviors to improve the accuracy of our recommendations.

Author Contributions

All the authors have made significant contributions to the work of the report. Lingmei Wu is mainly responsible for the construction of the idea of this article, the simulation experiment and the writing of the paper. Liqiang Zhang is mainly responsible for controlling the full text. Xing Zhang is mainly responsible for providing ideas. Linli Jiang is mainly responsible for simulation experiments, and Chunmei Wu is mainly responsible for obtaining data.

Conflict of Interest

There is no conflict of interest.

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References

[1] Wang, H., Zeng, Y., Chen, J., et al., 2022. A spatiotemporal graph neural network for session-based recommendation. Expert Systems with Applications. 202, 117114.

[2] Yang, C., Bai, L., Zhang, C., et al. (editors), 2017. Bridging collaborative filtering and semi-supervised learning: A neural approach for poi recommendation. Proceedings of the 23rd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining; 2017 Aug 13-17; Halifax. New York: Association for Computing Machinery. p. 1245-1254.

[3] Shu, K., Wang, S., Tang, J., et al. (editors), 2018. Crossfire: Cross media joint friend and item recommendations. Proceedings of the Eleventh ACM International Conference on Web Search and Data Mining; 2018 Feb 5-9; Los Angeles. New York: Association for Computing Machinery. p. 522-530.

[4] Corò, F., D'Angelo, G., Velaj, Y. (editors), 2019. Recommending links to maximize the influence in social networks. Proceedings of the Twenty-Eighth International Joint Conference on Artificial Intelligence (IJCAI 2019); 2019 Aug 10-16; Macao. International Joint Conferences on Artificial Intelligence. p. 2195-2201.

[5] Kim, Y., Kim, K., Park, C., et al. (editors), 2019. Sequential and diverse recommendation with long tail. Proceedings of the Twenty-Eighth International Joint Conference on Artificial Intelligence (IJCAI 2019); 2019 Aug 10-16; Macao. International Joint Conferences on Artificial Intelligence. p. 2740-2746.

[6] Fan, W., Derr, T., Ma, Y., et al. (editors), 2019. Deep adversarial social recommendation. Proceedings of the Twenty-Eighth International Joint Conference on Artificial Intelligence (IJCAI-19); 2019 Aug 10-16; Macao. International Joint Conferences on Artificial Intelligence. p. 1351-1357.

[7] Al Ridhawi, I., Otoum, S., Aloqaily, M., et al., 2020. Providing secure and reliable communication for next generation networks in smart cities. Sustainable Cities and Society. 56, 102080.

[8] Song, W., Xiao, Z., Wang, Y., et al. (editors), 2019. Session-based social recommendation via dynamic graph attention networks. Proceedings of the Twelfth ACM International Conference on Web Search and Data Mining; 2019 Feb 11-15; Melbourne. New York: Association for Computing Machinery. p. 555-563.

[9] Rendle, S., Freudenthaler, C, Schmidt-Thieme, L. (editors), 2010. Factorizing personalized Markov chains for next-basket recommendation. Proceedings of the 19th International Conference on World Wide Web; 2010 Apr 26-30; Raleigh. New York: Association for Computing Machinery. p. 811-820.

[10] Kang, W.C., McAuley, J. (editors), 2018. Self-attentive sequential recommendation. 2018 IEEE International Conference on Data Mining (ICDM); 2018 Nov 17-20; Singapore. New York: IEEE. p. 197-206.

[11] He, R., McAuley, J. (editors), 2016. Fusing similarity models with Markov chains for sparse sequential recommendation. 2016 IEEE 16th International Conference on Data Mining (ICDM); 2016 Dec 12-15; Barcelona. New York: IEEE. p. 191-200.

[12] Hidasi, B., Karatzoglou, A., Baltrunas, L., et al. (editors), 2016. Session-based recommendations with recurrent neural networks. 4th International Conference on Learning Representations; 2016 May 2-4; San Juan. International Conference on Learning Representations. p. 289.

[13] Li, J., Ren, P., Chen, Z., et al. (editors), 2017. Neural attentive session-based recommendation. Proceedings of the 2017 ACM on Conference on Information and Knowledge Management; 2017 Nov 6-10; Singapore. New York: Association for Computing Machinery. p. 1419-1428.

[14] Tan, Y.K., Xu, X., Liu, Y. (editors), 2016. Improved recurrent neural networks for session-based recommendations. Proceedings of the 1st Workshop on Deep Learning for Recommender Systems; 2016 Sep 15; Boston. New York: Association for Computing Machinery. p. 17-22.

[15] Song, K., Ji, M., Park, S., et al., 2019. Hierarchical context enabled recurrent neural network for recommendation. Proceedings of the AAAI Conference on Artificial Intelligence. 33(1), 4983-4991.

[16] Wu, S., Tang, Y., Zhu, Y., et al., 2019. Session-based recommendation with graph neural networks. Proceedings of the AAAI Conference on Artificial Intelligence. 33(1), 346-353.

[17] Xu, C., Zhao, P., Liu, Y., et al. (editors), 2019. Graph contextualized self-attention network for session-based recommendation. Proceedings of the Twenty-Eighth International Joint Conference on Artificial Intelligence (IJCAI-19); 2019 Aug 10-16; Macao. International Joint Conferences on Artificial Intelligence. p. 3940-3946.

[18] Qiu, R., Li, J., Huang, Z. (editors), et al., 2019. Rethinking the item order in session-based recommendation with graph neural networks. Proceedings of the 28th ACM International Conference on Information and Knowledge Management; 2019 Nov 3-7; Beijing. New York: Association for Computing Machinery. p. 579-588.

[19] Chen, T., Wong, R.C.W. (editors), 2020. Handling information loss of graph neural networks for session-based recommendation. Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining; 2020 Jul 6-10; New York. New York: Association for Computing Machinery. p. 1172-1180.

[20] Pan, Z., Cai, F., Chen, W., et al. (editors), 2020. Star graph neural networks for session-based recommendation. Proceedings of the 29th ACM International Conference on Information & Knowledge Management; 2020 Oct 19-23; New York. New York: Association for Computing Machinery. p. 1195-1204.

[21] Xu, K., Hu, W., Leskovec, J., et al., 2018. How powerful are graph neural networks? arXiv preprint arXiv:1810.00826.

[22] Vaswani, A., Shazeer, N., Parmar, N., et al. (editors), 2017. Attention is all you need. 31st Conference on Neural Information Processing Systems (NIPS 2017); Long Beach. New York: Association for Computing Machinery. p. 5998-6008.

[23] Dosovitskiy, A., Beyer, L., Kolesnikov, A., et al., 2020. An image is worth 16x16 words: Transformers for image recognition at scale. arXiv preprint arXiv: 2010.11929.

[24] Rives, A., Meier, J., Sercu, T., et al., 2021. Biological structure and function emerge from scaling unsupervised learning to 250 million protein sequences. Proceedings of the National Academy of Sciences. 118(15), e2016239118.

[25] Wang, P., Guo, J., Lan, Y., et al. (editors), 2015.

Learning hierarchical representation model for nextbasket recommendation. Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval; 2015 Aug 9-13; Santiago. New York: Association for Computing Machinery. p. 403-412.

[26] Cho, K., Van Merriënboer, B., Gulcehre, C., et al., 2014. Learning phrase representations using RNN encoder-decoder for statistical machine translation. arXiv preprint arXiv:1406.1078.

[27] Liu, Q., Zeng, Y., Mokhosi, R., et al. (editors), 2018. STAMP: Short-term attention/memory priority model for session-based recommendation. Proceedings of the 24th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining; 2018 Aug 19-23; London. New York: Association for Computing Machinery. p. 1831-1839.

[28] Wu, T., Sun, F., Dong, J., et al., 2022. Context-aware session recommendation based on recurrent neural networks. Computers and Electrical Engineering. 100, 107916.

[29] Yu, F., Zhu, Y., Liu, Q., et al. (editors), 2020. TAGNN: target attentive graph neural networks for session-based recommendation. Proceedings of the 43rd International ACM SIGIR Conference on Research and Development in Information Retrieval; 2020 Jul 25-30; Xi'an. New York: Association for Computing Machinery. p. 1921-1924.

[30] Zhang, M., Wu, S., Gao, M., et al., 2020. Personalized graph neural networks with attention mechanism for session-aware recommendation. IEEE Transactions on Knowledge and Data Engineering. 34(8), 3946-3957.

[31] Sarwar, B., Karypis, G., Konstan, J., et al. (editors), 2001. Item-based collaborative filtering recommendation algorithms. Proceedings of the 10th International Conference on World Wide Web; 2001 May 1-5; Hong Kong.New York: Association for Computing Machinery. p. 285-295.

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ARTICLE

A Systematic Overview of Underwater Wireless Sensor Networks: Applications, Challenge and Research Perspectives

Fethi Demim[1*]***, Rekia Bouguessa***[2]***, Abdenebi Rouigueb***[3]***, Abdelkrim Nemra***[1]

[1] *Guidance and Navigation Laboratory, Ecole Militaire Polytechnique, Bordj El Bahri, 16046, Algeria*
[2] *Energy Systems Laboratory, Ecole Militaire Polytechnique, Bordj El Bahri, Algiers, 16046, Algeria*
[3] *Artificial Intelligence and Virtual Reality Laboratory, Ecole Militaire Polytechnique, Bordj El Bahri, Algiers, 16046, Algeria*

ABSTRACT

Underwater Wireless Sensor Networks (UWSNs) are becoming increasingly popular in marine applications due to advances in wireless and microelectronics technology. However, UWSNs present challenges in processing, energy, and memory storage due to the use of acoustic waves for communication, which results in long delays, significant power consumption, limited bandwidth, and packet loss. This paper provides a comprehensive review of the latest advancements in UWSNs, including essential services, common platforms, critical elements, and components such as localization algorithms, communication, synchronization, security, mobility, and applications. Despite significant progress, reliable and flexible solutions are needed to meet the evolving requirements of UWSNs. The purpose of this paper is to provide a framework for future research in the field of UWSNs by examining recent advancements, establishing a standard platform and service criteria, using a taxonomy to determine critical elements, and emphasizing important unresolved issues.

Keywords: Wireless sensor networks; Ad-hoc networks; Internet of Things; Localization algorithms; Node mobility; Security mechanisms; Energy-efficient communication

1. Introduction

Wireless Sensor Networks (WSNs) are used to monitor aquatic environments via data collection and wireless transfer. Underwater Sensor Networks

*CORRESPONDING AUTHOR:
Fethi Demim, Ecole Militaire Polytechnique, Bordj El Bahri, Algiers, 16046, Algeria; Email: demifethi@gmail.com

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(UWSNs) have great potential in environmental monitoring, oceanographic research, and defense applications. Interconnected sensors form UWSNs, collecting and transmitting data wirelessly in underwater environments, facing unique communication and deployment challenges. Acoustic waves are primarily used for transmitting information underwater, resulting in high latency, power consumption, packet loss, and limited bandwidth. This paper covers key concepts of WSNs and underwater networks, as well as challenges associated with UWSNs. Additionally, it highlights various localization algorithms developed to mitigate these challenges. UWSNs are cost-effective for monitoring large bodies of water and providing real-time, accurate data about the underwater environment, allowing researchers to explore underwater areas that were previously uncharted. Several researchers [1,2] have worked on developing and implementing advanced techniques for achieving high-rate communication using underwater acoustic technology. Recent technological advances have enabled subsea exploration through the use of UWSN. These networks consist of aquatic sensors that collect data on water characteristics such as temperature, quality, and pressure. Sensor nodes are spread across the underwater environment and work together to detect and communicate potential threats. Deploying UWSNs requires a platform that can adapt to forced wireless communication resources. Adapting terrestrial WSNs to UWSNs is challenging due to the unique characteristics of the underwater environment. Designing and deploying UWSNs is further complicated by limited energy and storage capacity, harsh environmental conditions, and underwater object mobility. Nonetheless, the potential benefits make UWSNs an attractive research area. Several approaches have been proposed to address the challenges of UWSNs, including the use of acoustic communication [3], adaptive routing protocols [4], energy-efficient algorithms [5], and deployment strategies [6]. The Internet of Things (IoT) has also played a role in advancing UWSNs [7].

