

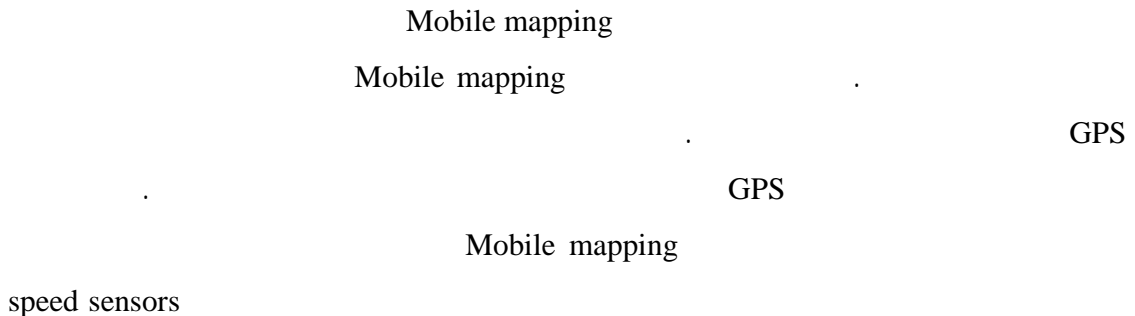
New Mobile Road Mapping System Using Digital Sensors

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Key words: Speed Sensor; Mobile Mapping; Horizontal Curve; Road Geometry.

SUMMARY

Mobile road mapping is very useful for several applications and has numerous advantages over the traditional mapping system. There are different mobile road mapping techniques have been used which are depending mainly on GPS and cameras that mounted horizontally or vertically. High-rise buildings around roads and the darkness represent the main obstacles for these systems. A new economic and accurate mobile road mapping system which is not affected by these obstacles is developed. The new system relies mainly on speed sensors for measuring the speeds of the vehicle rear wheels. The vehicle maneuvers road curvature with different speeds of the inner and the outer wheels, in other words, the traveling distance of the inner wheel will be shorter than that of the outer wheel. So, speed sensors can be fixed at the rear wheels to measure the inner and outer wheels speeds. The difference between the rear wheels speeds can be used to calculate the radius and the deflection angle of the curve. The theoretical base and simulation model of the new mobile mapping system are illustrated in this paper. The new system is low cost and applicable system that can be used in all weather conditions, all sites and at all times.



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1. INTRODUCTION

Mobile Mapping System is an information technology that has been developed since late 1980s with the advance and progress in mobile positioning technology, modern communication technology, spatial information technology and embedded technology, etc (Wang et al, 2004). Now Mobile Mapping System has been applied in many fields, such as intelligent transport, precision agriculture, field surveying, environment engineering, mobile phones, car navigator, office uses, and even for the pedestrian uses.

Several techniques have been developed for obtaining digital road maps. One of these techniques is the mobile mapping system i.e. mapping from moving vehicle. It can be also defined as moving platforms upon which multiple sensors and systems have been integrated to provide 2D or 3D near continuous positioning of both the platform and simultaneously collected geo-spatial data (Habib, accessed 2008). A mobile mapping system mainly consists of two main components, data acquisition devices and positioning devices (Manandhar and Shibasaki, 2001)

Several attempts have been done to obtain digital road maps using mobile mapping systems. (Ellum and El-Sheimy, 2002) stated that ground-based mobile mapping systems have been actively researched and developed as reaction to the need for a responsive technique for the survey of urban areas. Most of the mobile mapping systems have used the integration between photogrammetric techniques and GPS measurements. The photogrammetric techniques have been used to collect data of the road while the GPS measurements were for positioning.

(Manandhar and Shibasaki, 2001) have developed a mobile mapping system called VLMS – Vehicle borne Laser Mapping System- which consists of CCD cameras, Laser scanners, GPS, INS and Odometer mounted on a van. Also, (Desmet, 2005), develop a system containing two digital cameras, GPS , and odometer mounted on a van to capture precisely data of the road to develop a digital road mapping system. (Da Silva et al, 2003) have presented their mobile mapping system which consists of two digital video cameras, two GPS receivers, a notebook computer, and a sound frame synchronisation system mounted on and put in a van. (Gontran et al, 2005) presented a real-time mobile mapping system to determine the geometry of the road via a single camera. The overall accuracy of mobile mapping system depends on the accuracy of the used devices and their integrated output. (Barber et al, 2008) summarized the available systems for mobile mapping after (Ellum and El-Sheimy, 2002). High-rise buildings around roads and the darkness represent the main obstacles for the systems that depends on GPS and photogrammetry.

