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ARTICLE

Application of UAV in Road Safety in Intelligent Areas

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ABSTRACT

With the continuous development of remote sensing(RS) technology, the surface information can be collected conveniently and quickly by using the popular unmanned aerial vehicle(UAV). The application of UAV low altitude RS technology in road safety in intelligent area has certain practical significance. It can provide safety warning for most drivers, and provide auxiliary decision-making for the road supervision department. Through the collection, processing, calculation and analysis of the road image, the UAV can find out the road obstacles with potential safety hazards, identify the road pit, calculate the radius and depth of the road pit through the digital mapping system, predict the accident risk according to different speed and provide scientific basis for the road safety monitoring. At the same time, UAV can provide repair scheme for damaged roads, estimate the quantity of materials needed for repair, and achieve the target of resource saving and efficiency improvement. The experimental results show that the UAV can not only provide scientific prediction information for driving safety, but also provide relatively accurate material consumption for road repair.

1. Introduction

With the construction and development of traffic, the total mileage of highway is increasing year by year, the density of highway coverage is increasing grow with each passing day, and the mileage of various grades of highways is gradually expanding [10]. However, the obstacles on the road surface will bring inconvenience and hidden safety risks to the driving vehicles. The common obstacles on the road surface include large cracks, local bulges and potholes. In the process of driving, the driver can easily grasp the cracks and bulges of the road surface visually, so as to detour. But potholes are often hard to detect, according to industry insiders, when the car quickly through the road, the impact strength of the tire will increase. If the force is greater than the original bearing capacity of the tire, it may even cause bubbles or even rupture of the tire, resulting in traffic accidents. In addition, if the car passes through the pit at high speed, it will directly affect the suspension system of the car. In serious cases, the hub may break or even leak oil.

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If the road pit is too deep, it may even touch the chassis and cause more damage. Therefore, it is very important to check and maintain the road and sidewalk irregularly. In this paper, the UAV low altitude RS technology is used to collect and analyze the road image, and finally the judgment result is obtained, which provides the decision-making basis and auxiliary support for the road management department.

UAV was developed in the early 19th century. In the 1980s, drone technology began to be used in various fields, such as battlefield simulation, target surveillance, geodesy mapping, traffic management, resource detection, and environmental protection [3]. Since the beginning of the 21st century, UAV have matured. Its scope of application is constantly expanding, and has achieved good practical results and application value. Currently, drones have been used in more than 40 countries/regions around the world [4]. However, through literature search, it is found that drones are used less in road safety [8].

At present, various road safety inspections mainly rely on manual patrols to find and handle problematic roads through one-on-one inspections, photos and records, and people's reactions. However, the manual inspection has the following problems: Firstly, due to the large traffic road area, the manual inspection has a large workload and low efficiency. Manual inspection requires a lot of manpower, material and financial resources. Secondly, the diversification of road types and the impact of the surrounding environment of the road will inevitably lead to omissions in the inspection process. Thirdly, manual inspections are affected by subjective factors such as employees 'own qualities and professional skills, which can lead to poor accuracy or omissions. Road maintenance is also carried out by manual and special vehicles. The maintenance materials required for each road maintenance task can only be approximated. There is no relatively accurate reference value [9].

In view of the above situation, if the UAV technology with the advantages of intelligence, high efficiency, short cycle and large range is used instead of the traditional pure manual inspection method, the work efficiency will be greatly improved [12]. It can provide the basis for decision-making for road management in smart areas. Provide warning signals for driving vehicles, reduce unnecessary safety accidents, and provide scientific basis for maintenance work.

2. Research Methods

The main content of this research is to collect, process and identify road images. Through calculation and analysis of abnormal road objects, solutions are proposed respectively to provide scientific and quantitative decision-making basis for road safety guarantee or remediation.

During the research, the hardware mainly includes: the image data collection mainly uses the UAV low-altitude RS technology and the control point positioning uses the handheld GPS technology; the software mainly includes: Global Mapper, Pix4D mapper, ENVI and ArcGIS software. Then, the analysis results are provided to relevant departments in a visual form. The technical route is as follows:

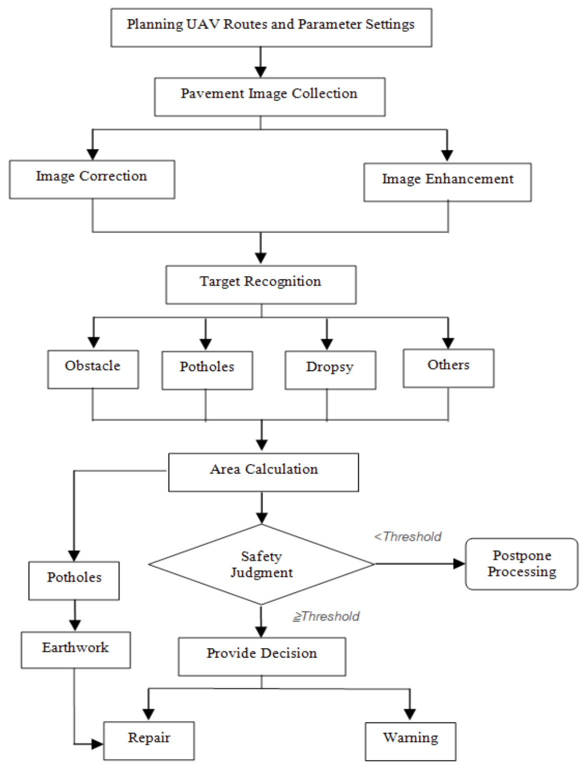

Figure 1. Technical roadmap

3. Research Area and Data Collection

This road safety monitoring data collection area is a Xin-Jian county in Nanchang city, China. Based on the previous Macro-survey of self-driving tours, data collection is divided into two categories. One is an ordinary highway with an average speed of 50 km/h on Xingguo Road and the other is a circular highway with an average speed of 80 km/h at the intersection of Hu-Rui line and Meiling Avenue on Fengsheng Highway.

This paper uses the ground control station software DJI GS PRO that comes with the UAV in Dajiang to plan and control the route. The main parameter settings are shown in Table 1, based on the identified subjects and the data collection range.

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Table 1. UAV parameter setting

Sampling Point Number	Area Location	Flight Mode	Altitude (m)	Resolution (px)	Overlap%		Return mode
					Course	Side-by	
Point 1	Xingguo Road	Isochronous	60	2.6	70	60	Auto return 10 meters above flight height
Points 2, 3, 4, 5 are on the same road	Intersection of Shanghai-Rui Line and Meiling Avenue	Isochronous	50	2.2	70	60	
		Isochronous	80	3.5	70	60	
		Isochronous	100	4.3	70	60	
		Hovered	100	4.3	70	60	

The two types of experimental areas were repeatedly photographed by UAV, and the best quality collected data was selected for processing. The orthophotos were processed by Pix 4D software.

4. Image Correction and Enhancement

4.1 Image Registration and Geometric Correction

Due to the error of the UAV image acquisition system itself, multiple orthophotos need to be geo-registered through software to accurately match the geographic location [1]. In this registration, 4 control points are selected on average in the aerial photography area, and the X, Y coordinates and residuals of the control points are set below 0.05 m.

Figure 2. The 1st point area (XingGuo Road)

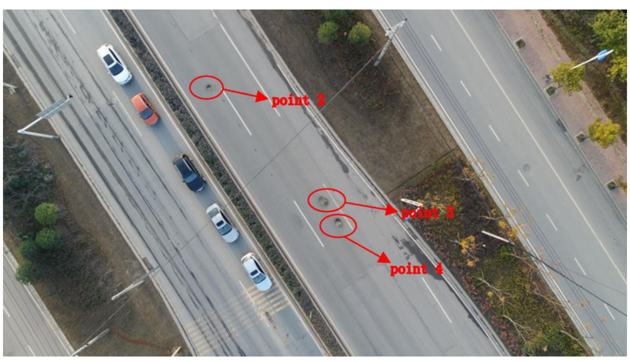

Figure 3. The 2nd&3rd&4th point area (Hu-Rui Line)

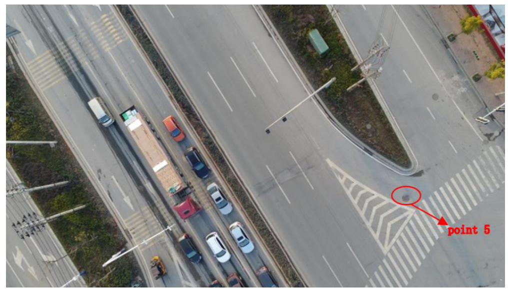

Figure 4. The5th point area (The intersection of Meiling Road and Hu-Rui Line)