However, protecting this type of network remains a challenge and is a current area of research [8]. Autonomous UWSNs consist of nodes that can gather and communicate environmental data on their own, with their locations not always predetermined [9]. These networks are used in various applications, including military and maritime ones. The nodes can be stationary or mobile, and they are connected via wireless links [5]. The major use of these networks is to locate and identify targets or barriers. Centralized and decentralized architectures are the foundation for most data fusion systems seen in the literature [10]. Efficient routing protocols are also important for UWSNs [11]. In this study, various filtering methods used in the distributed architecture, including Extended Kalman Filter (EKF), Non-Hinty Filter (NH∞), and Smooth Variable Structure Filter (SVSF), are covered [12-17]. The study aims to conduct a comparative review of the literature based on UWSNs. Distributed fault detection filter design for UWSNs is explored by Chen Y. [18], while Feng Y. [19] focuses on distributed filtering for multiple target tracking in cluttered underwater sensor networks. Ez-Zaidi A. [20] provides a comparative study of distributed filtering algorithms for underwater target tracking in multi-sensor networks, and Shu H. [21] proposes a distributed multi-target tracking algorithm based on an optimal joint probabilistic data association filter in underwater sensor networks.

In this article, we aim to provide a systematic overview of UWSNs, including their applications, challenges, and research perspectives. Specifically, we will define the key concepts related to UWSNs, explain the potential benefits of using these networks, and highlight the challenges that need to be overcome for their successful deployment. Our objective is to provide a comprehensive understanding of UWSNs to researchers, practitioners, and anyone interested in this emerging field.

This paper provides an overview of UWSNs in Section 2, discussing their importance and potential to transform underwater sensing. Section 3 covers the various underwater wireless communication systems and challenges associated with UWSNs such as energy efficiency, node placement, and communication protocols. Section 4 presents the restrictions of undersea wireless sensor networks and current research and development efforts to improve their performance. Sections 5 and 6 discuss the research methodology and security requirements and difficulties for UWSNs, respectively. Section 7 presents UWSN applications, while Section 8 covers their architectures. Sections 9 and 10 discuss open research issues and localization algorithms, including range-free and range-based algorithms. Finally, Section 11 concludes the paper and suggests future research directions.

2. Definitions and key concepts of UWSNs

A wireless underwater sensor network can be constructed by connecting many nodes via bidirectional acoustic links [5]. Until it reaches the base station, a network node can exchange information with nearby nodes and communicate with them (see **Figure 1**). Each node may have one or more sensors that capture environmental data for transmission, usually to platforms or buoys on the surface [22]. Localization algorithms for UWSNs are discussed by Han G. [23], while Pranitha B. [24] provides an overview of propagation models and statistical characterization of underwater acoustic communication channels. Liu J. [25] proposes a distributed data compression method for underwater wireless sensor networks.

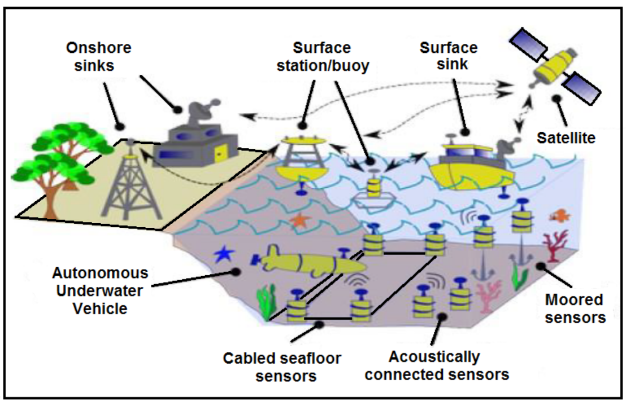


Figure 1. Underwater sensor networks [6].

UWSNs are networks of interconnected underwater sensor nodes that use acoustic and optical communication to transmit data to the base station. The design and deployment of these networks require consideration of factors like propagation delay, network lifetime, and routing protocols. In a study by Partan J. [26], the challenges of underwater communication and the need for reliable routing protocols are discussed. The proposed routing protocol, called "GloMoSim", uses geographic and network topology information to determine the optimal path for data transmission in UWSNs.

2.1 Components of a UWSN and their functions

- **Sensor Nodes**: These nodes are responsible for sensing the environment and collecting data. They use various types of sensors, such as temperature, pressure, and pH sensors, to measure the physical and chemical properties of water. Alsulami M. [27] discusses the design and implementation of sensor nodes in UWSNs, focusing on the challenges of sensor placement and power management.
- **Communication Modules**: These modules allow the nodes to communicate with each other wirelessly. Acoustic and optical communication modules are commonly used in UWSNs. Heidemann J. [28] presents a comprehensive survey of communication technologies used in UWSNs, including acoustic and optical communication. The authors review the advantages and disadvantages of each technology and discuss their applicability in different scenarios.
- **Power Modules**: These modules provide power to the nodes, which can be in the form of batteries or energy harvesting systems. They are responsible for ensuring that the network lifetime is maximized. Ali M. [29] discusses the use of energy harvesting systems in UWSNs to extend the duration of network operation. The authors propose a novel energy harvesting system that uses piezoelectric transducers to generate energy from water flow.
- **Base Station**: The base station is responsible for collecting data from the nodes and processing it. It also serves as a gateway for data transmission to the outside world. Khalid M. [30]

presents a review of base station architectures and their impact on network performance in UWSNs. The authors compare centralized and distributed base station architectures and discuss their trade-offs in terms of data processing, energy consumption, and reliability.

2.2 UWSNs design overview

The UWSN architecture comprises sensor nodes, communication modules, and a base station that gathers data from the underwater environment and transmits it wirelessly. Data can be transmitted to external systems via satellite or terrestrial networks. The routing protocol plays a crucial role in data transmission. Ismail A.S. [31] identified several challenges in underwater acoustic sensor networks, including node localization, channel modeling, and network topology control. Various routing protocols have been proposed for UWSNs, and they can be classified based on different criteria such as data delivery, energy consumption, and network lifetime. UWSN network lifetime depends on factors such as energy consumption, transmission range, and data rate, and ensuring network longevity is essential for efficient underwater data collection and transmission.

3. Underwater wireless communication techniques

In this article, the construction of a UWSN using bidirectional acoustic links for underwater communication is discussed. The advantages of acoustic wave communication over other types of waves are highlighted, along with the challenges of attenuation and limited range, as presented by Goh J.H. [32] and Yan H. [33] The article also introduces Magneto-Inductive Communication (MIC) as a potential replacement for wireless networks in UWSNs. The unique features and challenges of UWSNs are also explained in this work, and key concepts related to the technology, such as energy efficiency, routing protocols, and network lifetime, are defined by Goyal N. [34] and Kashif Manzoor M. [35]

3.1 Underwater acoustic communication

Unlike traditional wireless networks that use electromagnetic waves for communication, UWSNs rely on underwater acoustic communication. Acoustic waves travel much slower in water than electromagnetic waves, and their signals are affected by various factors such as water temperature, pressure, and salinity.

3.2 Energy constraints

UWSNs are typically powered by batteries, which have limited energy capacity. Thus, energy efficiency is a critical design consideration for UWSNs, and various techniques such as duty cycling and node clustering have been proposed to reduce energy consumption.

3.3 Localization

In UWSNs, localization refers to the process of determining the position of nodes in the network. Due to the unique challenges of underwater communication, localization in UWSNs is a complex task and requires specialized techniques such as range-based or range-free localization.

3.4 Mobility

Some UWSNs may involve mobile sensors, such as underwater robots or autonomous vehicles, that can move around in the water environment to collect data from different locations.

The Internet of Underground Objects (IoUT) could also be referred to by the acronym IoUT, and it deploys sensor nodes and transceivers underground for real-time monitoring [36-40]. There are several aquatic wireless communication techniques (see **Figure 2**), including:

- **Acoustic communication**: It uses sound waves for underwater communication, which has advantages such as long-distance transmission, but also faces challenges like interference and attenuation. However, this method is limited by its bandwidth, propagation delay, noise susceptibility, and reverberation [35,39].

- **Optical communication**: It uses light to transmit data in water, providing high data rates but is vulnerable to absorption and scattering. Its advantages include high bandwidth, immunity to electromagnetic interference, and low propagation delays. However, limitations such as attenuation and absorption leading to limited range, signal distortion, and the need for specialized equipment and expertise make it challenging for underwater applications [35,38].
- **Radio communication**: It uses radio waves to transmit data through water. Radio signals can penetrate the water's surface, but they are subject to high attenuation and interference in water [35].
- **Magnetic communication**: It uses magnetic fields to communicate through the water. Magnetic signals can achieve moderate data rates and can penetrate obstacles, but they are subject to interference from the Earth's magnetic field [35].

It is worth noting that communication protocols are essential for efficient data transmission in UWSNs [41-43]. They are responsible for managing the network topology, routing data, and ensuring reliable communication. Some of the commonly used communication protocols in UWSNs are:

- **Medium Access Control (MAC)**: The MAC protocol is responsible for managing access to the communication medium, such as Time-Division Multiple Access (TDMA) and Carrier Sense Multiple Access (CSMA) [5].
- **Routing Protocols**: Routing protocols are responsible for determining the optimal path for data transmission from the source node to the destination node. Examples include Adhoc On-Demand Distance Vector (AODV), and Destination Sequenced Distance Vector (DSDV) [5,41].
- **Transport Layer Protocols**: These protocols provide end-to-end communication services for applications. Some examples of transport layer protocols are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) [42,43]. Other transport layer protocols include Stream Control Transmission Protocol (SCTP), Datagram Congestion Control Protocol (DCCP), and Multipath TCP (MPTCP) [42,43].

4. Challenges of UWSNs

Designing UWSNs is challenging due to the unique characteristics of acoustic waves in marine environments. Highly variable underwater conditions, such as temperature, salinity, and currents, can impact sensor performance and lead to data inaccuracies. UWSNs face challenges such as high attenuation and multipath propagation, high energy consumption, interference, limited storage and processing power, and security threats. These challenges can significantly impact their performance, leading to communication failures, reduced transmission range, data loss, and potential security breaches. Studies [5,44,45] highlight specific design difficulties and challenges faced by UWSNs.

4.1 Limited bandwidth

The bandwidth of the underwater acoustic channel is small and highly dependent on the trans-

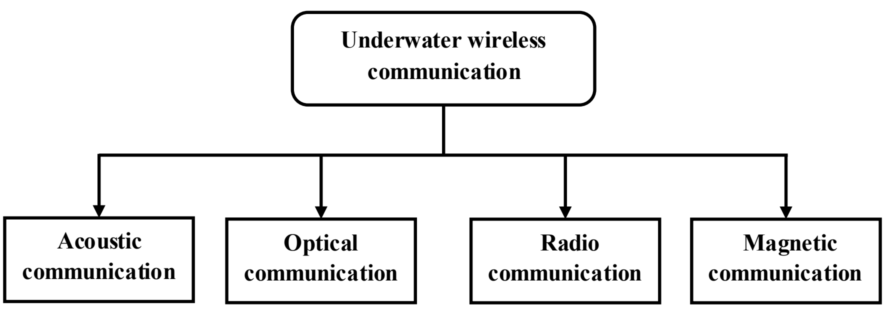


Figure 2. Underwater wireless communication techniques.

mission's range and frequency, as mentioned by Li N. [46]. Due to the high attenuation of radio signals in the water, underwater wireless communication channels have limited bandwidth, making it difficult to transmit large amounts of data, thus affecting the sensor network's performance.

4.2 Limited power resources

Designing underwater sensor nodes is challenging due to limited hardware resources and energy supply, particularly for long-range acoustic communication. Battery power is limited, leading to restricted data collection and computation capabilities, and a shortened lifespan of underwater sensor networks. Current research [5] focuses on energy-saving techniques, which can result in a short lifespan, requiring frequent maintenance and replacement.

