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ARTICLE

Embedding 3-D Gaze Points on a 3-D Visual Field: A Case of Transparency

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ABSTRACT

The paper seeks to demonstrates the likelihood of embedding a 3D gaze point on a 3D visual field, the visual field is inform of a game console where the user has to play from one level to the other by overcoming obstacles that will lead them to the next level. Complex game interface is sometimes difficult for the player to progress to next level of the game and the developers also find it difficult to regulate the game for an average player. The model serves as an analytical tool for game adaptations and also players can track their response to the game. Custom eye tracking and 3D object tracking algorithms were developed to enhance the analysis of the procedure. This is a part of the contributions to user interface design in the aspect of visual transparency. The development and testing of human computer interaction uses and application is more easily investigated than ever, part of the contribution to this is the embedding of 3-D gaze point on a 3-D visual field. This could be used in a number of applications, for instance in medical applications that includes long and short sightedness diagnosis and treatment. Experiments and Test were conducted on five different episodes of user attributes, result show that fixation points and pupil changes are the two most likely user attributes that contributes most significantly in the performance of the custom eye tracking algorithm the study. As the advancement in development of eye movement algorithm continues user attributes that showed the least likely appearance will prove to be redundant.

1. Introduction

Gaze points are attributes in an eye movement behaviour studies. It involves a voluntary or involuntary coordinates of points made by the movement of the eyes, which helps to acquire fixation and tracking of visual stimuli. The eyes are mostly the visual organ or part of the body that moves using a system of six muscles [1-4]. The retina part of the eye senses light and convert light

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into electro-chemical signals which travel along the optic nerve to the brain tissue and interpreted as vision in a practical visual cortex. Humans are one of the primates that uses natural phenomenon of voluntary eye movement to track objects of interest; this phenomenon includes the smooth pursuit (sideways movement), saccades and vergence shifts (Figure 1). These voluntary eye movement generated as gaze points appear to be initiated by captured by infrared light of an eye tracker which records the eye movementa tiny cortical region in the brain anterior lobe, this action and behaviour of the eye can be behaviour. The reflexes of the eyes can shift toward a moving light and is intact even though the voluntary control is annihilated. The eye movement not only reacts to light intensity and movement, but can also portray an emotional response to stimuli.

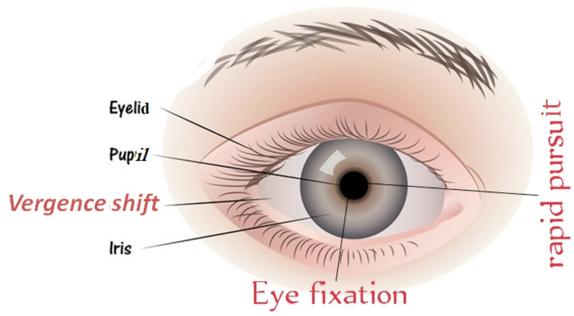


Figure 1. Picture showing the different attributes of the eye and direction of eye movements: Courtesy, Google images

In physiological response, gaze points of eye movement can be classified according to different systems:

1) The involvement of one eye as duction, both eyes as version, movement in similar and in opposite direction as vergence.

2) Also can be classified as fixational, gaze stabilising, shifting, whose movement is referred to as vestibulo-ocular reflex and optokinetic reflex, the mechanism is referred to as saccades and pursuit movements [6,7].

This paper is only limited to discussing representation of the gaze point of eye movement on a 3D context as a form of heat map and visualised in a 3D environment based on the vergence or convergence movement that involves both eyes, to make sure the image (3D object) being looked at falls on the corresponding spot on both retina of the eyes. This helps in the depth perception of the 3D object [5-8]. The area of the saccade, pursuit movement or smooth pursuit will be dealt with in later research. Saccades in relation to this paper is the space between two or more 3D gaze points, which could be overlapping in some cases and an enlarged gaze point depending on the amount of time a person spent looking at a particular area of the 3D visual field.