This paper presents a new mobile system for mapping road geometry. The system based on using digital sensors for measuring vehicle rear wheels speeds or rear wheels traveling distances. The difference between the inner and outer wheels speeds can be used to calculate the radius and the

deflection angle of the curve. The theoretical base and simulation model of the new mobile mapping system are illustrated in this paper. The proposed new system is low cost and applicable system that can be used in all weather conditions, all sites and at all times. The produced road map will be in shape of the car paths on the road.

2. METHODOLOGY

This paper introduces the theory of a new method for mobile road mapping with a simulation model for the new system. The new system relies mainly on speed sensors for measuring the speeds of the vehicle rear wheels. The vehicle maneuvers road curvature with different speeds for the inner and the outer wheels, in other words, the traveling distance of the inner wheel will be shorter than that of the outer wheel. So, speed sensors can be fixed at the rear wheels to measure the inner and outer wheels speeds. The difference between the rear wheels speeds can be used to calculate the radius and the deflection angle of the curve as explained in section 4. Of course if there is no differences between the vehicle rear wheels speeds, this means the road is straight. The road is curving right or left will depends on the speeds difference sign. The data from the two sensors will be real time transferred to an onboard computer. The transferred data will be used to compute the radius and angle of deflection at each time interval which can be used to calculate the point coordinates on the road path with the help of the coordinates of the starting point. These coordinates are used for mapping the road.

3. SENSOR TYPES AND RESOLUTION

A great variety of rotational speed sensors have been developed. This includes: Inductive sensors, Hall Effect sensors, Optical sensors, Magnetic sensors and Magneto-Optical sensors. Inductive sensors can work in the case of very high circular speed but they cannot work at low speed. Hall Effect sensors, widely used in many applications have problems with electronically noisy environments. Optical sensors possess, in principle, a very large dynamic range but they put severe restrictions on the state of the optical path along which the light beam is transmitted which must be free of obstacles, dust, etc. Magneto-Optics provide the opportunity to combine the advantages of the optical methods (contact less), wide dynamic range, absence of electric connections—with those of magnetic methods—easing the requirements imposed to the overall setup (Didosyan et al, 2003). Magnetic sensors have been explained in details by (Treutler, 2001) and (Giebeler, 2001). (Tan et al, 2000) have obtained a magnetic angular position sensor with 160,000 pulses/rev., this means an angle resolution of ± 8.1 sec/pulse. (Madni and Wells, 2000) have widely introduced the optical sensors with their specifications. The principles of the Magneto-Optics sensors have been illustrated by (Didosyan et al, 2003).

To analyze the resolution of the sensor and convert it to a speed or distance resolution, the following steps were conducted:

Assume:

- s*: sensor resolution to be 8.1 sec/pulse
- r*: wheel radius to be 16 inches = 0.4064 m
- p*: wheel perimeter to be 2.5538 m (calculated)
- eD*: distance error/revolution
- dD*: distance resolution
- dv*: speed resolution
- v*: wheel speed

$$eD = r \cdot s = 0.4064 \times 8.1 / 206265 = 1.5959E^{-5} \text{ m/rev}$$

$$dD = eD / p = 1.5959E^{-5} / 2.5538 = 6.25E^{-6} \text{ m/m} \quad \dots\dots\dots (1)$$

dv = error in the traveled distance in unit time

$$dv = dD \times v \text{ (m/s)}$$

$$dv = 6.25E^{-6} \cdot v \quad \dots\dots\dots (2)$$

e.g. *v* = 60 km/h

$$dv = 6.25E^{-6} \times 60 / 3.6 = 1.04E^{-4} \text{ m/s}$$

4. COMPUTATIONAL MODEL

In figure (1), the following were assumed:

- v*₁: speed of inner wheel
- v*₂: speed of outer wheel
- $\Delta v = v_2 - v_1$
- w*: axle width
- t*₀: time at the first point
- t*₁: time at the second point
- t*: traveling time = *t*₁ - *t*₀
- D*₁: traveled distance of the inner wheel
- D*₂: traveled distance of the outer wheel
- R*: curve radius
- I*: deflection angle between tangents (radians)