4.3 Unreliable communication channel

Acoustic systems operate at 30 kHz, and the bandwidth of acoustic channels decreases with distance. Hydrological factors such as temperature, density, noise, and multipath and Doppler effects greatly affect underwater acoustic channels, leading to bit errors, delays, packet loss, and node failure. The studies [47,48] provide more insights into these factors and their impacts.

4.4 Vulnerability

UWSNs are subject to a number of active and passive limitations that leave them open to various dangers and malicious attacks. Nodes deployed in hostile environments are particularly vulnerable to physical damage due to hydrological topology. Ali M.F. [47] highlights these challenges and suggests that UWSNs are difficult to secure and monitor in deep-water conditions.

4.5 Interference

Interference from other underwater devices, marine mammals, and human activities can affect the performance of underwater wireless sensor networks. Developing communication protocols that can mitigate the effects of interference is a significant challenge [49].

4.6 Deployment and maintenance

Deploying and maintaining UWSNs in harsh and remote ocean environments is challenging. Researchers must develop efficient strategies for the deployment, anchoring, retrieval, and repair of sensor nodes. Jiang P. [48] highlights the need for effective methods to address these challenges.

4.7 Data management

Researchers face challenges in managing and processing the vast amounts of data generated by UWSNs due to high data rates and intermittent connectivity. They need to develop efficient data routing, storage, and processing techniques to handle these challenges (see **Figure 3**). These are just some of the many obstacles researchers and engineers face in developing and deploying effective UWSNs [5].

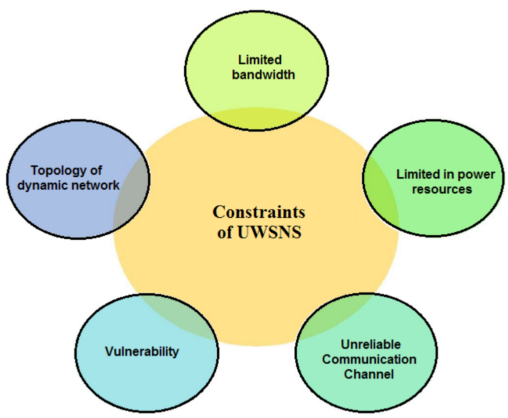


Figure 3. Challenges of UWSNs.

4.8 Topology of dynamic network

The deployment and mobility of wireless underwater sensors are challenging due to their high cost and the difficulties of real-time operations. Underwater objects' mobility creates a dynamic network structure that can affect the data flow and accuracy rate of data transfer. Researchers [50,51] have addressed this issue in the sensor network's architecture.

5. Research methodology

There are different research methodologies used to study UWSNs, depending on the research questions and objectives. Some of the common research methodologies used in UWSNs research include:

5.1 Experimental research methodology

This methodology involves conducting experiments on UWSNs to measure their performance, efficiency, and reliability. For instance, researchers can test the communication range, data transmission rate, and power consumption of UWSNs.

5.2 Simulation research methodology

This methodology involves simulating UWSNs using software tools to study their behavior and performance in a virtual environment. This method is cost-effective and allows researchers to test different scenarios, network topologies, and algorithms without the need for physical deployment.

5.3 Analytical research methodology

This methodology involves developing mathematical models to analyze the performance of UWSNs. For instance, researchers can use queuing theory, optimization theory, and probability theory to analyze the delay, throughput, and energy consumption of UWSNs.

5.4 Case study research methodology

The methodology involves studying UWSNs deployed in real-world applications to identify their challenges, limitations, and success factors. UWSNs are a type of wireless sensor network used in various applications, including oceanography, environmental monitoring, underwater surveillance, and offshore exploration. Different platforms exist in UWSNs, as shown in **Figure 4**:

- **AQUA**: It is a UWSN platform developed by the University of California, Santa Barbara. It supports high data rates and low-latency communication between underwater nodes through hardware and software components such as acoustic modems and routing protocols. Research on AQUA has been presented in studies by Ayaz M. [52] and Ma Y. [53].
- **UWMAC**: An Under Water Medium Access Control protocol (UWMAC) developed by the University of Manitoba. It is designed to provide efficient and fair sharing of the communication medium among underwater nodes and to support multiple access techniques, including time division multiple access (TDMA), Frequency Division Multiple Access (FDMA), and Code Division Multiple Access (CDMA) [54,55].
- **DOLPHIN**: It is a platform for underwater optical wireless communication developed by the University of California, San Diego. It is designed to support high data rates and low-power consumption and to enable real-time video and audio streaming between underwater nodes [56].
- **WSNLab**: It is a simulation platform for UWSNs developed by the University of Rome. It is designed to enable the evaluation of different protocols and algorithms in a controlled environment and to provide a realistic simulation of underwater conditions, including water depth, temperature, and salinity [57,58].

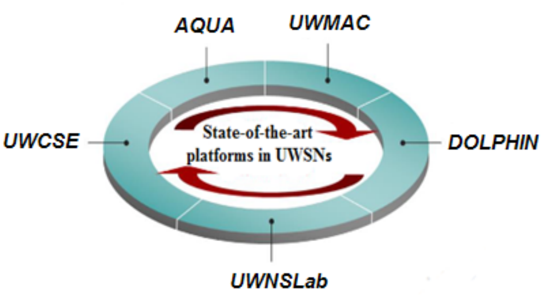


Figure 4. The UWSN platforms.

- **UWCSE**: It is a platform for underwater cognitive sensor networks to enable intelligent decision-making among nodes. It supports distributed sensing and actuation with cognitive radios and machine learning algorithms. The platform is developed by the University of Virginia [42].

6. Security requirements

6.1 Passive attacks

Detecting passive attacks in wireless sensor networks is difficult as they don't impact network functionality. Encryption can make it harder for intruders to gain access to data. Passive attacks involve nodes trying to obtain data without disrupting normal operations, and jamming can interfere with radio transmissions [58-62]. Packet captures enable packet decryption, eavesdropping, and secret communication delivery and can help to predict natural communication, as can be seen in **Figure 5**.

6.2 Active attack

Wireless sensor networks face vulnerabilities due to technical limitations like low energy consumption, radio waves, and low computational capacity. Active attacks by insiders or outsiders can modify or destroy data, while internal attacks can cause significant damage [63]. Attackers can be external to the network, making it challenging to isolate them, causing severe damage [58,64]. Encryption and authentication are critical security tools to address these challenges:

Node compromise attacks

Submarine sensor nodes in hostile sea environments face security challenges requiring specialized equipment. Nodes can be compromised and used for monitoring or interruption, causing significant damage [65-67]. Memory-based data access makes these nodes vulnerable to cracking and collection.

Repudiation attacks

In repudiation attacks, malicious nodes decline to participate in a certain communication action with other nodes. Whether the communication is malicious or not, a node involved in such a communication action will refuse. A subset of the features that can be anticipated from a security protocol, secret or authentication properties, is the subject of the verification of non-repudiation properties [54,67].

Routing attacks

To prevent malicious routing protocol attacks, cryptographic techniques are proposed, despite their higher power consumption. This approach is often used to protect against attacks, in addition to traditional computer security measures involving access control, authentication systems, and cryptographic protocols [54,68].

Flooding attacks

Flooding attacks can be carried out in two ways, one where an attacker sends common packets intensively to a single destination, making it difficult to distinguish between malicious and legitimate traffic, and another where an attacker asks for connection establishment until resources are depleted, causing valid requests to be rejected [69-71].

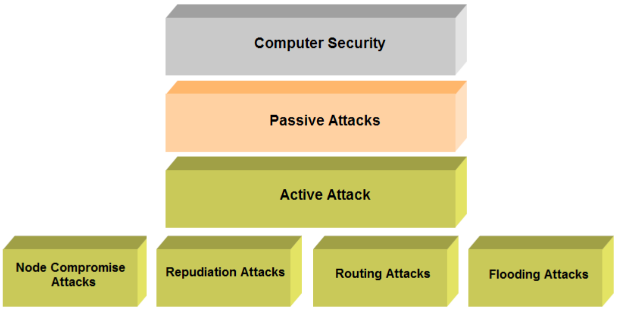


Figure 5. Emerging research direction and challenges.

6.3 Security criteria

Authentication

UWSNs require encryption to secure the acoustic channel and prevent attackers from intercepting and manipulating packet content. Proper identification of nodes can also enhance security. Intrusion Detection Mechanisms are effective in detecting anomalies and removing malicious nodes [70].

Confidentiality and survivability

Confidentiality is crucial to safeguard wireless networks from unauthorized access. Low-power encryption can prevent malware from stealing sensitive information. Ensuring the networks' survivability is important for maintaining essential services in real-time during attacks. The overall security of the network depends on the survivability of the Message Authentication Code (MAC) and the confidentiality of routing information [66].

Innovativeness

Lee J. [72] emphasizes that to achieve freshness in data transmission in real-time through the routing process, it is essential to ensure that the delay in messages does not reflect the wrong state of the network and leads to a large loss of information. This requires the strong application of technologies prioritizing the telecommunications, signal processing, and computer science sectors.

Integrity

UWSNs require measures to ensure data integrity and availability while protecting against unauthorized access and malicious attacks. This is important due to the unique challenges of operating in an underwater environment. The field of UWSNs is evolving, and its security measures must adapt accordingly. Ensuring the integrity of data is essential to prevent unauthorized alteration, corruption or loss of data [70,72].

Isolation

The use of isolation techniques and cryptographic algorithms can help identify and isolate malicious nodes in WSNs. Acoustic modems are also important for resource sharing and dependable underwater wireless transmission. Lower-layer protocols can be exploited to achieve better control of information transfer in the marine environment. This approach is independent of the protocol architecture used in different sensor networks [73,74].

Availability

To ensure the availability of UWSNs, a self-adaptive redundancy technique can be introduced to maintain communication services, even in the case of node failures or attacks. Achieving robustness against attacks requires risk modeling, intrusion detection, and node protection, as stated by Akyildiz I.F. [5]. Securing emerging systems, such as acoustic modems, is also essential and can be done through cryptography processes.

Self-stabilization

Self-stabilization consists in making the nodes recover in real time from attacks independently and without human intervention. If a node is self-stabilized in the face of malicious attacks in the network, it can recover that node by itself, even if the attacker is still trying to penetrate or remain in the network [59,74,75].

6.4 Security solutions

Encryption

Encryption is an effective solution for ensuring confidentiality and integrity. It encodes the data to prevent unauthorized access and ensures that the data are not tampered with during transmission [59].

Intrusion detection systems

Intrusion Detection Systems (IDS) can detect and prevent node compromise and data tampering. IDS can monitor the network and alert the authorities if any suspicious activity is detected [59].

Key management

Key management is crucial for secure communication in UWSNs. It ensures that the keys used for encryption and decryption are secure and not compromised [75].

Watermarking

Watermarking is a technique used for detecting data tampering. It embeds a unique digital signature in the data, which can detect any modifications made to the data during transmission [59].

Physical security

Physical security is the practice of protecting people, property, and assets from physical threats like theft, vandalism, or unauthorized access. It involves using physical barriers, locks, alarms, and surveillance systems to deter, detect, and respond to potential security breaches. Physical security is crucial for an effective overall security strategy and can help prevent or reduce the impact of security incidents [75].

7. UWSN applications

UWSNs have numerous potential applications in various fields such as environmental monitoring, maritime security, oceanic exploration, pipeline surveillance, etc. These technologies offer high precision and extensive coverage, which can help solve complex issues in the oceans and better understand the marine environment [40,76]:

7.1 Environmental monitoring

UWSNs can be used for monitoring environmental conditions in the oceans, such as temperature, salinity, water quality, presence of pollutants, etc. This information can help in better understanding climate change and preventing natural disasters.

7.2 Oil and gas industry

UWSNs can be used in the oil and gas industry for monitoring underwater pipelines, offshore drilling, and offshore platforms. They can help in detecting leaks, measuring pressure, and monitoring equipment performance.