In actual sense, the eyes are never completely at rest: they make frequent fixations of eye movement even though they are in a particular point. We can relate these movements to the photoreceptors and the ganglion cells of the brain. A constant visual stimulus could lead to an unresponsive ganglion cell while a changing or dynamic stimulus makes the photoreceptors become responsive as illustrated by the dynamic 3D game interface used in this paper. Most of the eye control motor is generated based on saccades (rapid eye movement) which is used while scanning a visual scene. According to [9-12], the eyes do not move smoothly across a *XY* Cartesian plane or a printed page during for example a reading session, instead they make short and rapid movements which are the saccades. And during each saccade the eyes move very fast and an involuntary movement (not consciously controlled). Each of the movement is represented by a few minutes of arc about four to five seconds at regular intervals. This is represented by the space between gaze points in a visual field mostly indicated by straight lines across fixations points. One of its uses is to scan a greater part of the area of interest with a high-resolution fovea of the eyes.

The rational for using a 3D visualisation field in this paper is based on the fact that not always did the picture content in the catalogue correspond to the expectations of the intended clients and with the eventually expected results. Some users or customers turn out to be unhappy with what they saw through advertisement after all the design work is been finished or after purchase of an item online. With the advent of panoramic pictures in recent times, as well as the progression of different bulky programs and formats of image transmission, a lot of companies have moved towards the virtual catalogues. In this environment, they can get potential users or customers to be acquainted with the 3D game visualisation of the inner part of the environment in an immense format. A 3D visualisation of the game interior can give a finite definition to user behaviour with a 3D gaze point on a visual game interface and also an excellent opportunity to interact with the objects in every detail such as the entire panorama and also from a different angle [13-16]. The designers can also afford to see the weaknesses and strength of each level based on session overview.

Integrating a 3D eye movement algorithm in a 3D environment will allow consideration of not only the architectural shape of the visual objects, but also how the project will look like in its final stage of completion during decision making. A 3D gaze point on the 3D interphase visualisation of the game will have a common vision of the future construction at the initial stage. The photo realistic rendering applied is an expensive and improved version of the current project [17-19].

Objectives

The objectives behind this paper are to:

1) Model a virtual scene that involves eye movement in a 3D environment

2) Create a 3D eye movement scene on objects in a 3D game interface

3) Develop a custom algorithm to identify basic user eye movement behaviour in a virtual environment.

This will open new opportunities in any field of human computer interface design, manufacturing, computer graphics and many others.

2. Literature Review

The 3D visual interface is the "Wonder World" a simple came designed using "Struckd", one of the first game console used in this area of research. The game is about a princess sent underworld to defeat some unnamed creatures and gain access to a porthole that leads to a dungeon to get a diamond crown to present to royals and bearers of the royal crown. She has to cross four levels to get to the crown. Each level leaves a more challenging and advanced battle than the other. Each level of the game interface enables the user (player) to cross to a higher level after overcoming the obstacles in the previous level. The embedded gaze point will allow for monitoring of the different stages of user behaviour through their eye movement. The user activity is recorded and used for predictions of user gaze points on the 3D visual field [20-22]. The aim and purpose is to create data-driven designs and eliminate guesswork of user engagement and interaction using the location of the gaze point [20-22]. This will allow user experience designers, web managers, developers to visualise usage patterns, optimize and also gather objective data that involves 3D-data visualisation [23-25]. Also the algorithm designed for the eye movement recognition will involve powerful features such as pupillary measurement and heat maps on both two dimensional and 3D visual field, this will automatically sort out areas of interest (AOI). The algorithm involves three (3) modules, this is inform of an engine that automatically detects the pupillary position of the eyes (Algorithm 1) using the camera lens of a PC, this is then used to identify the 3-D objects (Algorithm 2) in a virtual field. The gaze points Algorithm (Algorithm 3) is used to trace and locate 3-D objects at the AOI using the PC's camera lens to calibrate the eye's position.

The 3D object detection (Algorithm 2) detects images or scene in a virtual field given a reference image of the object. The algorithm presents a straight forward step used in detecting specific objects based on finding the point corresponding to reference and target image. This can also detect objects despite changes in the scale in plane rotation of movement [23-25]. It is basically robust to small amount of virtual plain rotation. The steps are suitable for most objects in the scene that exhibit non repeating texture patterns, which give rise to unique feature matches. This feature is suited for any object in the scene that moves both in a vertical or horizontal plane in the video game console [23-25].