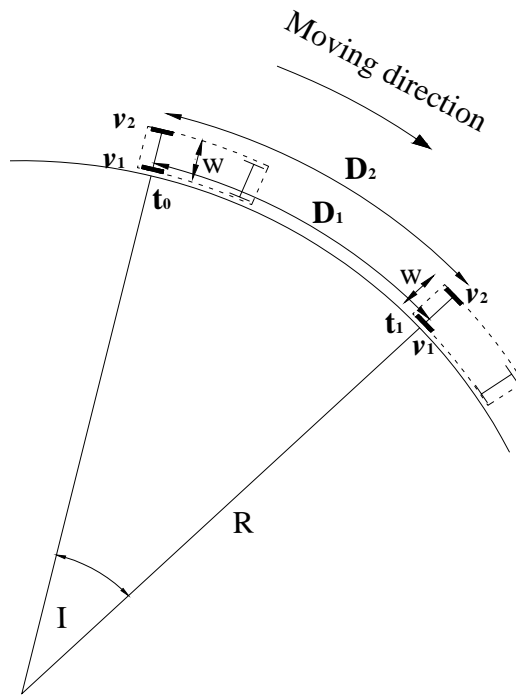


Figure (1): The principle of the proposed method.

From figure (1):

$$D_1 = t.v_1 \quad \dots\dots\dots (3)$$

$$D_1 = R.I \quad \dots\dots\dots (4)$$

$$R = \frac{D_1}{I} \quad \dots\dots\dots (5)$$

$$R = \frac{t.v_1}{I} \quad \dots\dots\dots (6)$$

$$D_2 = t.v_2 \quad \dots\dots\dots (7)$$

$$D_2 = (R + w).I \quad \dots\dots\dots (8)$$

$$R = \frac{D_2}{I} - w \quad \dots\dots\dots (9)$$

From equations (3) and (6)

$$\frac{D_1}{I} = \frac{D_2}{I} - w \dots\dots\dots (10)$$

$$D_1 = D_2 - w.I \dots\dots\dots (11)$$

$$I = \frac{D_2 - D_1}{w} \dots\dots\dots (12)$$

$$I = \frac{(v_2 - v_1).t}{w} \dots\dots\dots (13)$$

So, $dI / dt = (v_2 - v_1) / w$

Curvature rate of change is constant when the difference between the outer and inner speeds is constant (straight road). Using equation (12) and substituting in equation (5), the radius R can be calculated as follows:

$$R = \frac{w.D_1}{D_2 - D_1} \dots\dots\dots (14)$$

Using equation (13) and substituting in equation (6), the radius R and be also calculated as follows:

$$R = \frac{w.v_1}{v_2 - v_1} \dots\dots\dots (15)$$

The curve radius (R) can be calculated using equation (14) if the traveling distances of the rear wheels are measured while equation (15) is used if the speeds of the rear wheels are measured.

5. THEORETICAL STUDY OF THE NEW SYSTEM

Any new system must be studied theoretically to find out its accuracy before trying it practically. To carry out the theoretical study for the new mapping system, an error propagation have been done to find out the influence of the parameters, shown in equation (13) and (15), on the accuracy of the computed radius (R) and deflection angle (I). Also, a theoretical test of the system has been done using different speeds and different sensor accuracies.

5.1 Error Propagation

It is very important to calculate the errors that will happen in the computed radius due to the errors in the measured values (speeds or distances) to fix the system components in certain accuracy for having the final outcomes required accuracy.

Case 1: Assuming that the measured values are D_1 and D_2 and their errors are dD_1 and dD_2 respectively and the deflection angle (I) and the radius (R) were computed using equations (12) and (14), the errors will be as follows:

$$dI = \frac{1}{w} \sqrt{(dD_1)^2 + (dD_2)^2} \dots\dots\dots (16)$$

$$dR = \frac{w}{(D_2 - D_1)^2} \sqrt{(D_2^2 \cdot (dD_1)^2 + D_1^2 \cdot (dD_2)^2)} \dots\dots\dots (17)$$

If $dD_1 = dD_2$

$$dI = \frac{dD_1 \sqrt{2}}{w} \dots\dots\dots (18)$$

$$dR = \frac{w \cdot dD_1 \sqrt{(D_2^2 + D_1^2)}}{(D_2 - D_1)^2} \dots\dots\dots (19)$$