7.3 Marine biology

UWSNs can be used for marine biology research, such as monitoring and tracking marine species, studying their behavior, and studying the underwater ecosystem.

7.4 Oceanographic data collection

UWSNs can be used for collecting oceanographic data such as temperature, salinity, and pressure. The collected data can be used for climate modeling, weather forecasting, and oceanography research.

7.5 Military and defense

UWSNs can be used for military and defense applications, such as underwater surveillance and monitoring of enemy activity. They can also be used for underwater communication and navigation.

7.6 Underwater infrastructure monitoring

UWSNs can be used for monitoring underwater infrastructure such as bridges, dams, and underwater tunnels. They can help in detecting structural damage, measuring water levels, and monitoring traffic.

8. UWSN architectures

8.1 Static two-dimensional (2D) architectures

Sensor nodes anchored to the ocean floor transmit data through a transmit-receive process to an underwater base station which transmits the information to a surface station via a transceiver. The communication between the surface station and surface and ground base stations is facilitated through a Radio Frequency (RF) signal, as illustrated in **Figure 6(a)**. Direct transmission of data from each sensor to the receiver is less energy-efficient and multi-hop transmission through intermediate sensors saves energy and expands network capacity. However, this method also poses challenges in routing the data [75].

8.2 Static three-dimensional (3D) architecture

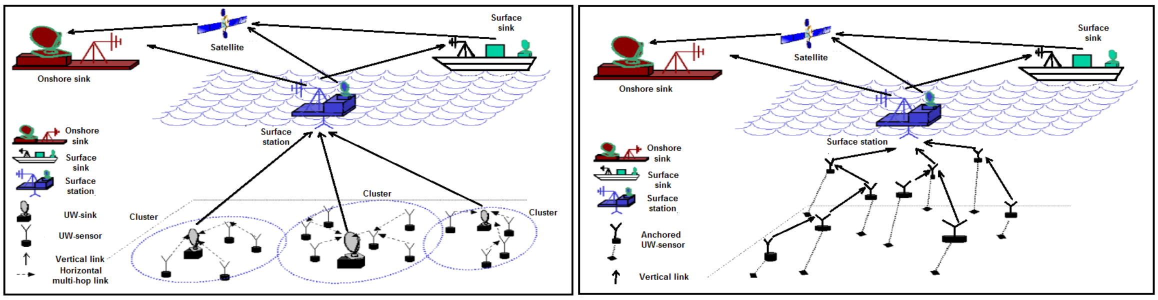
In this architecture, each sensor is anchored to the ocean floor and equipped with a floating buoy that fixes the sensor to the ocean surface [75-79] shown in **Figure 6(b)**. This architecture poses many problems that need to be solved to allow 3D tracking:

Detection coverage

The sensors in an underwater network need to collaborate to adjust their depths and obtain a 3D coverage of the ocean column based on their detection ranges. This enables them to sample the desired phenomenon at all depths and achieve global coverage [78].

Communication coverage

Isbitiren G. [79] and Cui J. [81] and have pointed out that 3D submarine networks require multiple relay points rather than a single base station for communication between sensors and the surface station as shown in **Figure 6(b)**. These multi-hop paths ensure



(a) (b)

Figure 6. UWSN architectures [76]: (a) Two-dimensional (2*D*) static underwater sensor arrays, (b) Static three-dimensional (3*D*) underwater sensor networks.

the reliable transmission of data. Coordination of depth levels is also important for maintaining a connected network topology. A minimum of one path between each sensor and the surface station is necessary for effective communication, making designing and operating such networks particularly challenging.

8.3 Autonomous sensor networks with underwater vehicles (4D)

Autonomous Underwater Vehicles (AUVs) have diverse applications in oceanography and seafloor exploration, using wireless or wired controls [25,38]. They are cost-effective and can navigate at different depths via sensors. Integrating AUVs with static sensor networks can improve UWSNs, and innovative methods are needed to achieve this objective [77], such as:

Adaptive sampling

Adaptive sampling, also known as control strategies, can be used to command mobile vehicles in hostile locations to ensure the usefulness of the data collected. Felemban E. [56] has proposed these strategies for surveillance missions. An example of this is increasing node density in an area when a high sampling frequency is required for a given monitoring phenomenon.

Self-configuration

AUVs can set up and maintain sensor networks by detecting connectivity devices and responding to node failure or data channel attenuation. They can deploy new sensors, establish network infrastructure, and act as temporary relay nodes. Solar-powered AUVs are an ideal choice, as they can continuously collect data for several months without needing to be recharged. Bian T. [75], Cui J. [77] and Blidberg D.R. [80] present this concept, which is illustrated in **Figure 7**.

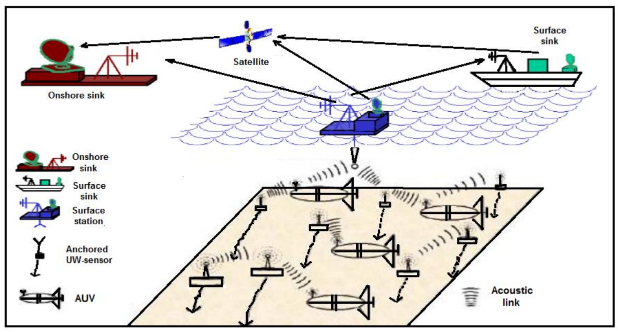


Figure 7. Three-dimensional underwater sensor networks with AUVs (4*D*) [75].

9. UWSNs based localization algorithms

9.1 Centralized localization algorithm

Localization in UWSNs is based on estimation, with sensor nodes lacking initial knowledge of their location. The control center calculates node positions during the post-processing stage through data gathering. Centralized systems involve a control center that gathers data on estimated distances between nodes and anchor nodes to determine node placement, as discussed by Jiang S.M. [51] and Ameer P.M. [81]. After identifying the positions of the sensor nodes, it sends location data back to the appropriate nodes, as described by Mirza D. [82] and depicted in **Figure**

8(a). The Centralized Localization Algorithm (CLA) for UWSNs is shown in **Figure 9**.

Hyperbola based localization scheme

The parabolic curve localization method, which utilizes hydrophones, is an effective approach to locating a mammal target. Felemban E. [56] presented a centralized sensor node that calculates the position, normalizes and calculates the error model, and transmits long-range signals to an anchoring node located at approximately 1 km distance. This method uses normal distribution for modeling and calibrating estimating errors and hyperboles for localization-based Schemes (HLS). Ayaz M. [52] noted that the HLS method is more reliable in finding unidentified nodes and reducing the risk of distance measurement inaccuracy compared to the circle approach.

Motion aware self-localization scheme

The Motion-Aware Self-Localization (MASL) system is proposed by Mirza D. [82] to address the difficulty of quickly collecting telemetry data in mobile UWSNs due to node mobility. The MASL system aims to identify errors in distance estimations and provide an accurate positioning scheme, but the longer signal propagation delay in the underwater environment may lead to outdated data due to the longer time required to gather distance estimations for localization.

Three-D multi-power area localization scheme

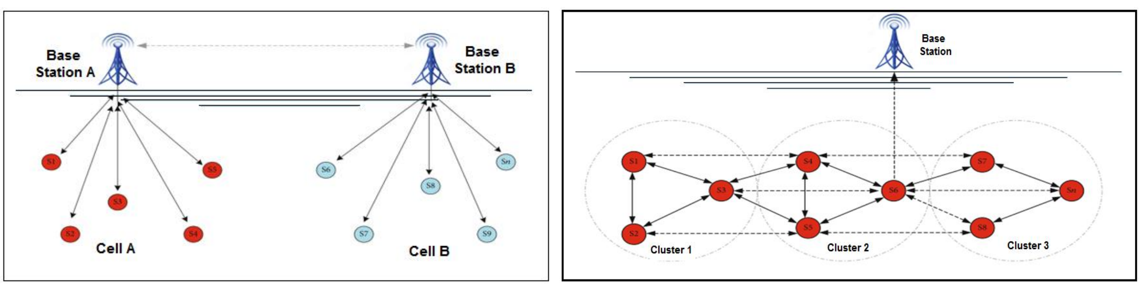
The 3D-Multi-power Area Localization Scheme (3D-MALS) is an advanced method proposed by Chandrasekhar V. [83], which uses a variable rate of transmission energy and vertical buoy mobility with a mechanical device called Detachable Elevator Transceiver (DET) to localize nodes. DET broadcasts its GPS coordinates at different energy concentrations and then descends underwater. Each surface buoy in a hybrid UWSN is equipped with a multi-powered acoustic transceiver and DET, which communicates with unknown nodes and then descends to broadcast position information at pre-configured depths. The DET broadcasts beacon signals at different powers from each broadcast site. This scheme offers high accuracy and robustness in a variety of underwater environments [84].

Area localization scheme

The Area Location Scheme (ALS) is a localization method for estimating the position of unknown nodes in large-scale underwater environments. It works by transmitting signals at different power levels and dividing the working region into non-overlapping areas using anchor nodes [85]. The ALS provides an estimate of the node's placement rather than precise coordinates, making it suitable for situations where accuracy is not crucial. The transmission power can be adjusted by anchor nodes, as demonstrated by Cheng W. [78] and the method does not require synchronization while having a low received signal strength. For more detailed information, Othman A.K. [86] offers a comprehensive description of ALS.

Collaborative localization scheme

The Collaborative Localization Scheme (CLS) is a technique for determining the position of underwater sensors without relying on long-range transponders. It utilizes two types of underwater nodes, including profilers that can dive deeper than other



(a) (b)

Figure 8. UWSN algorithms [82]: (a) Centralized network topology, (b) Distributed network topology.

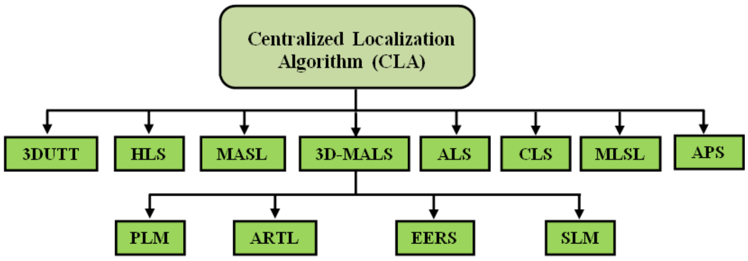


Figure 9. Centralized network algorithm.

nodes. To assign profilers to successor nodes, ToA is utilized based on the distance between them. This approach facilitates the collection and transfer of deep ocean data from underwater sensors to the surface. In this case, Bian T. [87] provides a description of the CLS.

Sensor arrays-based localization approach

The Maximum-Likelihood Source Localization (MLSL) method, proposed by Ma Y. [53] is commonly used in UWSNs that use sensor arrays to locate targets emitting narrowband acoustic signals. MLSL estimates the target position by analyzing the amplitudes of the received signals, utilizing the negative log-likelihood function. The global likelihood function is obtained by summing the local likelihood functions. MLSL does not require time synchronization or distance measurement, making it ideal for UWSNs. MLSL is connected to the Sensor Arrays based Localization Approach (SALA) via wired connections.

Probabilistic localization method

The multi-iteration approach used in terrestrial applications to reduce distance measurement error is not practical for underwater localization due to high communication costs. However, the probability distribution of distance measurement error in underwater environments follows a distinct pattern that can be leveraged to improve accuracy. Han G. [23], Bian T. [75], and Ameer P.M. [81] consider both uniform and normal error distributions and propose a Probabilistic Localization Method (PLM) to increase accuracy. Compared to other statistical approaches like Minimal Mean Squared Error (MMSE) and Minimum Mean Absolute Error (MMAE), PLM requires less information transmission [88].

Asymmetrical round-trip based localization

The Asymmetrical Round Trip based Localization (ARTL) algorithm proposed by Liu, B. [88] assumes that unknown nodes cannot receive their own packets, but anchor nodes can. The ranking scheme is used to determine distances between anchor nodes and unknown nodes based on the difference in arrival time. The base station uses this data and previously collected information to initiate the localization process. ARTL is a simple and efficient solution for UWSNs that does not require time synchronization, complex computations, or immediate replies from unknown nodes.