As object detection is very important in many computer vision and HCI studies so is the discovery of ways to improve activity recognition, automotive safety and application of 3D visionary as applied in this is paper. Before tracing a particular 3D object, one needs to first detect it, hence the cascaded iris detection algorithm. This detects the location of the object in a video frame. It is configured to detect not only 3D objects but also two dimensional objects as it moves or changes direction. The behaviour of the subject's pupil is also recorded such as, 'Intense', 'Ease', Confused', 'Slack', 'Stressed' and 'Relaxed' mood, this represent the characteristical behaviour of the eyes during concentration (Table 1), it would enable designers to identify areas that need basic optimisation.

For the embedding phase the Java platform was used to integrate the eye tracking algorithms as a standalone on the 3D game console designed with "Stuckd". Both engines were sychronised to run on the same platform using the PC camera lens for calibration. Because of the easy steps with algorithm calibration runs faster with a minimum speed of 0.5 MHz per seconds. User can interact with the game while their eye movement behaviour is captured alongside the video game console.

3. Method

The pilot study started with simulation of gaze data containing one thousand five hundred instances as a training set. This was used as input to the custom eye movement detection algorithm for the video game console. In later study, fifty participants were recruited to take part in the game interface. They were given a consent form to sign confirming their involvement in the game and safety precautions were taken concerning their emotional status, such as their familiarity with the game and web interactions (Figure 2). The data are then simulated to a thousand and used as the test set. The performance on the dataset is demonstrated to show the predictive ability of

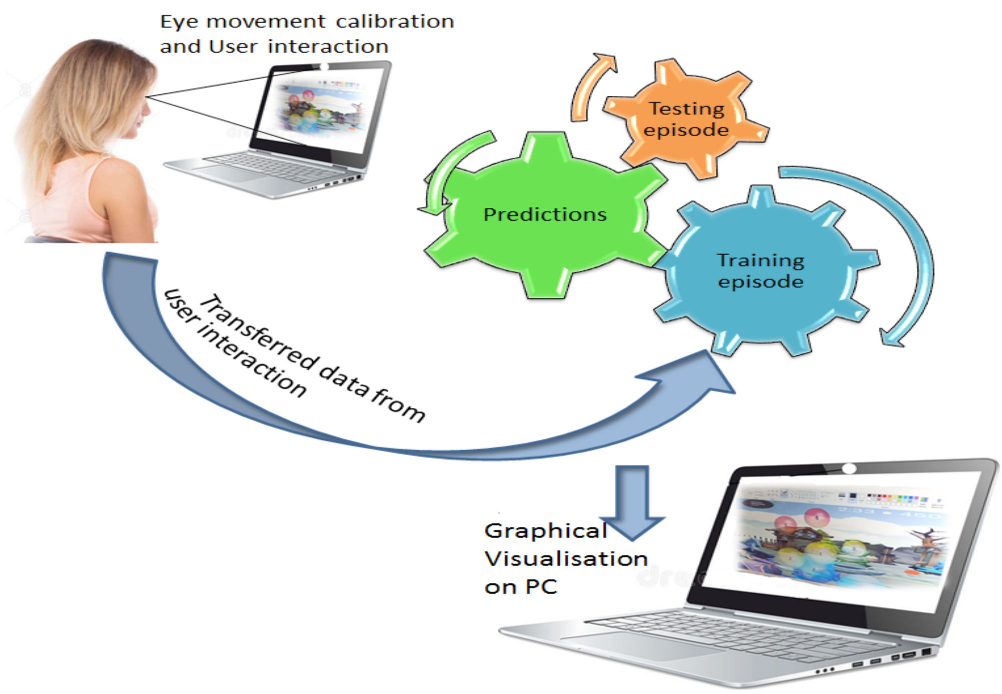


Figure 2. User interaction with game interface with data transferred and simulated for training, testing and predictions.

the custom eye movement detection algorithm (Algorithm 1, 2, 3). A graphical visualisation of the entire episode is visualised on a PC (Figure 2).