Case 2: Assuming that the measured values are v_1 and v_2 and their errors are dv_1 and dv_2 respectively and the deflection angle (I) and the radius (R) were computed using equations (13) and (15), the errors will be as follows:

$$dI = \frac{t}{w} \sqrt{(dv_1)^2 + (dv_2)^2} \dots\dots\dots (20)$$

$$dR = \frac{w}{(v_2 - v_1)^2} \sqrt{(v_2^2 \cdot (dv_1)^2 + v_1^2 \cdot (dv_2)^2)} \dots\dots\dots (21)$$

If $dv_1 = dv_2$

$$dI = \frac{t \cdot dv_1 \sqrt{2}}{w} \dots\dots\dots (22)$$

$$dR = \frac{w \cdot dv_1 \sqrt{(v_2^2 + v_1^2)}}{(v_2 - v_1)^2} \dots\dots\dots (23)$$

5.2 Theoretical Test

Theoretical test were performed on the proposed system using different speeds, different values of sensor resolution, and different rear wheels speed differences. The axle width (w) was assumed to be 1.4 m as most vehicles have this value for the rear axle width. In this case it won't have any influence in the computed elements. The influence of the other parameters on the computed radius will be evaluated by fixing some parameters and changing the others. These parameters are speed values (v_1) and (v_2), and sensor resolution (s) which can be used as it is or as speed resolution (dv). The speeds of the inner wheel (v_1) assumed to be 20, 40, 60, 80 km/h. For each value of v_1 a range of values of v_2 starting from a value equal to v_1 to a value equal to $v_1 + 1$ with interval of 0.10 km/h were studied. The sensor resolution assumed to be 4.05, 8.1, 16.2 and 24.3 sec/pulse. The sensor resolution is preferred to be used rather than speed resolution (dv) which change with the speed value as shown in equation (2) . Equations (20) and (21) were used to calculate the error in the radius (dR) for different combinations of (v) and (s).

5.2.1 Results

The results of the error in the radius (dR) were obtained, tabulated and used for graphical representation of the relationships between the effective parameters. Figures (2) through (5) show samples of the relations of the results.

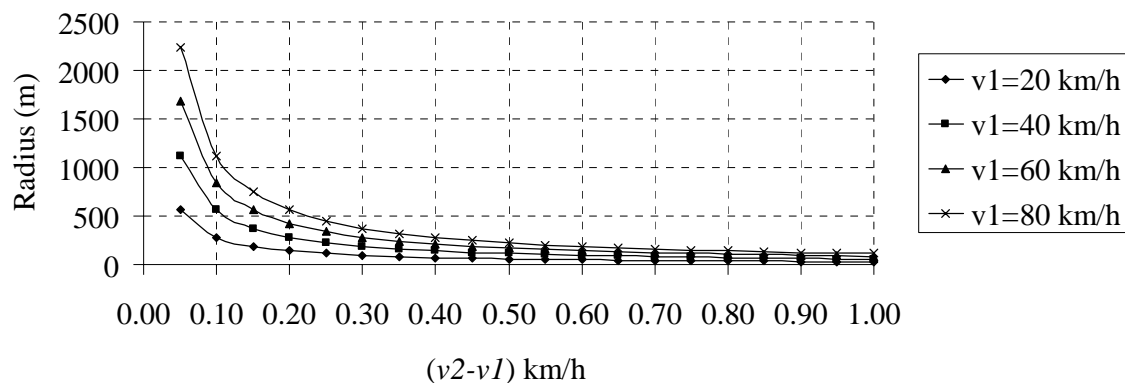


Figure (2): Relation between ($v_2 - v_1$) and the radius R for different speeds

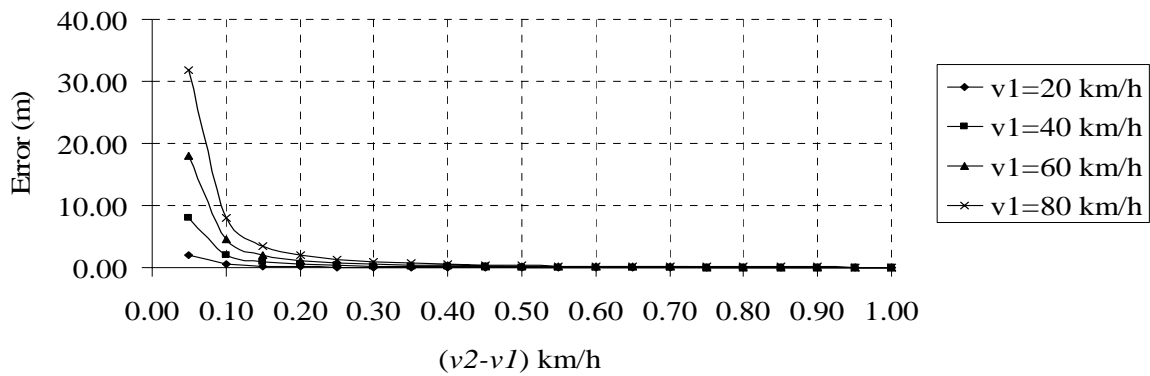


Figure (3): Relation between $(v_2 - v_1)$ and error in R for different speeds
[Sensor accuracy = 8.1 sec/pulse]