Absolute positioning scheme

AUVs provide researchers with new methods of ocean access, but accurate positioning data is crucial for their effective use. To address this issue, Liu B. [88] proposes an Absolute Positioning Scheme (APS) for locating AUVs. However, the acoustic interrogation pulse limits the localization coverage to only one AUV, and the timing difference of the signal arrivals is imprecise due to the motion of both the AUV and the ship. Using the ship's GPS-located hydrophone for AUV localization, as described by Isbitiren G. [79] is not practical due to high energy requirements and hardware costs.

Energy-efficient ranging scheme

Isbitiren G. [79] proposes an Energy-Efficient Ranging Scheme (EERS) for localizing sensor-equipped drifters in mobile UWSNs. EERS addresses the challenge of unpredictable mobility by using Sufficient Distance Map Estimation (SDME) to measure range through a one-way time of exchange message arrival. SDME includes synchronization-data collection (SDME-S) for time synchronization and distance estimation (SDME-D) using a two-step process. This method is more energy-efficient since not all nodes need to broadcast localization messages during the distance estimation process [22].

Three-dimensional underwater target tracking

The Three-Dimensional Underwater Target Tracking (3DUTT) algorithm is proposed for tracking underwater targets in two phases [79]. First, sensor nodes passively listen to the environment to detect targets, and then a projector node periodically sends pings to localize the target in the active ranging phase. The target's location and velocity are tracked by the sink node using trilateration for localization. The algorithm uses an adaptive approach to identify and activate new boundary nodes to prevent energy depletion. The sink node selects a new projector node based on the calculation results. The 3DUTT scheme is described by Isbitiren G. [79].

Silent localization using magnetometers

The traditional method of localizing nodes in UWSNs is limited due to sound scattering, but Silent Localization using Magnetometers (SLM) is suggested as a solution, replacing acoustics with magnetometers. The technique involves a friendly ship with a known magnetic dipole to locate unknown nodes with triaxial magnetometers. Each unknown node has a pressure sensor and an accelerometer for estimating depth and sensor orientation. An Extended Kalman Filter (EKF) is used to predict the vessel's trajectory and unknown node locations simultaneously. SLM is beneficial in shallow water environments where sound scattering is significant [89].

9.2 Distributed localization algorithm

The Distributed Localization based Algorithm (DLA) is a decentralized solution proposed by Chandrasekhar V. [83] for nodes in underwater sensor networks to locate themselves using neighborhood distance and anchor position information, and transmit data to a super node. Randomly distributed anchor nodes are used for position reference using distributed positioning techniques. Unlike terrestrial networks, GPS-equipped nodes cannot serve as anchor nodes in underwater networks, as cited by Mirza D. [82]. Nodes communicate through point-to-point leaves in a distributed network, as shown in **Figure 8(b)**, and the algorithm is presented below in **Figure 10**.

AUV assisted localization technique

The AUV Assisted Localization Technique (AUV-ALT) proposed by Erol M. [90] is designed for a hybrid 3D UWSN system comprising underwater sensor nodes and moving AUVs. The AUV determines its position using the "dead reckoning" method and receives GPS coordinates periodically when it travels to the water's surface. The locating process begins when an underwater sensor node sends a request signal to the AUV, which triggers the locating process, and the AUV responds with a signal. During the AUV cycle, a wake-up signal may be transmitted from a different location along its course to improve the accuracy of localization.

Dive and rise localization scheme

The Dive and Rise Localization Scheme (DNRLS) is a distributed location algorithm that uses mobile anchoring for underwater sensor node localization [91]. Dive 'N' Rise (DNR) beacons are mobile anchoring nodes that use GPS receivers to obtain their sea surface coordinates. The underwater sensors use the ToA method to measure distances from DNR beacons and calculate their location based on range estimations and anchor node coordinates. DNRLS has several benefits such as being silent, requiring low communication, and being energy efficient.

Three-dimensional underwater localization

The Three-dimensional Underwater Localization (3DUL) procedure involves three buoys floating on the surface and numerous underwater sensors at various depths, and has the drawback of requiring a long localization time and no time synchronization [91,92]. The procedure is carried out in two algorithmic phases, with ranging used to gather depth data in the first phase and dynamic trilateration used as a reference node to project buoy positions in the second phase.

Range-free scheme-based mobile beacons

The Range-Free Scheme based Mobile Beacons (RFSMB) technique is a range-free localization scheme that employs a mobile anchor node moving across the sea surface to random destinations to obtain depth information from pressure sensor installations on unidentified nodes [91]. This allows the unknown nodes to estimate their own localization independently by selecting three beacons that have been received. The RFSMB technique adheres to the Random destination point model [92].

Localization scheme using directional beacons

Luo, H. [93] introduced a novel Localization Scheme using Directional Beacons (LSDB) for two-dimensional localization in a sparse underwater environment. It utilizes a low-cost pressure sensor to detect the depth of a node and estimate its 2D position at the fixed depth. The nodes receive a series of beacons from an AUV while it moves in a straight line at a constant depth to enable localization.

Ray bending-based localization

The Ray Bending based Localization (RBL) approach addresses the issue of sound rays bending in water due to the depth-dependent sound speed, which affects the performance of traditional localization techniques that assume straight-line sound propagation. The RBL approach, presented by Ameer P.M. [94] and Porter M.B. [95] considers the spherical shape of constant range interval surfaces, which results from the assumption of constant velocity and a straight line trajectory.

Node discovery and localization protocol

The Node Discovery and Localization Protocol (NDLP) is a GPS and anchor-free algorithm for subsea localization [27]. It involves a primary seed node with a known position that identifies the relative placements of nearby nodes and selects a secondary seed node. NDLP allows for large-scale localization of unknown nodes by repeatedly selecting seed nodes, making it an effective solution for sub-sea localization.

Reactive localization algorithm

The Reactive Localization Algorithm (RLA) is an event-based localization algorithm presented by Toky A. [96]. It involves a sensor node detecting an event and broadcasting a message with its ID and energy level to its neighbors. At least four non-coplanar anchor nodes are discovered by the K-Node Coverage Algorithm. In the reactive localization phase, the selected anchor nodes respond with their position data, and the sensor node uses quadrilateration to locate itself. RLA provides an efficient approach to event-based localization in wireless sensor networks.

Multi-stage AUV-assisted localization scheme

The Multi-Stage AUV-assisted Localization Scheme (MS-AUV-LS) is a hybrid approach that combines AUV-aided localization and Silent Localization techniques [83]. The algorithm uses passive listening of localization messages by unknown nodes to improve localization accuracy and reduce localization time. Simulation results show that the entire localization process can cover over 95% of the network in less than 10 minutes. However, MS-AUV-LS is prone to accumulate errors like other multi-stage algorithms.

Multi-frequency active localization method-based TDoA

Multi-Frequency Active Localization Method (MFALM) is a proposed localization method for mobile UWSNs based on TDoA and only localizes nodes detecting events, as their positions can change at any time. The network consists of three types of nodes: Buoy, relay, and standard nodes. Buoy nodes use GPS to locate themselves and broadcast their location via low-frequency acoustic signals periodically. Relay nodes use low-frequency signals to partition the network into different localization regions and determine the maximum hops for each area. Common nodes that detect events receive low-frequency signals from buoy nodes to locate themselves [83,97].

Underwater localization using directional beacons

The Underwater Localization using Directional

Beacons (ULDB) method is suitable for a hybrid 3D underwater sensor network, where stationary nodes are located using an AUV [93]. The AUV determines its self-location when it reaches the water's surface and receives GPS coordinates, then dives to a specific depth and moves across the area of interest during the localization process. It uses a directional acoustic transceiver to transmit its position and transceiver angle, resulting in lower energy consumption than the AAL method, which is a silent localization method [98-101].

Multi-stage DNR localization scheme

The Multi-Stage DNR Localization Scheme (MS-DNR-LS) aims to locate an unallocated node in a 3D underwater sensor network. The method adds coverage, delays the localization of a further stage, and uses effectively located submarine nodes as anchor nodes. Three distinct nodes are used to estimate the coordinates and distance of the unallocated node [98].

Underwater positioning scheme

The Underwater Positioning Scheme (UPS) uses auditory range and/or direction, followed by triangulation, to monitor and operate underwater divers or vehicles [98]. It is used for various purposes, including oil and gas exploration, marine science, rescue, and military needs. UPS is extended for UWSNs in a TDoA-based tracking system proposed by Luo J. [99], which uses four anchors to transfer messages from tags sequentially.

Large-scale hierarchical localization approach

The Large-Scale Hierarchical Localization (LSHLA) proposed by Zhou Z. [102] uses surface buoys with GPS for absolute positioning and anchor nodes for communication. Unknown nodes communicate with anchor nodes for localization, while anchor nodes can directly communicate with surface buoys for their absolute positions. The approach involves two sub-processes: Anchor node localization and unknown node localization.

Wide coverage positioning

Nodes near anchor knots need five anchors to solve the problem. In the case of Wide Coverage Positioning (WPS), four anchors are used whenever a distinctive location can be reached using four anchors called UPS (4); otherwise, WPS will use five anchors (UPS (5)). UPS (4) and UPS (5) are used together to solve the overhead and communication cost for sensor nodes with four anchors that can already be located [103,104]. These nodes consume the same energy as the initial location system.

Underwater sensor positioning

The Underwater Sensor Positioning (USP) method uses pressure sensors to map anchors and determine underwater node positions [93,98]. Neighboring nodes' messages are used to refine estimated positions, and non-localized nodes use bi-lateralization to localize using only two anchors.

Anchor-free localization

Underwater localization techniques often require specialized devices or a large number of anchor nodes. However, Anchor-Free Localization (AFL), as stated by Fu B. [101], uses data from neighboring nodes instead of anchor node information. Cheng X. [100] proposed another technique that enables the discovery of unlinked nodes on a Line-of-Sight and any rigid reference node, allowing for anchorless and surface-reflective location methods using a protocol without GPS to find nodes and their relative location.

Scalable localization with mobility prediction

The Scalable Localization with Mobility Prediction (SLMP) technique uses surface buoys, anchor nodes, and common nodes to estimate positions. This method utilizes mobility models to predict anchor node positions, and GPS coordinates received by buoys to estimate their positions. The anchor node then uses distance measurements to estimate its position, and the mobility model is checked periodically for validity. This approach is scalable and efficient for large underwater sensor networks [59,105].

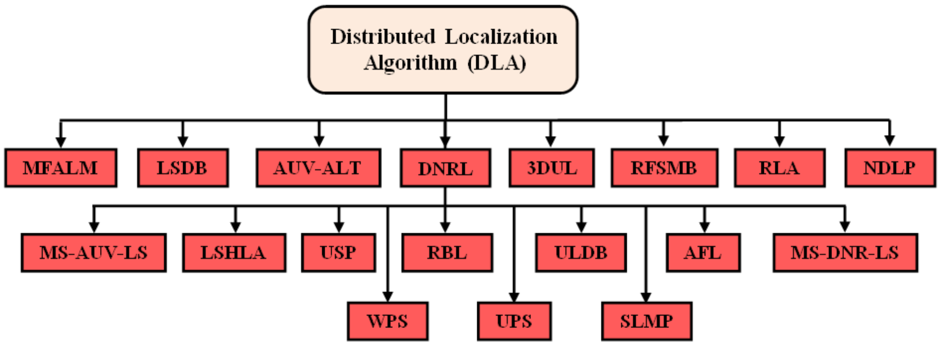


Figure 10. Distributed network algorithm.

10. Range-free and range based algorithms

10.1 Range-based algorithm

The Range-based Algorithm is a localization technique used in UWSNs to estimate the distance or angle between nodes using methods such as Time Difference of Arrival (TDoA), Time of Arrival (ToA), Angle of Arrival (AoA), and Received Signal Strength Indicator (RSSI). TDoA measures the time difference between signal transmission by different reference nodes to calculate distance, while ToA calculates the distance by measuring the ToA of signals. The latter is the most commonly used technique in UWSNs and is similar to the terrestrial sensor network. However, RSSI is not always practical in UWSNs due to certain constraints [106,107]. Zhou M. [108] and Luo J. [109] also proposed the use of ToA in UWSNs.