Algorithm 1. (Subject's iris detection)

1. *Ready subject's iris*
2. *Set pupil localisation*
3. *Trace iris position*
4. *If eye closed, wait else goto 2*
5. *If eye open and no iris detected to 2 else 3*
6. *End*

Algorithm 2. (3D object detection on a 3D video game console)

1. *Start*
2. *Initial the Algorithm 1 as a cascade detector object*
3. *Read in the video frame (V_F) and run the detector (Algorithm 1)*
4. *Read 3D objects from the scene*
5. *Detect feature points using Algorithm 1*
6. *Extract feature point descriptors by surrounding the object with 3D gaze cascade*
7. *Find the putative point matches*
8. *Locate the object in the scene using step 4*
9. *Detect another 3D object*
10. *Is video frame < total V_F goto 2 else goto 10*
11. *End*

Table 1. User Characteristical Behaviour of Eye movement detection on 3D game console: Overlapping colors tend to blend to give a unique hue.

User Behaviour	Parameter Value	Calibration point	Color
Intense	5	0.6	Light Red
Ease	2	0.4	White
Confused	3	0.8	Light Blue
Slack	1	0.7	Blue
Relaxed	4	0.2	Yellow
Stressed	6	0.3	Red

Algorithm 3. (Custom eye tracking on a 3D video game console)

1. *Begin*
2. *Set calibration for both eyes*
   i. *Locate iris position using Algorithm 1*
   ii. *Set point of location as middle of visual field*
   iii. *Set scan-path to four corners of visual field*
   iv. *Save gaze calibration data*
3. *Detect 3-D object at the virtual centre field*
4. *Locate eye positions*
5. *If eye position detection fails, goto 3 else goto 6*
6. *Save eye detection data $T_{c(k)}$*
7. *Detect other 3-D objects*
8. *Track eye position using iris detection algorithm*
9. *Verify eye positions using Iris detector (Algorithm 1)*
10. *If eye verification is complete, goto 11, else goto 8*

11. *Reset counter to update eye position*
12. *If counter* < $T_{c(l)}$ *goto 7 else goto 3*
13. *Set counter+1*
14. *If gaze off screen goto 4 to reset gaze position else goto 7*
15. *Search for 3-D objects complete? goto 16 else go 7*
16. *End.*

Task

The 3D Wonder World game consists of four levels and users were simply asked to play the game by first calibrating their eyes with the PC camera lens (Figure 1). The participants were asked to play the first two levels for twenty seconds and their activity was captured. The eye movements were recorded and sent to a subfolder for analysis.

4. Results

An initial detected object is first seen at the middle of the visual field based on the calibration of the point gaze from Algorithm 1. Figure 3 shows a predicted gaze point at the middle of the video game console as calibrated in the initial stage. There was no particular mechanism to define the appearance of this scene only that the red, blue, yellow and white color mixture indicates a vague reaction from the user. The proceeding section discusses some of the most significant results and performance of the algorithm on the dataset obtained from the experimental study.

Figure 3. Predicted Gaze point in the middle of the visual field of the 3D game console.

4.1 Level 1

This level (Figure 4) captured a scene of gaze point on the arrow held by the game character with the mood of the user indicating "ease" "relaxed" and "slack" which is represented by 1, 2, and 4. The gaze point also shows a stress mood overlapped by other expressions conveyed by the user while looking towards the porthole to the dungeon. Expression of emotion on visual field is very useful in so many ways, for instance our physical reaction to stress towards a visual scene can be reduced by minimising the level of obstacles encountered on a particular frame; or can be used to increase the level of intensity on a game console if the purpose is to hinder the player from crossing to the next level with ease. In most cases the aim is to encourage players to the first two levels by reducing the number of obstacles and increase the level of intensity in the proceeding levels. This induces or records the level of intelligence of the player and determines if the game console is suitable for an average or an advanced player.

