3D Geospatial modeling of accident scene using Laser Scanner data

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Abstract
The aim of traffic reconstruction is to recreate motor vehicle collision scenes in order to analyze the dynamics of the collision events, to provide evidence in court cases and allow the manufacturers to evaluate the vehicle's design. However, at the scene of the accident it is not known exactly the amount of information that will be required for the analysis and often relevant data are missing. The emergence of terrestrial laser scanning has enabled the 3D documentation of accident events in a safer way, as information can be collected without any lane closures or traffic interruptions, and in a more flexible and faster way, as a single user can operate the instrument in complete darkness or direct sunlight. The notion of this paper is to model accident scene using terrestrial laser scanning data. With the intersection-related crashes making up a high proportion of total fatal crashes, there is a need for recording their current status in order to improve the design and operation of road intersections. Terrestrial laser scanning provides the capability of recording such infrastructures in a fast and reliable way, where a number of different information, including traffic control features, volumes, accident characteristics and detailed spatial data, can be easily obtained. This information can then be integrated within traffic management integrated systems and be used for accident prevention purposes.
Keywords: Terrestrial laser scanner (TLS), Momentum, speed, Accuracy.

1.0   Introduction
Traffic accidents can occur whenever significant deficiencies, oversights, errors, omissions, or unanticipated changes are present. Any one of these conditions can be a precursor for an accident; the only uncertainty is when the accident will occur and the degree of the accident. To conduct a complete accident/incident investigation, the factors contributing to an accident, as well as the means to prevent accidents, must be clearly understood. However, most are caused.

Understanding how to prevent or control traffic accidents requires knowledge of the sequence of events leading to an accident, in order to identify and implement counter measures. Therefore, the process of accident reconstruction can be considered as a sequence of operations involving the collection of data about the road transportation components (road, vehicles and people) and continues through inferences and conclusions about the sequence of events that constitute the accident and the relationship of these components during the events [6]

Five levels of activity in accident investigation are: (a) reporting, where basic data collection is used to identify and classify an accident, (b) at-scene investigation, whereby extra data are collected at the accident scene along with the results of the accident, such as marks on the road and debris, tire marks etc, (c) technical follow-up, which studies all available data relating to an accident, such as speed and acceleration of vehicles, visibility of vehicles, pedestrians etc, and is undertaken for legal and other specific purposes, (d) professional reconstruction which determines from the available data how the road, driver and vehicle contributed to a particular accident, and (e) cause analysis, which determines from the available data why the accident happened (e.g. deficiencies of road or vehicle design).

Clearly, the data collection and recording at the accident scene is the most critical aspect as they are needed in all the aforementioned five levels of investigation. Furthermore, traffic recording systems should be technologically sophisticated to provide more timely, fast, accurate, integrated, accessible and more standardized and uniform data. Also, the measurement process should be as least disruptive to traffic as possible and provide end products that are easily transformed to 2D drawings.

The most commonly measuring approach is 2D surveying where measurements of distances along and offset from a road edge or centerline are performed. Frequently, total stations and laser range finders are employed but with the disadvantage of being disruptive to traffic. GPS surveying is successfully used but only in unobstructed areas. Recently, close-range digital photogrammetric or 3D Laser Scanning for Road Safety and Traffic Accident systems have been developed which provide fast and accurate data acquisition but can be relatively expensive and complex to use for local police and traffic agencies[6].

More recently, the emergence of terrestrial laser scanning has enabled the 3D documentation of accident events in a safer way, as information can be collected without any lane closures or traffic interruptions, and in a more flexible and faster way, as a single user can operate the instrument in complete darkness or direct sunlight. The end products of the laser scanner data include 3D animations of scenes, and even 3D physical models that can be used into the jury room.

The advantage of the 3D digital models is that they provide further help in analysing
what happened in a crash, for example measuring the vehicle deformation helps to determine the speed at impact and other contributing factors. Scene capture that is both fast and complete is another advantage. The huge volumes of data collected with a laser scanner may not always be used at each level of traffic investigation but certainly allow the return visits to the accident scene be made virtually[6].

Figure 1 – Some types of terrestrial laser scanners

2.0   Accuracy of Terrestrial Laser Scanner observations (TLS)

To achieving the results that meet the specifications of a given project, the knowledge of the accuracy of the surveying equipment is inevitable. Surveying results must meet certain specifications in order to provide the necessary accuracy standards for a certain application. On the other hand, if instruments and methods are used which yield accuracy far above the needed standard, this will result in unnecessary cost and expenditure. Therefore, any geometric surveying task comprises not only the derivation of the relative positions of points and objects but also an estimation of the accuracy of the results [5].

There are different accuracies for the single point measurement. With the total station, the single point accuracy is higher. A successful accident scheme using a terrestrial laser scanner may call for measurements of high precision and accuracy. The instrument manufacturers' quoted precision and accuracy rarely matches the actual capabilities of the instrument.

3.0   Mathematical model of Terrestrial Laser Scanner

Range of scans is a function of the laser intensity and reflectivity of the object scanned. The ranging capability of a laser scanner is more important than it first seems. In some cases, the lack of ranging ability will completely eliminate the ability to do certain projects [1, 2]. Ranging errors can be observed when known distances in range direction are measured with the scanner. If scanners are not equipped with a defined reference point (such as forced

centering), it is only possible to determine the range accuracy of laser scanner by comparing the accuracy of the calculated distance between reflective marks resulted from laser scanner and the calculated distance from other accurate instrument (for example total station).