Time difference of arrival

A TDoA-based localization algorithm is proposed that does not require synchronization between base stations, which typically is necessary for improving accuracy. The method avoids using wideband signals or wire connections, which reduces operating costs. The proposed algorithm can locate a target even if the anchor nodes are asynchronous [97,110].

Time of arrival

Vaghefi R.M. [110] proposed a new method called ToA-Based Tracked Synchronization (ToA-TS) to address the need for balancing the target with anchor nodes in the ToA-based systems. This method uses GPS for time synchronization and identifies where beacon signals do not coincide. The receiver records the time of reception based on the submersible's local clock. Additionally, the author introduces a combined localization technique for Time of Flight (ToF) and Direction of Arrival (DoA).

Angle of arrival

An AoA algorithm estimates the location and orientation of underwater nodes by detecting signal angles from nearby nodes [97]. It uses a small antenna array to initialize the DoA as the azimuth direction of the vertex power and measures the phase derivative along the array axis to estimate the DoA. However, the range of arrivals may not always be precise. The algorithm provides close nodes around the node axis for each node in a network with zero attenuation [110].

Received signal strength indicator

In UWSNs, localization of sensors is a challenging task and commonly used methods are ToA and RSSI. RSSI-based localization relies on radio wave propagation path loss and has been implemented using acoustic signals [109]. Maximum likelihood estimation and frequency-dependent differential process are the proposed estimators. However, evaluating the distance between anchor nodes and unknown nodes is still a challenge, and ToA or RSS signals are commonly used for telemetry algorithms in UWSNs.

10.2 Range-free localization algorithm

The Range-free Localization Algorithms (RFLA) do not require bearing information and a hybrid localization algorithm for multi-platform mobile underwater acoustic networks was proposed by Guo

Y. [106]. The algorithm divides sensor nodes into multistage nodes, utilizing both range-based and range-free techniques to enhance localization accuracy and reduce communication costs. These techniques are valuable in underwater environments since they do not require prior knowledge of velocity.

Centroid algorithm

The 3D underwater location algorithm utilizes both mooring nodes and underwater sensor nodes to estimate positions. However, the Centroid Algorithm may not apply to 3D networks. Therefore, a joint and distributed establishment control of generic multi-agent robots is proposed for underwater applications like Autonomous Surface Vehicles (ASV). The algorithm aims to maintain a predefined geometrical shape with a leading agent whose dynamics are similar to those of its other supporters [75].

Hop count-based algorithms

The Hop Count-based Algorithm (HCA) utilizes anchor nodes placed along the boundaries or corners of a square grid. Several algorithms such as Distance Vector Hop (DV-Hop), Solid Positioning Algorithm (SPA), and DHL are presented to estimate the distance to anchor nodes. DV-Hop uses an average estimation of the spectrum of hops and the counted number of hops, while SPA adds an extra refinement step to improve accuracy. DHL dynamically estimates distance using density consciousness. These techniques are discussed in a study by Poursheikhali S. [97].

Area-based algorithm scheme

The Area-based Localization Scheme (ALS) is a range-free localization method that employs a synchronized sensor node clock, and is impervious to variations in sound speed underwater. 3D-MALS extends ALS to 3D, while Approximate Point in a Triangle (APIT) requires a heterogeneous network [78,97]. Anchors with high-power transmitters can use GPS coordinates for accurate location data. Zhou Z. [105] proposed a novel technique using MFCCs to extract underwater radiated noise characteristics.

11. Conclusions

The study highlights the need for further exploration and optimization of communication and localization techniques in UWSNs to improve accuracy and reliability. New communication protocols, algorithms, and hardware solutions need to be developed to address challenges such as low data rates, limited power supply, and unreliable information in UWSNs. Cost-effectiveness should also be considered in the design and deployment of UWSNs. To ensure a satisfactory future for UWSNs, it is essential to have a flexible architecture that enables wireless communication between different technologies. Future research should focus on improving node mobility, cooperative control, and high-level planning, with an emphasis on enhancing acoustic communication.

Challenges still exist in enhancing the capabilities and reliability of UWSNs for ocean monitoring and exploration. Research in this field could focus on developing hybrid energy harvesting strategies and exploring complex network scenarios. Another key area is developing data processing techniques to improve the accuracy of environmental measurements, including detecting and classifying underwater objects. Investigating the use of advanced sensors and actuators and integrating artificial intelligence and machine learning could further improve UWSN performance and enhance data analysis. Additionally, developing new approaches to energy harvesting and storage is critical for improving the endurance and reliability of UWSNs. Finally, integrating underwater robotics and autonomous vehicles could revolutionize the capabilities of UWSNs in ocean exploration and monitoring. By addressing these challenges, UWSNs can be fully realized, resulting in a better understanding and protection of the ocean environment.

Conflict of Interest

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References

[1] Stojanovic, M., 1996. Recent advances in high-speed underwater acoustic communications. IEEE Journal of Oceanic Engineering. 21(2), 125-136. Available from: http://users.isr.ist.utl.pt/~jpg/proj/phitom/refs/stojanovic_apr96_joe_MergePDFs.pdf

[2] Sozer, E., Stojanovic, M., Proakis, J.G., 1999. Design and simulation of an underwater acoustic local area network. Proceedings Opnetwork. 99, 65-72. Available from: https://www.semanticscholar.org/paper/Design-and-Simulation-of-an-Underwater-Acoustic Sozer-Stojanovic/cb61efbdc764edfc310bfd8ac8940843bff59d14

[3] Stojanovic, M., Preisig, J., 2009. Underwater acoustic communication channels: Propagation models and statistical characterization. IEEE Communications Magazine. 47(1), 84-89. DOI: https://doi.org/10.1109/MCOM.2009.4752682.

[4] Chen, K., Ma, M., Cheng, E., et al., 2014. A survey on MAC protocols for underwater wireless sensor networks. IEEE Communications Surveys & Tutorials. 16(3), 1433-1447. DOI: https://doi.org/10.1109/SURV.2014.013014.00032

[5] Akyildiz, I.F., Pompili, D., Melodia, T., 2005. Underwater acoustic sensor networks: Research challenges. Ad Hoc Networks. 3(3), 257-279. DOI: https://doi.org/10.1016/j.adhoc.2005.01.004

[6] Climent, S., Sanchez, A., Capella, J.V., et al., 2014. Underwater acoustic wireless sensor networks: Advances and future trends in physical, MAC and routing layers. Sensors. 14(1), 795-833. DOI: https://doi.org/10.3390/s140100795

[7] Al-Fuqaha, A., Guizani, M., Mohammadi, M., et al., 2015. Internet of things: A survey on enabling technologies, protocols, and applications. IEEE Communications Surveys & Tutorials. 17(4), 2347-2376. DOI: https://doi.org/10.1109/COMST.2015.2444095

[8] Perrig, A., Szewczyk, R., Tygar, J.D., et al., 2002. SPINS: Security protocols for sensor networks. Wireless Networks. 8(5), 521-534. Available from: https://people.eecs.berkeley.edu/~tygar/papers/SPINS/SPINS_wine-journal.pdf

[9] Fleury, E., Simplot-Ryl, D., 2009. Réseaux de Capteurs: Théorie et Modélisation (French) [Sensors Networks: Theory and Modelling]. Auteurs : FLEURY Éric, SIMPLOT-RYL David. pp. 1-364. Available from: https://www.lavoisier.fr/livre/physique/reseaux-de-capteurs-theorie-et-/fleury/descriptif-9782746221222

[10] Webster, S.E., 2010. Decentralized single-beacon acoustic navigation: Combined communication and navigation for underwater vehicles [PhD thesis]. Baltimore: Johns Hopkins University. Available from: https://apps.dtic.mil/sti/pdfs/ADA528005.pdf

[11] Souiki, S., 2015. Protocoles de Routage Performants Dédies aux Réseaux de Capteurs sans Fil sous l'eau (French) [Efficient Routing Protocols Dedicated to Underwater Wireless Sensor Networks] [PhD thesis]. Algerie: Université Abou Bekr Belkaid de Tlemcen. Available from: https://www.theses-algerie.com/1180796419097579/these-de-doctorat/universite-abou-bekr-belkaid-tlemcen/protocoles-de-routage-performants-dedies-aux-reseaux-de-capteurs-sans-fil-sous-leau

[12] Jahan, K., Rao, S.K., 2020. Implementation of underwater target tracking techniques for Gaussian and non-Gaussian environments. Computers & Electrical Engineering. 87, 106783. DOI: https://doi.org/10.1016/j.compeleceng.2020.106783

[13] Ribas, D., Ridao, P., Tardós, J.D., et al., 2008. Underwater SLAM in man-made structured environments. Journal of Field Robotics. 25(11-12), 898-921.

DOI: https://doi.org/10.1002/rob.20249

[14] Demim, F., Nemra, A., Abdelkadri, H., et al., 2019. NH∞-SLAM algorithm for autonomous underwater vehicle. Lecture Notes in Advances in Computing Systems and Applications Book Series. Springer, Cham.: Berlin. pp. 193-203.

[15] Demim, F., Nemra, A., Louadj, K., et al., 2017. An adaptive SVSF-SLAM algorithm to improve the success and solving the UGVs cooperation problem. Journal of Experimental & Theoretical Artificial Intelligence. 30(3), 389-414. DOI: https://doi.org/10.1080/0952813X.2017.1409282

[16] Demim, F., Rouigueb, A., Nemra, A., et al., 2022. A new filtering strategy for target tracking application using the second form of smooth variable structure filter. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering. 236(6), 1224-1249. DOI: https://doi.org/10.1177/09596518221079485

[17] Demim, F., Benmansour, S., Abdelkrim, N., et al., 2022. Simultaneous localisation and mapping for autonomous underwater vehicle using a combined smooth variable structure filter and extended kalman filter. Journal of Experimental & Theoretical Artificial Intelligence. 34(4), 621-650. DOI: https://doi.org/10.1080/0952813X.2021.1908430

[18] Cheng, Y., Liu, Q., Wang, J., et al., 2018. Distributed fault detection for wireless sensor networks based on support vector regression. Wireless Communications and Mobile Computing. 4349795. DOI: https://doi.org/10.1155/2018/4349795

[19] Zhang, Z., Mehmood, A., Shu, L., et al., 2018. A survey on fault diagnosis in wireless sensor networks. IEEE Access. 6, 11349-11364. DOI: https://doi.org/10.1109/ACCESS.2018.2794519

[20] Ez-Zaidi, A., Rakrak, S., 2016. A comparative study of target tracking approaches in wireless sensor networks. Journal of Sensors. 3270659. DOI: https://doi.org/10.1155/2016/3270659

[21] Kou, K., Li, B., Ding, L., et al., 2023. A distributed underwater multi-target tracking algorithm based on two-layer particle filter. Journal of Marine Science and Engineering. 11(4), 858. DOI: https://doi.org/10.3390/jmse11040858

[22] Park, M.K., Rodoplu, V., 2007. UWAN-MAC: An energy-efficient MAC protocol for underwater acoustic wireless sensor networks. IEEE Journal of Oceanic Engineering. 32(3), 710-720. DOI: https://doi.org/10.1109/JOE.2007.899277

[23] Han, G., Jiang, J., Shu, L., et al., 2012. Localization algorithms of underwater wireless sensor networks: A survey. Sensors. 12(2), 2026-2061. DOI: https://doi.org/10.3390/s120202026

[24] Pranitha, B., Anjaneyulu, L., 2011. Analysis of underwater acoustic communication system using equalization technique for ISI reduction. Procedia Computer Science. 167, 1128-1138. Available from: https://www.sciencedirect.com/science/article/pii/S1877050920308814

[25] Kim, Y.G., Kim, D.G., Kim, K., et al., 2022. An efficient compression method of underwater acoustic sensor signals for underwater surveillance. Sensors. 22(9), 3415. DOI: https://doi.org/10.3390/s22093415

[26] Partan, J., Kurose, J., Levine, B.N., 2007. A survey of practical issues in underwater networks. ACM SIGMOBILE Mobile Computing and Communications Review. 11(4), 23-33. DOI: https://doi.org/10.1145/1347364.1347372

[27] Alsulami, M., Elfouly, R., Ammar, R. (editors), 2014. Underwater wireless sensor networks: A review. Proceedings of the 11th International Conference on Sensor Networks. p. 202-214. DOI: https://doi.org/10.5220/0010970700003118

[28] Heidemann, J., Stojanovic, M., Zorzi, M., 2012. Underwater sensor networks: Applications, advances and challenges. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 370(1958), 158-175.