Figure 4. Level one of the game interface showing gaze points representing different user behaviour towards the visual scene

4.2 Level 2

Level 2 (Figure 5) captures the scene where the player is looking towards the dungeon that holds the diamond crown with an "intense", "slack" and "ease" mood. The intense mood showed a bit of a stress hue (red color) and less stress hue at two locations. This would prompt a designer to optimise the process by picking one of the locations to apply either of the moods (picking slack mood with stress or slack mood without stress) to get to the target object. 3D object tracking across video frames can support object detection and frame segmentation. The detecting phenomena or activities are only recognised taking the entire stream of images into account; the video analysis used here presents unique challenging resource management and model architecture that could be improved based on the performance of the object tracking or gaze data generated from the test phase.

To test the performance of the dataset generated from the study conducted with 3D gaze points on the game interface. A dynamic control model was used to predict the gaze and user behaviour data on both the simulated and actual data generated from the eye tracking study. The error plots from the model are discussed in the proceeding section.

Figure 5. Game interface showing captured scene of stress gaze point on the target object and location of arrow with intense (5), slack (1) and ease (2).

4.3 Performance on Dataset Models

The dataset generated were in two sets, the simulated and actual data, a dynamic control system based on discrete time variant models was used on the data models for both test (actual data) and training (simulated data). The rational for using the dynamic control system is the fact that it uses internal dynamics or memory of past state functions like integrators and tunable parameters (certain or uncertain values) of attributes to produce recurrent values. This is best suited for user behaviour data which are very complex and difficult to predict e.g. a residual or R^2 value of 0.62 score is highly probable for human behaviour data, especially those that involve complex eye movement readings. The control system can help decided whether anomalies in the dataset can be excluded or not. Due to environmental constraints, some outliers are termed feasible and important in datasets such as those involve with user behaviour studies.

The user attributes used in the datasets include the fixation points, fixation duration, pupil changes and saccades. These are basically the most significant variables that can help predict user eye movement behaviour on a 3D visual interface like the game console.

Error in the performance of the data models were visualised and discussed. Figure 6 shows the output in error performance of the training set on different scenes. The dataset for both the training and test set were divided into four different scenarios (two user attributes, three user attributes, four user attributes and all user attributes). The simulated dataset (training set) and original dataset (testing set) were executed on five different episodes, with the error in performance recorded.

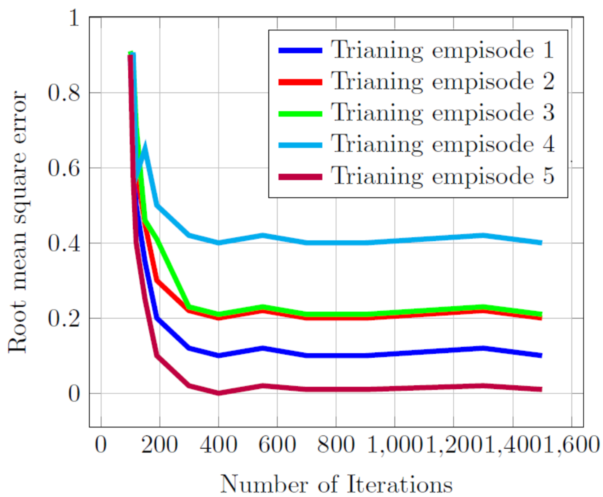
The data settings changes every time the model is executed. To give a constant or an alleviated edge to the dataset output, the ranging style was set to default value. The least error appeared in the training set on the fifth episode (Figure 6a) with error in performance below 0.01, which is a recorded performance of 99%. This is on the training set with two important user attributes; the gaze point coordinates and pupil changes. This also demonstrates the importance and inevitability of the pupil dilation and fixation points in user eye movement readings.

The least error for the test dataset on five different scenarios appeared at the fifth episode (Figure 6b) with a minimum error of 0.1 above the expected rate of 0.01. This has a performance of 90% and above maximum expectations. This outcome is reflected on the dataset and has the same user attributes as the training set. The minimum error also appeared on test data with all user attributes (Figure 6d), showing a least performance of 0.2. As the advancement in development of eye movement algorithm continues user attributes that show the least likely appearance will prove redundant, based on the result of this paper and similar but different research outputs in some papers [26,27], these attributes contributes the least to behaviour predictions.