4.2 Target Recognition

In order to effectively identify the image content after registration, accurately locate the research object, and identify different targets from the road, in the data collection area, the main road surface abnormalities are divided into obstacles (mainly belonging to things that fall from the moving vehicles), water accumulation (rainwater stored in low-lying areas on the road), and potholes (as a result of long-term rolling, especially the rolling of overloaded vehicles, the depressions on the road surface are pressed deeper and deeper, forming potholes). According to the actual situation in the survey area, obstacles (almost undetected) and accumulated water (the sampling day is sunny) are not considered, so the main research object is road surface depression (referred to as "road pit"). The main task of road pit identification is to determine its boundary. The data after data preprocessing uses RS image processing software (ENVI) to perform target recognition on the image data. The main process is:

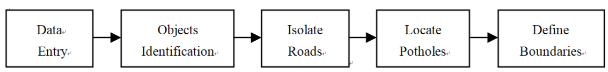

Figure 5. Target recognition process

In the isochronous aerial mode, the boundary between point 1 with an aerial photo height of 60m and point 2-5 with an aerial photo height of 50m is determined as follows:

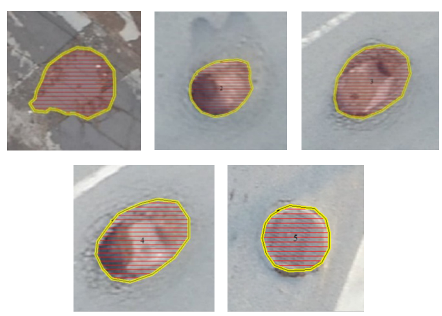

Figure 6. The 1st to 5th point boundary graph

5. Experimental Results

As mentioned earlier, four different types of flight modes were adopted for points 2-5, namely, isochronous flight height of 50 meters, isochronous flight height of 80 meters, isochronous flight height of 100 meters, and hover height of 100 meters. As a result, it was found that the ground resolution of the isochronous aerial altitude of 50 meters was the highest, which was conducive to data calculation and analysis. Therefore, in the later calculations, points 2-5 used this aerial photography data.

After determining the boundary of the road pit by using ENVI for extracting the abnormal target of the road surface, calculate the perimeter and area of the road pit. The depth of the road pit is temporarily replaced by the average value, and then carefully considered when calculating the amount of earthwork in the later period. The calculation data is as follows:

Table 2. The Calculation results of 1st to 5th points data (Unit: m/m^2)

ID	Circumference	Area	Average elevation of road pit Center	Average elevation of surrounding ground	Road pit depth
1	8.05	4.33	39.33	39.47	0.14
2	2.12	0.33	22.66	22.78	0.12
3	3.51	0.91	22.02	22.12	0.10
4	3.30	0.77	22.00	22.09	0.09
5	3.43	0.87	19.89	19.96	0.07

6. Application of Results

According to the research technical route, it mainly analyzes from two aspects of safety warning and road repair. The calculation results should provide people with quantitative and scientific basis, and display it in an intuitive way, which is convenient for later treatment and prevention.

6.1 Safety Alert

For the pavement with pit, the road safety is analyzed from two aspects of speed and pit size, and the vehicle size and performance are not considered temporarily.

First factor: Speed

In the process of road driving, the higher the speed, the greater the risk of traffic accidents. According to the research of relevant departments in Australia, when the vehicle speed exceeds 60km/h, the risk of traffic accident for every 5km/h increase in vehicle speed is basically twice that of the original. Therefore, when the vehicle is running at a higher speed, small speed changes will have a very obvious impact on driving safety.

The relationship between vehicle speed and the risk of traffic accidents is based on the risk at a speed of 60km/h (set as 1). The risk after each increase of 5km/h is as follows:

Table 3. Relationship between risk index and vehicle speed

vehicle speed (km/h)	60	65	70	75	80	85
Risk Index	1.00	2.00	4.16	10.60	31.81	56.55

Second factor: Road pit size

First of all, the radius of the pit should be accurately calculated, and then the risk analysis should be carried out. Through the target recognition of the image, it is found that the shape of the pavement potholes is approximately circular. In the analysis process, the radius is approximately taken as the model parameter.

Accurate calculation of road pit radius, the author believes that there are two methods, ring average algorithm and ray average method.

(1) Ring average algorithm. For irregular road pit polygons, the change range of its radius is usually not too large, but floating within a certain range. At this time, the average value of the maximum and minimum radius can be used to calculate the size of the road pit radius, as shown in the figure.