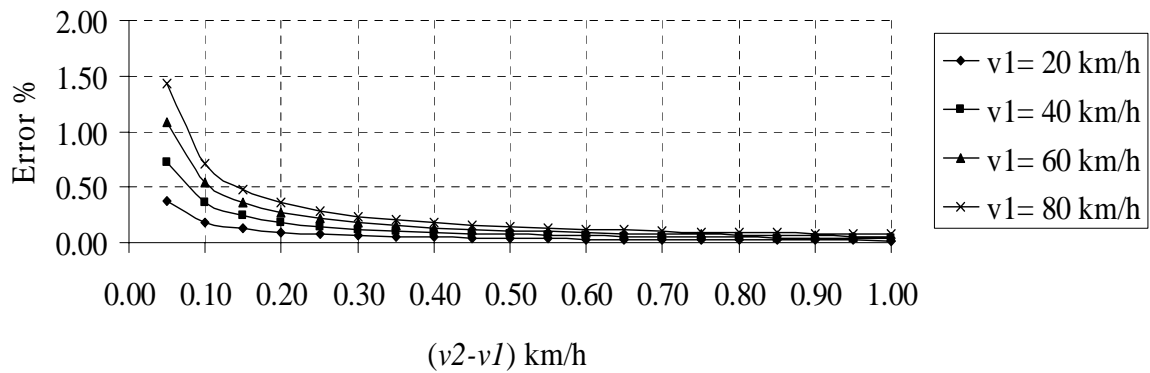


Figure (4): Relation between $(v_2 - v_1)$ and the relative error in R for different speeds
[Sensor accuracy = 8.1 sec/pulse]

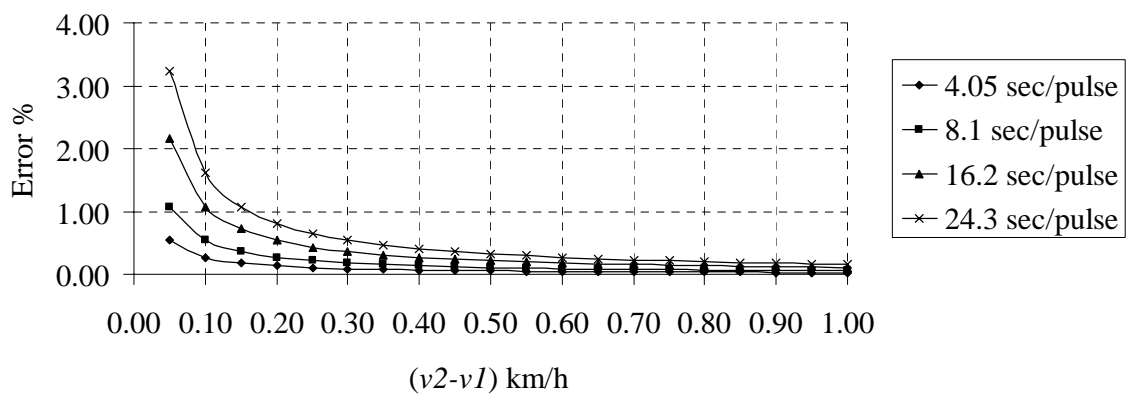


Figure (5): Relation between $(v_2 - v_1)$ and the relative error in R for different sensor resolutions
[$v_1 = 60$ km/h]

5.2.2 Analysis

The above figures show that the proposed method for mobile road geometry mapping is accurate even with sensor resolution less than the available (8.1 sec/pulse). It can be used with any road shape and the vehicle can move at any speed. Figure (2) shows that the proposed system can be used to determine the curve radius with a range from about 20 m up to 2300 m. Figure (3), shows that the error in the computed radius is close to zero to all values of (Δv) greater than 0.30 km/h. the maximum error is about 30 m in the maximum curve radius (2300 m). Figures (4) and (5) show that the relative error decreasing with decreasing the speed and with increasing the sensor resolution. Generally, the rate of increasing of determined radius, error and relative error is slow for the values of (Δv) greater than 0.30 km/h, the highest rate of increasing when (Δv) is less than 0.10 km/h.