DOI: https://doi.org/10.1098/rsta.2011.0214

[29] Ali, M., Khan, A., Mahmood, H., et al., 2019. Cooperative, reliable, and stability-aware routing for underwater wireless sensor networks. International Journal of Distributed Sensor Networks. 15(6), 1-11.
DOI: https://doi.org/10.1177/1550147719854249

[30] Khalid, M., Ullah, Z., Ahmad, N., et al., 2017. A survey of routing issues and associated protocols in underwater wireless sensor networks. Journal of Sensors. 7539751.
DOI: https://doi.org/10.1155/2017/7539751

[31] Ismail, A.S., Wang, X., Hawbani, A., et al., 2022. Routing protocols classification for underwater wireless sensor networks based on localization and mobility. Wireless Networks. 28(2), 797-826.
DOI: https://doi.org/10.1007/s11276-021-02880-z

[32] Goh, J.H., Shaw, A., Al-Shamma'a, A.I., 2009. Underwater wireless communication system. Journal of Physics: Conference Series. 178, 012029.
DOI: https://doi.org/10.1088/1742-6596/178/1/012029

[33] Yan, H., Ma, T., Pan, C., et al. (editors), 2022. Statistical analysis of time-varying channel for underwater acoustic communication and network. Proceedings of the International Conference on Frontiers of Information Technology (FIT); 2021 Dec 13-14; Islamabad. New York: IEEE.
DOI: https://doi.org/10.1109/FIT53504.2021.00020

[34] Goyal, N., Dave, M., Verma, A.K., 2019. Protocol stack of underwater wireless sensor network: Classical approaches and new trends. Wireless Personal Communications. 104, 995-1022.
DOI: https://doi.org/10.1007/s11277-018-6064-z

[35] Kashif Manzoor, M., Amir Latif, R.M., Haq, I., et al., 2022. An energy-efficient routing protocol via angle-based flooding zone in underwater wireless sensor networks. International Journal of Intelligent Systems and Applications in Engineering. 10(2s), 116-123. Available from: https://www.ijisae.org/index.php/IJISAE/article/view/2371/955

[36] Celik, A., Romdhane, I., Kaddoum, G., et al., 2023. A top-down survey on optical wireless communications for the Internet of Things. IEEE Communications Surveys & Tutorials. 25(1), 1-45.
DOI: https://doi.org/10.1109/COMST.2022.3220504

[37] Chehri, A., Farjow, W., Mouftah, H.T. (editors), et al., 2011. Design of wireless sensor network for mine safety monitoring. Proceedings of the 24th Canadian Conference on Electrical and Computer Engineering; 2011 May 8-11; Niagara Falls. New York: IEEE.
DOI: https://doi.org/10.1109/CCECE.2011.6030722

[38] Zhao, C., Liu, F., Hai, X., 2013. An application of wireless sensor networks in underground coal mine. International Journal of Future Generation Communication and Networking. 6(5), 117-126.
DOI: http://dx.doi.org/10.14257/ijfgcn.2013.6.5.11

[39] Saeed, N., Celik, A., Al-Naffouri, T.Y., et al., 2017. Energy harvesting hybrid acoustic-optical underwater wireless sensor networks localization. Sensors. 18(1), 51.
DOI: https://doi.org/10.3390/s18010051

[40] Fattah, S., Gani, A., Ahmedy, I., et al., 2020. A survey on underwater wireless sensor networks: Requirements, taxonomy, recent advances, and open research challenges. Sensors. 20(18), 5393.
DOI: https://doi.org/10.3390/s20185393

[41] Luo, J., Chen, Y., Wu, M., et al., 2021. A survey of routing protocols for underwater wireless sensor networks. IEEE Communications Surveys & Tutorials. 23(1), 137-160.
DOI: https://doi.org/10.1109/COMST.2020.3048190

[42] Xie, P., Cui, J.H., 2007. An FEC-based reliable data transport protocol for underwater sensor networks. Proceedings of the 16th IEEE International Conference on Computer Communications and Networks; 2007 Aug 13-16; Honolulu. New York: IEEE.
DOI: https://doi.org/10.1109/ICCCN.2007.4317907

[43] Wang, H., Wang, S., Zhang, E., 2016. An improved data transport protocol for underwater

acoustic sensor networks. Proceedings of the OCEANS MTS/IEEE Monterey; 2016 Sep 19-23; Monterey. New York: IEEE.
DOI: https://doi.org/10.1109/OCEANS.2016.7761436

[44] Prasan, U.D., Murugappan, S., 2012. Underwater sensor networks: Architecture, research challenges and potential applications. International Journal of Engineering Research and Applications. 2(2), 251-256. Available from: https://www.ijera.com/papers/Vol2_issue2/AP22251256.pdf

[45] Draz, U., Ali, T., Yasin, S., et al. (editors), 2018. A parametric performance evaluation of SMDBRP and AEDGRP routing protocols in underwater wireless sensor network for data transmission. Proceedings of the IEEE International Conference on Advancements in Computational Sciences; 2018 Feb 19-21; Lahore. New York: IEEE.
DOI: https://doi.org/10.1109/ICACS.2018.8333484

[46] Li, N., Martínez, J.F., Meneses Chaus, J.M., et al., 2016. A survey on underwater acoustic sensor network routing protocols. Sensors. 16(3), 414.
DOI: https://doi.org/10.3390/s16030414

[47] Ali, M.F., Jayakody, D.N.K., Chursin, Y.A., et al., 2020. Recent advances and future directions on underwater wireless communications. Archives of Computational Methods in Engineering. 27, 1379-1412.
DOI: https://doi.org/10.1007/s11831-019-09354-8

[48] Jiang, P., Dong, L., Pang, X. (editors), 2016. Deployment strategy of wireless sensor networks: A survey. Proceedings of the 2016 6th International Conference on Machinery, Materials, Environment, Biotechnology and Computer; 2016 Jun 11-12; Tianjin. New York: IEEE.
DOI: https://doi.org/10.2991/mmebc-16.2016.286

[49] Khan, A., Javaid, N., Ali, I., et al., 2017. An energy efficient interference-aware routing protocol for underwater WSNs. KSII Transactions on Internet and Information Systems. 11(10), 4844-4864.
DOI: https://doi.org/10.3837/tiis.2017.10.009

[50] Wei, L., Han, J., 2020. Topology control algorithm of underwater sensor network based on potential-game and optimal rigid sub-graph. IEEE Access. 8, 177481-177494.
DOI: https://doi.org/10.1109/ACCESS.2020.3024742

[51] Jiang, S., 2018. On securing underwater acoustic networks: A survey. IEEE Communications Surveys & Tutorials. 21(1), 729-752.
DOI: https://doi.org/10.1109/COMST.2018.2864127

[52] Ayaz, M., Baig, I., Abdullah, A., et al., 2011. A survey on routing techniques in underwater wireless sensor networks. Journal of Network and Computer Applications. 34(6), 1908-1927.
DOI: https://doi.org/10.1016/j.jnca.2011.06.009

[53] Ma, Y., Hu, Y.H. (editors), 2009. ML source localization theory in an underwater wireless sensor array network. 2009 5th International Conference on Wireless Communications, Networking and Mobile Computing; 2009 Sep 24-26; Beijing. New York: IEEE. p. 1-4.
DOI: https://doi.org/10.1109/WICOM.2009.5303840

[54] Dini, G., Duca, A.L., 2012. A secure communication suite for underwater acoustic sensor networks. Sensors. 12(11), 15133-15158.
DOI: https://doi.org/10.3390/s121115133

[55] SSharif-Yazd, M., Khosravi, M.R., Moghimi, M.K., 2017. A survey on underwater acoustic sensor networks: Perspectives on protocol design for signaling, MAC and routing. Journal of Computer and Communications. 5, 12-23.
DOI: https://doi.org/10.4236/jcc.2017.55002

[56] Felemban, E., Shaikh, F.K., Qureshi, U.M., et al., 2015. Underwater sensor network applications: A comprehensive survey. International Journal of Distributed Sensor Networks. 11(11), 896832.
DOI: https://doi.org/10.1155/2015/896832

[57] Bhalla, M., Pandey, N., Kumar, B. (editors), 2015. Security protocols for wireless sensor networks. Proceedings of the International Conference on Green Computing and Internet of Things; 2015 Oct 8-10; Greater Noida. p. 1005-1009. Available from: https://cibtrc.com/wp-content/uploads/2019/12/bhalla2015.pdf

[58] Fouchal, S., Mansouri, D., Mokdad, L., et al., 2015. Recursive-clustering-based approach for denial of service (DoS) attacks in wireless sensors networks. International Journal of Communication Systems. 28(2), 309-324.
DOI: https://doi.org/10.1002/dac.2670

[59] Fengzhong, Q.U., Shiyuan, W., Zhihui, W.U., et al., 2016. A survey of ranging algorithms and localization schemes in underwater acoustic sensor network. China Communications. 13(3), 66-81.
DOI: https://doi.org/10.1109/CC.2016.7445503

[60] Li, H., He, Y., Cheng, X., et al., 2015. Security and privacy in localization for underwater sensor networks. IEEE Communications Magazine. 53(11), 56-62.
DOI: https://doi.org/10.1109/MCOM.2015.7321972

[61] Hahn, M.J., 2005. Undersea navigation via a distributed acoustic communication network [Master's thesis]. Annapolis: Naval Postgraduate School Monterey CA: United States Naval Academy. Available from: https://apps.dtic.mil/sti/citations/ADA435873

[62] Sandhiyaa, S., Gomathy, C., 2022. Performance analysis of routing protocol in underwater wireless sensor network. Proceedings of the IEEE International Conference on Sustainable Computing and Data Communication Systems; 2022 Apr 7-9; Erode. New York: IEEE.
DOI: https://doi.org/10.1109/ICSCDS53736.2022.9760816

[63] Gavrić, Ž., Simić, D., 2018. Overview of DOS attacks on wireless sensor networks and experimental results for simulation of interference attacks. Ingeniería e Investigación. 38(1), 130-138.
DOI: http://dx.doi.org/10.15446/ing.investig.v38n1.65453

[64] Liou, E.C., Kao, C.C., Chang, C.H., et al. (editors), 2018. Internet of underwater things: Challenges and routing protocols. Proceedings of IEEE International Conference on Applied System Invention; 2018 Apr 13-17; Chiba. New York: IEEE. p. 1171-1174.
DOI: http://dx.doi.org/10.1109/ICASI.2018.8394494

[65] Celik, A., Saeed, N., Shihada, B., et al., 2020. A software-defined opto-acoustic network architecture for internet of underwater things. IEEE Communications Magazine. 58(4), 88-94.
DOI: http://dx.doi.org/10.1109/MCOM.001.1900593

[66] de Oliveira Filho, J.I., Trichili, A., Ooi, B.S., et al., 2020. Toward self-powered internet of underwater things devices. IEEE Communications Magazine. 58(1), 68-73.
DOI: http://dx.doi.org/10.1109/MCOM.001.1900413

[67] Cong, Y., Yang, G., Wei, Z., et al. (editors), 2010. Security in underwater sensor network. 2010 International Conference on Communications and Mobile Computing; 2010 Apr 12-14; Shenzhen. New York: IEEE. p. 162-168.
DOI: http://dx.doi.org/10.1109/CMC.2010.18