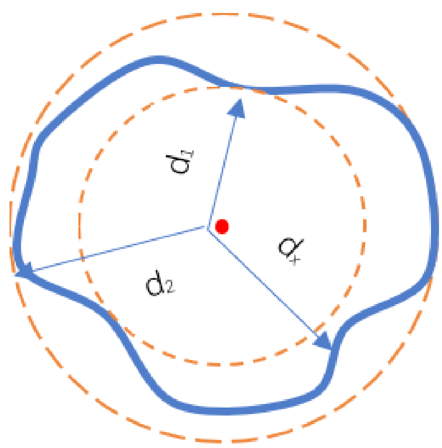

Figure 7. The radius of the ring mean value algorithm

The solid line outline represents the actual road pit polygon, and the two dashed lines inside and outside refer to the ring formed by the minimum inscribed circle radius and the maximum circumscribed circle radius. Then the average radius is: $d_x = (d_1 + d_2) / 2$

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Table 4. The calculation radius and error of the ring mean value algorithm (unit: m/m^2)

ID	Circumference	Area	Backcalculation radius	Inner tangent circle radius	Circumscribed circle radius	Mean radius	error
1	8.05	4.33	1.23	0.75	1.51	1.13	0.10
2	2.12	0.33	0.33	0.24	0.40	0.32	0.01
3	3.51	0.91	0.55	0.43	0.63	0.53	0.02
4	3.30	0.77	0.51	0.37	0.57	0.47	0.04
5	3.12	0.79	0.50	0.49	0.50	0.50	0.00

The above theoretical calculation radius is the average value of the radius inversely calculated by the perimeter and area, and the average radius is the average value of the radius of the inscribed circle and the radius of the circumscribed circle. According to the calculation results and field investigation, the radius difference between the back calculation radius algorithm of point 1 and the ring average algorithm is 10cm, which is relatively large. The reason is that this is a large road pit formed by long-term rolling of vehicles. The larger the pit is, the greater the impact on the surrounding subgrade is. Finally, the irregular area is formed. The closer the polygon is to the circle, the smaller the error of this method is. Otherwise, the greater the error is Like the area of point 1; point 2, 3 and 4 are approximate to the circle, so the ring average algorithm is approximate to the radius of back calculation; the error of two calculation results of point 5 is 0, because here is a well cover, and the surrounding area of the well cover is higher than here due to road renovation, forming a low-lying well cover.

(2) Feature ray average algorithm. The characteristic ray is made from the center of the road pit to the edge of the surrounding pit. The so-called characteristic ray is to find the characteristic point (the point with great curvature change) on the polygonal boundary line, and the line from the center to the characteristic point is the characteristic ray. The sum of all characteristic ray lengths is divided by the number of rays, and the value is the approximate size of the variable pit radius, as shown in the figure:

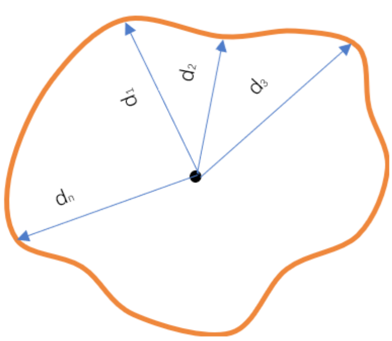

Figure 8. The radius of the characteristic ray averaging algorithm

Road pit radius: $d_x=(d_1+d_2+d_3+\ldots\ldots+d_n)/n=\sum_{i=1}^{n} di/n.$.

Table 5. The calculation radius and error of characteristic ray averaging algorithm(unit: m)

ID	Backcalculation radius	radius of characteristic ray 1	radius of characteristic ray 2	radius of characteristic ray 3	radius of characteristic ray 4	radius of characteristic ray 5	Mean radius	error
1	1.23	1.45	1.37	1.19	1.24	1.21	1.29	0.06
2	0.33	0.28	0.41	0.27	0.33	0.29	0.32	0.01
3	0.55	0.68	0.51	0.54	0.48	0.45	0.53	0.02
4	0.51	0.43	0.44	0.58	0.39	0.46	0.46	0.05
5	0.50	0.49	0.50	0.51	0.53	0.48	0.50	0.00

The principle of feature ray selection is to find out the feature points with great changes along the road pit boundary. Connecting this point to the road pit center is the feature curve. The above five feature rays are taken for calculation. The calculation results are not difficult to find, the error of point 1 is still large, the error of points 2, 3 and 4 is small, and the error of point 5 is still 0, because the well cover area here is approximately round, and the feature points have little change.

As mentioned above, the danger coefficient of driving has an exponential relationship with the speed of the vehicle, and the danger coefficient of driving has a regional linear relationship with the radius of the road pit. Therefore, in the case of bad road conditions, especially multi-pit roads, the driving hazard coefficient, vehicle speed and road pit size are in line with the binary nonlinear regression analysis model, and it is increasing.