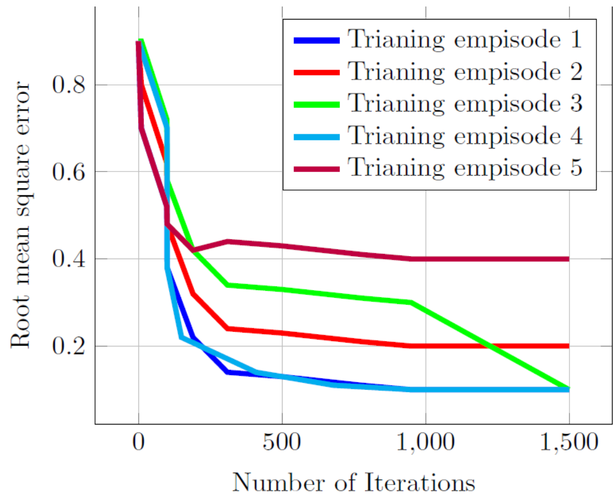
Figure 7 shows the error in test data on four different episode, these episode are situations where users' attributes are applied based on their level of importance such as saccade length and fixation coordinates in both the *XY* plane, fixation duration, pupil dilation, pupil constriction, off screen location and number of clicks per milliseconds. Figure 7d shows the error plot on test dataset with five attributes using five scenes. The least error (0.01) appeared on the fifth scene where all attributes are applied.

5. Conclusions

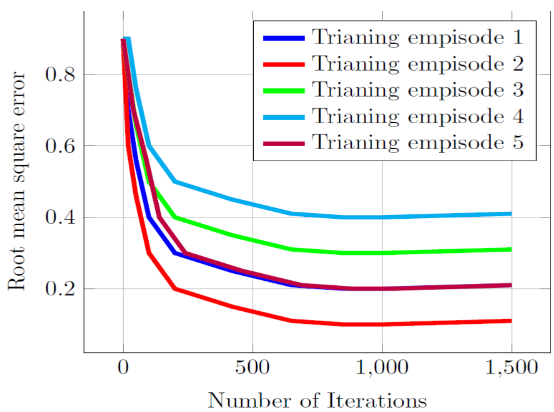
The paper demonstrates the possibility of embedding 3D gaze point on a 3D visual field, this visual field is inform of a game console where the user has to play from



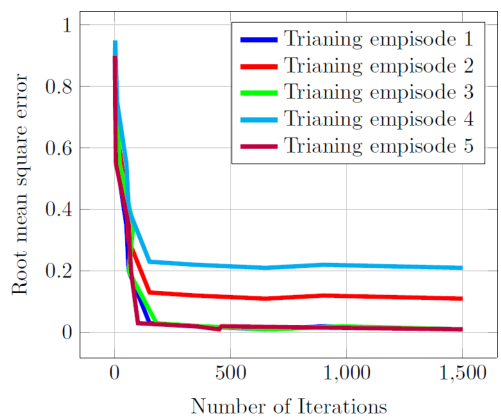
(a): Error plot for the training set on five episodes: the fifth episode shows the least error.



(b): Error plot on training set on five episodes for dataset with two user attributes: the first episode shows the least error.

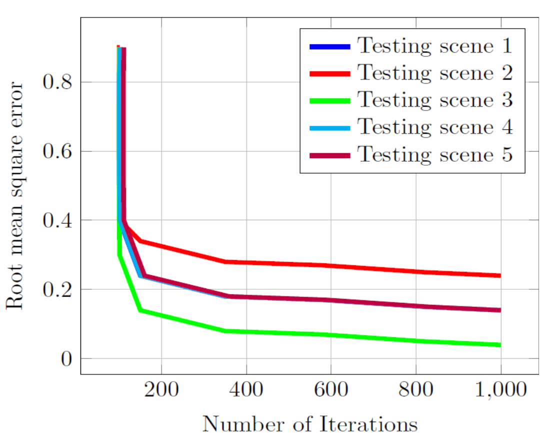


(c):Error plot for training set on five episodes for the dataset with three user attributes: the second episode showed the least error.