[68] Souza, E., Wong, H.C., Cunha, Í., et al. (editors), 2013. End-to-end authentication in under-water sensor networks. 2013 IEEE Symposium on Computers and Communications (ISCC); 2013 Jul 7-10; Split. New York: IEEE. p. 000299-000304.
DOI: https://doi.org/10.1109/ISCC.2013.6754963

[69] Jiang, S., 2018. Wireless networking principles: From terrestrial to underwater acoustic. Springer: Berlin.
DOI: https://doi.org/10.1007/978-981-10-7775-3

[70] Goyal, N., Dave, M., Verma, A.K., 2017. Trust model for cluster head validation in underwater wireless sensor networks. Underwater Technology. 34(3), 106-113.
DOI: https://doi.org/10.3723/ut.34.107

[71] Han, G., Liu, L., Jiang, J., et al., 2016. A collaborative secure localization algorithm based on trust model in underwater wireless sensor networks. Sensors. 16(2), 229.
DOI: https://doi.org/10.3390/s16020229

[72] Lee, J., Shah, B., Pau, G., et al., 2018. Real-time communication in wireless sensor networks. Wireless Communications and Mobile Computing. 9612631.
DOI: https://doi.org/10.1155/2018/9612631

[73] Peng, C., Du, X., 2017. SDBR: A secure depth-

based anonymous routing protocol in underwater acoustic networks. International Journal of Performability Engineering. 13(5), 731-741.
DOI: https://doi.org/10.23940/ijpe.17.05.p16.731741

[74] Saeed, N., Nam, H., Al-Naffouri, T.Y., et al., 2019. A state-of-the-art survey on multidimensional scaling-based localization techniques. IEEE Communications Surveys & Tutorials. 21(4), 3565-3583.
DOI: https://doi.org/10.1109/COMST.2019.2921972

[75] Bian, T., Venkatesan, R., Li, C. (editors), 2010. An improved localization method using error probability distribution for underwater sensor networks. 2010 IEEE International Conference on Communications; 2010 May 23-27; Cape Town. New York: IEEE. p. 1-6.
DOI: https://doi.org/10.1109/ICC.2010.5501953

[76] Yang, G., Dai, L., Wei, Z., 2018. Challenges, threats, security issues and new trends of underwater wireless sensor networks. Sensors. 18(11), 3907.
DOI: https://doi.org/10.3390/s18113907

[77] Cui, J., Feng, D., Li, Y., et al., 2020. Research on simultaneous localization and mapping for AUV by an improved method: Variance reduction FastSLAM with simulated annealing. Defence Technology. 16(3), 651-661.
DOI: https://doi.org/10.1016/j.dt.2019.10.004

[78] Cheng, W., Teymorian, A.Y., Ma, L., et al. (editors), 2008. Underwater localization in sparse 3D acoustic sensor networks. IEEE INFOCOM 2008—The 27th Conference on Computer Communications; 2008 Apr 13-18; Phoenix. New York: IEEE. p. 236-240.
DOI: https://doi.org/10.1109/INFOCOM.2008.56

[79] Isbitiren, G., Akan, O.B., 2011. Three-dimensional underwater target tracking with acoustic sensor networks. IEEE Transactions on Vehicular Technology. 60(8), 3897-3906.
DOI: https://doi.org/10.1109/TVT.2011.2163538

[80] Blidberg, D.R., Jalbert, J., Ageev, M.D., 1997. Some Design Considerations for a Solar Powered Auv; Energy Management and Its Impact On Operational Characteristics [Internet]. Available from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=d3bb7c97b0b1c587a300808e82ef1a759e52640c

[81] Ameer, P.M., Jacob, L., 2013. Underwater localization using stochastic proximity embedding and multi-dimensional scaling. Wireless Networks. 19, 1679-1690. Available from: https://link.springer.com/article/10.1007/s11276-013-0563-3

[82] Mirza, D., Schurgers, C. (editors), 2007. Collaborative localization for fleets of underwater drifters. OCEANS 2007; 2007 Sep 29-Oct 4; Vancouver. New York: IEEE. p. 1-6.
DOI: https://doi.org/10.1109/OCEANS.2007.4449391

[83] Chandrasekhar, V., Seah, W. (editors), 2006. An area localization scheme for underwater sensor networks. OCEANS 2006-Asia Pacific; 2006 May 16-19; Singapore. New York: IEEE. p. 1-8.
DOI: https://doi.org/10.1109/OCEANSAP.2006.4393969

[84] Zhou, Y., Gu, B.J., Chen, K., et al., 2009. An range-free localization scheme for large scale underwater wireless sensor networks. Journal of Shanghai Jiaotong University (Science). 14, 562-568. Available from: https://link.springer.com/article/10.1007/s12204-009-0562-9

[85] Erol-Kantarci, M., Oktug, S., Vieira, L., et al., 2011. Performance evaluation of distributed localization techniques for mobile underwater acoustic sensor networks. Ad Hoc Networks. 9(1), 61-72.
DOI: https://doi.org/10.1016/j.adhoc.2010.05.002

[86] Othman, A.K. (editor), 2008. GPS-less localization protocol for underwater acoustic networks. 2008 5th IFIP International Conference on Wireless and Optical Communications Networks (WOCN'08); 2008 May 5-7; Surabaya. New York: IEEE. p. 1-6.
DOI: https://doi.org/10.1109/WOCN.2008.4542532

[87] Bian, T., Venkatesan, R., Li, C. (editors), 2009. Design and evaluation of a new localization scheme for underwater acoustic sensor networks. GLOBECOM 2009-2009 IEEE Global Telecommunications Conference; 2009 Nov 30-Dec 4; Honolulu. New York: IEEE. p. 1-5.

DOI: https://doi.org/10.1109/GLOCOM.2009.5425366
[88] Liu, B., Chen, H., Zhong, Z., et al., 2010. Asymmetrical round trip based synchronization-free localization in large-scale underwater sensor networks. IEEE Transactions on Wireless Communications. 9(11), 3532-3542.
DOI: https://doi.org/10.1109/TWC.2010.090210.100146
[89] Callmer, J., Skoglund, M., Gustafsson, F., 2010. Silent localization of underwater sensors using magnetometers. Eurasip Journal on Advances in Signal Processing. 10, 1-8.
DOI: http://dx.doi.org/10.1155/2010/709318
[90] Erol, M., Vieira, L.F.M., Gerla, M. (editors), 2007. AUV-aided localization for underwater sensor networks. International Conference on Wireless Algorithms, Systems and Applications (WASA 2007); 2007 Aug 1-3; Chicago. New York: IEEE. p. 44-54.
DOI: https://doi.org/10.1109/WASA.2007.34
[91] Lee, S., Kim, K., 2012. Localization with a mobile beacon in underwater sensor networks. Sensors. 12(5), 5486-5501.
DOI: https://doi.org/10.3390/s120505486
[92] Isik, M.T., Akan, O.B., 2009. A three dimensional localization algorithm for underwater acoustic sensor networks. IEEE Transactions on Wireless Communications. 8(9), 4457-4463.
DOI: https://doi.org/10.1109/TWC.2009.081628
[93] Luo, H., Guo, Z., Dong, W., et al., 2010. LDB: Localization with directional beacons for sparse 3D underwater acoustic sensor networks. Journal of Networks. 5(1), 28-38.
DOI: https://doi.org/10.4304/jnw.5.1.28-38
[94] Ameer, P.M., Jacob, L., 2010. Localization using ray tracing for underwater acoustic sensor networks. IEEE Communications Letters. 14(10), 930-932.
DOI: https://doi.org/10.1109/LCOMM.2010.090810.101237
[95] Porter, M.B., Bucker, H.P., 1987. Gaussian beam tracing for computing ocean acoustic fields. The Journal of the Acoustical Society of America. 82(4), 1349-1359.
DOI: https://doi.org/10.1121/1.395269
[96] Toky, A., Singh, R.P., Das, S., 2020. Localization schemes for underwater acoustic sensor networks-a review. Computer Science Review. 37, 100241.
DOI: https://doi.org/10.1016/j.cosrev.2020.100241
[97] Poursheikhali, S., Zamiri-Jafarian, H. (editors), 2015. TDOA based target localization in inhomogenous underwater wireless sensor network. 2015 5th International Conference on Computer and Knowledge Engineering (ICCKE); 2015 Oct 20-29; Mashhad. New York: IEEE. p. 1-6.
DOI: https://doi.org/10.1109/ICCKE.2015.7365873
[98] Yang, K.W., Guo, Y.B., Wei, D.W., et al., 2010. MFALM: An active localization method for dynamic underwater wireless sensor networks. Computer Science. 37(1), 114-117. Available from: https://www.jsjkx.com/EN/Y2010/V37/I1/114
[99] Luo, J., Fan, L., Wu, S., et al., 2017. Research on localization algorithms based on acoustic communication for underwater sensor networks. Sensors. 18(1), 67.
DOI: https://doi.org/10.3390/s18010067
[100] Cheng, X., Thaeler, A., Xue, G., et al. (editors), 2004. TPS: A time-based positioning scheme for outdoor wireless sensor networks. IEEE INFOCOM 2004; 2004 Mar 7-11; Hong Kong. New York: IEEE. p. 2685-2696.
DOI: https://doi.org/10.1109/INFCOM.2004.1354687
[101] Fu, B., Zhang, F., Ito, M., et al., 2008. Development of a new underwater positioning system based on sensor network. Artificial Life and Robotics. 13(1), 45-49.
DOI: https://doi.org/10.1007/s10015-008-0583-8
[102] Zhou, Z., Cui, J.H., Zhou, S., 2010. Efficient localization for large-scale underwater sensor networks. Ad Hoc Networks. 8(3), 267-279.
DOI: https://doi.org/10.1016/j.adhoc.2009.08.005
[103] Gao, I.X., Zhang, F., Ito, M. (editors), 2012. Underwater acoustic positioning system based

on propagation loss and sensor network. 2012 Oceans-Yeosu; 2012 May 21-24; Yeosu. New York: IEEE. p. 1-4.
DOI: https://doi.org/10.1109/OCEANS-Yeosu.2012.6263441

[104] Emokpae, L., Younis, M. (editors), 2011. Surface based anchor-free localization algorithm for underwater sensor networks. 2011 IEEE International Conference on Communications (ICC); 2011 Jul 28; Kyoto. New York: IEEE. p. 1-5.
DOI: https://doi.org/10.1109/icc.2011.5963364

[105] Zhou, Z., Peng, Z., Cui, J.H., et al., 2010. Scalable localization with mobility prediction for underwater sensor networks. IEEE Transactions on Mobile Computing. 10(3), 335-348.
DOI: https://doi.org/10.1109/TMC.2010.158

[106] Guo, Y., Kang, X., Han, Q., et al., 2019. A localization algorithm for underwater wireless sensor networks based on ranging correction and inertial coordination. KSII Transactions on Internet and Information Systems (TIIS). 13(10), 4971-4987.
DOI: https://doi.org/10.3837/tiis.2019.10.009

[107] Cheng, X., Shu, H., Liang, Q., et al., 2008. Silent positioning in underwater acoustic sensor networks. IEEE Transactions on Vehicular Technology. 57(3), 1756-1766.
DOI: https://doi.org/10.1109/TVT.2007.912142

[108] Zhou, M., Zhong, Z., Fang, X., 2013. Sensor-target geometry for hybrid bearing/range underwater localization. IFAC Proceedings Volumes. 46(20), 724-729.
DOI: https://doi.org/10.3182/20130902-3-CN-3020.00111

[109] Luo, J., Fan, L., 2017. A two-phase time synchronization-free localization algorithm for underwater sensor networks. Sensors. 17(4), 726.
DOI: https://doi.org/10.3390/s17040726

[110] Vaghefi, R.M., Buehrer, R.M. (editors), 2013. Asynchronous time-of-arrival-based source localization. 2013 IEEE International Conference on Acoustics, Speech and Signal Processing; 2013 Oct 21; Vancouver. New York: IEEE. p. 4086-4090.
DOI: https://doi.org/10.1109/ICASSP.2013.6638427

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