6. SIMULATION MODEL

The proposed method was applied on theoretical example to illustrate the measuring steps or the measuring flowchart. In this example a road contains two curves of 79.58 m radius and their centers were at opposite sides of the road was assumed. A car with two speed or distance sensors connected to its rear wheels with the following assumptions:

- Sensor No. 1 is that at the right rear wheel.
- v_1 is assumed equal to 50 km/h
- $w = 1.40$ m
- the sensor resolution = 8.1 sec/pulse.
- time interval = 1 sec
- v_1 and v_2 should be measured at each time interval.
- the coordinates of the start point should be known.
- the azimuth of the road at the start point should be known.

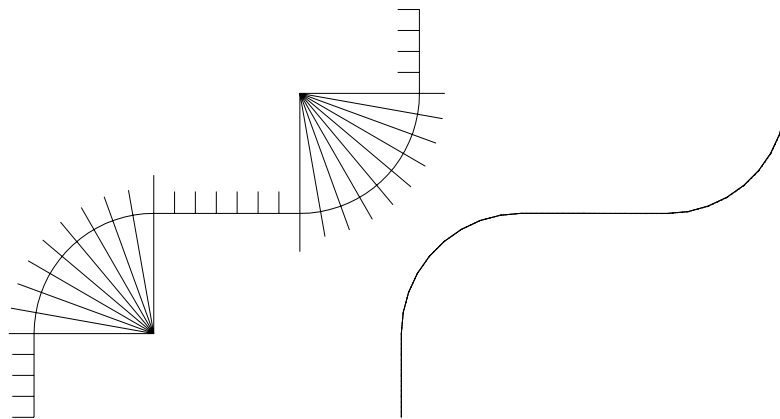
The calculation steps will be as follows:

- calculate R and I using v_1 and v_2 for each time interval.
- calculate the length of the chord (L_c) using R and I
- calculate the azimuth of the chord using the azimuth of the previous one and I
- calculate the departure and latitude of the chord
- calculate the coordinates of the chord's end using that of the previous one.

These coordinates represent the points along the track of the right rear wheel.

The calculations in this example were done twice, once without errors in R and I and once again with errors in R and I . The first calculations were done to check the ability of the system to represent the real path of the road. The second calculations to check the error in the computed path of the road. The error components at the end of the path (458 m long) in this example were $\Delta x = 0.37$ m and $\Delta y = -0.38$ m.

These errors can be corrected if the coordinates of the end point were known. In this example the coordinates of the end point were assumed to be known and the path was processed as a closed traverse to correct the coordinates of the points along it. The results of the applied example are shown in figure (6).



a) The actual path

b) The calculated path

Figure (6): The applied example

7. CONCLUSIONS

A new system for mobile road mapping has been developed. It based on measuring the speeds or the traveling distances of the vehicle rear wheels by using digital sensors. From the difference in speeds or traveling distance between the inner and outer wheels, the radius of the curve (R) and the deflection angle (I) can be calculated.

The accuracy of the new system depends on the used sensors resolution which are available at cheap prices and high accuracy. The new system is not affected by any obstacles like high building or darkness which may affect the already used systems.

The new system can be used in any weather conditions and in any road structures like tunnels or underpaths.

A theoretical study has been done to find out if there will be any deficiency of the system regarding to the use or the obtained accuracy. The results showed that it is simple and easy to be used for mapping roads. The obtained results showed also that the system is accurate and can give a road map for the vehicle path.

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BIOGRAPHICAL NOTES

Ass. Prof. Dr. Mostafa Ebrahim graduated in 1986 from Civil Engineering Department, Faculty of Engineering, Assiut University, Egypt. In 1992, he has been awarded his M. Sc. Degree in close range photogrammetry from Assiut University. In 1996, he has been awarded Eduard Dolezal Award from ISPRS in its XVIII congress, Vienna, Austria. In 1998, he has been awarded his Ph.D degree in Digital Close Range Photogrammetry from Innsbruck University, Austria. In 2005 he has been promoted to Assistant professor Position at Civil Engineering Department, Faculty of Engineering, Assiut University, Egypt.

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