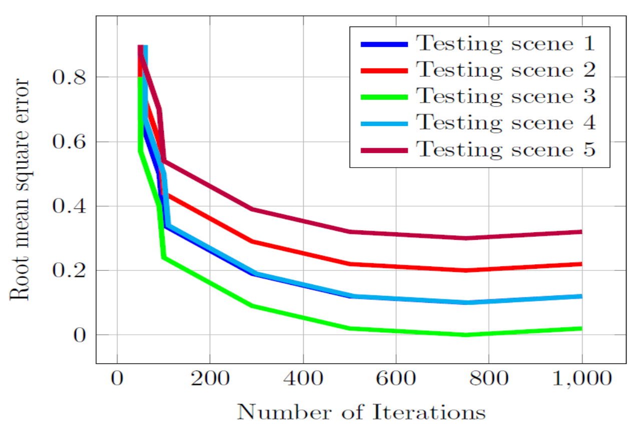


(d): Error plot show the fifth episode with the least error on test set data with four attributes

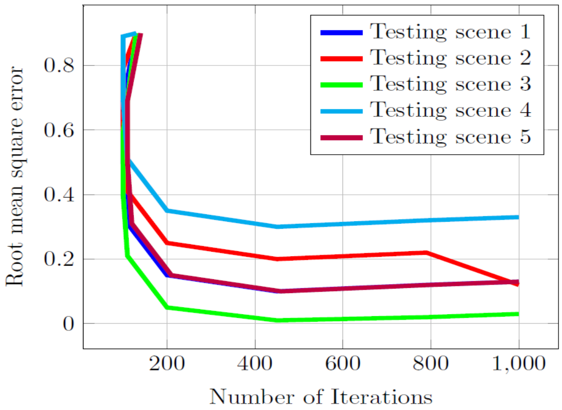
Figure 6. Error in Performance of the test dataset on five different episodes.



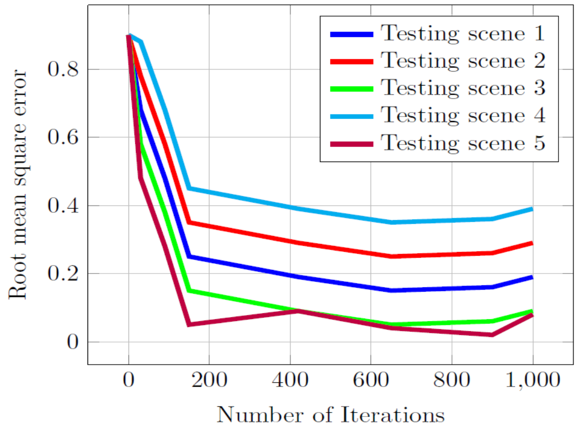
(a): Error plot on test dataset using five different scenario, the least error appeared in the fourth scene.



(b).: Error on dataset with two variables using five different scenario, the least error appeared on the third scene.



(c): Error plot on test dataset with three user attributes using four user attributes, the least error appeared on the third scene.



(d): Error plot on test dataset with five attributes using five scenes, the least error appeared on the fifth scene.

Figure 7. Error in Performance of dataset on four different episodes using five different scenes.

one level to the other by over overcoming obstacles that will take them to the next level. Custom eye tracking and 3D object tracking algorithms were developed to enhance the analysis of the procedures. This is part of the contributions to user interface design in the aspect of visual transparency.

The development and testing of human computer interaction uses and application is more easily investigated than ever, part of the contribution to this is the embedding of 3-D gaze point on a 3-D visual field. This could be used in a number of applications, for instance in medical applications that includes long and short sightedness, dyslevia and glaucoma diagnosis and treatment. The 3-D eye tracking gaze point model is user friendly and could be well suited for industrial use and across ergonomics laboratory for usability testing. Part of its limitations is the time synchronisation of events and custom eye and iris calibration at the initial stage of the algorithm. This problem can be tackled with constant testing and experimental setup that involves execution of standard classification algorithms. The system is just another example of eye tracking models that most organisations find more ways to incorporate for accuracy and user friendly capabilities with enhanced visual tendering and easy calibration. This will encourage more innovative and finite discoveries that offers research based eye tracking systems with both software and hardware capabilities.

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