The functional relationship between the risk factor and vehicle speed and road pit radius is expressed as:

$W=W_1(v)+W_2(d)$

Here's a hypothesis based on the facts:

(1) When $0<d<2/3$ r:W_2 is approximately equal to 0, when the pit radius is less than two-thirds of the wheel radius, it is considered safe and can be decelerated through;

(2) When $2/3r<d<r$:W_2 increases rapidly with d, it should be especially cautious and avoid passing.

(3) When $d > 2r$: W_2 decreases with d increasing, that is, the size of the road pit is much larger than the size of the wheel, if there is no water in the road pit, it can slow down the passage.

For an example of a general domestic car, the tire radius = tire width×aspect ratio+inner radius×25.4 (mm).The letter 195/65R15 is marked on the tire of the Ford car that the author drives, so the tire radius = 195×0.65+15×25.4/2=317.3mm. Comparing with the five collecting points, give some reference traffic opinions.

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Table 6. Reference of vehicle passing through the pit (The tyre radius is 0.32m)

ID	Radius of road pit calculated by characteristic ray method	Wheel comparison	Opinions about passage
1	1.29	>2r	If there is no water in the pit, you can slow down the passage
2	0.32	2/3r<d<r	Slow down for passage
3	0.53	0<d<r2/3	Please avoid
4	0.46	0<d<r2/3	Please avoid
5	0.50	0<d<r2/3	Please avoid

Based on this analysis result, data updates can be made with traffic broadcasting, electronic maps or navigation software to promptly alert car owners to avoid accidents.

6.2 Road Repair

The key to effectively solve the pavement repair is to know the degree of road damage in advance, and then calculate the required materials. This paper excludes other road damage, in terms of pit repair, the solution is based on the collected data. Since the general shape of the road pit is similar to that of a cone, the calculation of the amount of soil in the road pit is expressed as:

$V=S\times h/3$

V is the amount of soil in the road pit, S is the area of the pit, h is the depth of the pit.

Of course, the general road pit is not a regular cone, that is, the road pit is not a fixed value. Here we can only estimate roughly. If you need to calculate the amount of earth carefully, you can use the calculating method to calculate the volume capacity of the pit. Based on road construction experience, materials are often prepared 1.3 times the amount of earth calculated, according to $V=1.3(V_1+V_2+...V_n)$. Prepare for reasonable allocation of manpower, resources and time. In this paper, the list of soil quantity of road pits in the experimental image collection is as follows:

Table 7. Calculation results of earthwork of points (unit: m^3)

ID	Area	Road pit depth	Earthwork volume
1	4.33	0.14	0.20
2	0.33	0.12	0.01
3	0.91	0.10	0.03
4	0.77	0.09	0.02
5	0.87	0.07	0.02

For the study area, the total soil volume of the five road pits collected is:

$V=1.3*(V_1+V_2+V_3+V_4+V_5=0.20+0.01+0.03+0.02+0.02)=0.364m^3$

When this data is fed back to the municipal or road management departments, it is targeted at repairing the road pit before preparing 0.364 m^3 materials. This not only makes the quantification scientific, avoids waste of materials, but also improves the work efficiency.

As mentioned above, whether it is safety warning or road repair, it is feasible to use UAV low-altitude remote sensing technology. If the scope is widened and the processed data is reported to the transportation department and the government department in time, it has certain practical significance to prevent traffic accidents and scientific road repair.

7. Conclusion

Through the low-altitude RS technology of the UAV, collecting road images, after processing and analysis, will greatly improve the efficiency of road detection, reduce costs of road maintenance and road safety and maintenance ,and bring convenience to actual production and life. Successful studies in this area are as follows:

(1) It is economical and practical to use UAV technology to collect road image data. Taking full advantage of UAV can collect data conveniently and quickly, reduce cost and improve efficiency.

(2) It is reliable and feasible to process image data through professional RS and GIS software. All the data are processed by mature software, the process is not affected by human factors, and the data obtained is consistent with the actual situation.

(3) The method of geographic mathematical modeling is used for analysis and judgment, which is both accurate and precise. In-depth mining of the collected data to establish a judgment model to provide accurate and precise judgment results, so it can withstand practical tests.

(4) It can provide decision-making basis for road management department through visual expression, which is easy to read and understand. The visual expression allows road managers and users to see the research results at a glance, quickly assist decision-making, and make timely responses to reduce accidents and property losses caused by hidden road safety hazards.

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