The length of side, from its end coordinates, can be calculated by:

$$S = \sqrt{\left(X_j - X_i\right)^2 + \left(Y_j - Y_i\right)^2 + \left(Z_j - Z_i\right)^2} \tag{1}$$

By differentiation equation (1) and by using propagation law, the accuracy of the side length between two points can be determined by using the following formula:

$$m_S^2 = \left(\frac{X_j - X_i}{D}\right)^2 m_{X_j}^2 + \left(\frac{X_i - X_j}{D}\right)^2 m_{X_i}^2 + \left(\frac{Y_j - Y_i}{D}\right)^2 m_{Y_j}^2 + \left(\frac{Y_i - Y_j}{D}\right)^2 m_{Y_i}^2 +$$

$$+ \left(\frac{Z_j - Z_i}{D}\right)^2 m_{Z_j}^2 + \left(\frac{Z_i - Z_j}{D}\right)^2 m_{Z_i}^2 \tag{2}$$

If the coordinates of laser scanner position equal (0, 0, 0) at any scan, then the length of side from any scanned point to the laser scanner position will be expressed in the form:

$$S_i = \sqrt{X_i^2 + Y_i^2 + Z_i^2} \tag{3}$$

Then, accuracy of the length of side from any mark to the laser scanner by applying equation (2) can be calculated by using the error propagation as:

$$m_S^2 = \frac{X^2}{X_i^2 + Y_i^2 + Z_i^2} m_{X_i}^2 + \frac{Y^2}{X_i^2 + Y_i^2 + Z_i^2} m_{Y_i}^2 + \frac{Z^2}{X_i^2 + Y_i^2 + Z_i^2} m_{Z_i}^2 \tag{4}$$

4.0 Horizontal angles (Horizontal Plane)

As shown in figure 2, the horizontal angle α_{AB} can be calculated from the geometry of horizontal triangle $OA'B'$ as following:

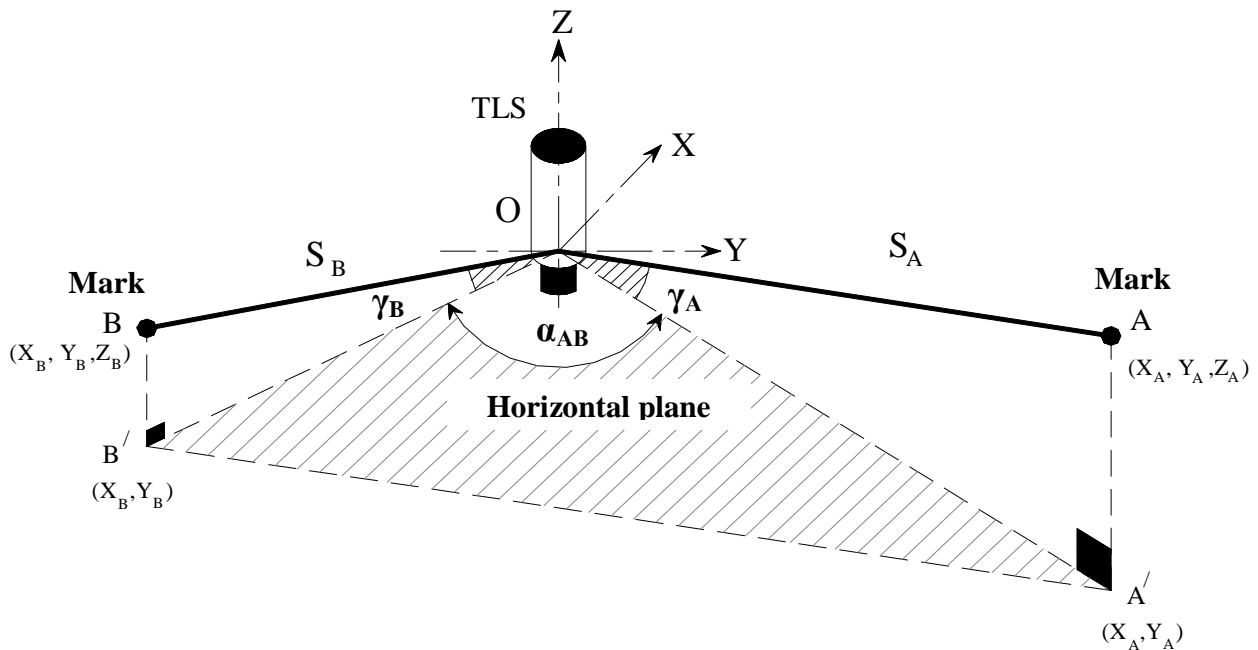$$\cos \alpha_{AB} = \frac{OA'^2 + OB'^2 - A'B'^2}{2\ OA\ OB}. \tag{5}$$

Figure 2 – Scanning two points by using terrestrial laser scanner (TLS)

If the coordinates of laser scanner position equal (0, 0, 0) at any scan, the equation (5) can be reconstructed by using the points coordinates as following:

$$\cos \ \alpha_{AB} = \frac{X_A X_B + Y_A Y_B}{\sqrt{X_A^2 + Y_A^2} \cdot \sqrt{X_B^2 + Y_B^2}}, \qquad (6)$$

The accuracy of horizontal angle has the form:

$$m_{\alpha_{AB}}^2 = (\frac{\partial \alpha_{AB}}{\partial X_A})^2 m_{X_A}^2 + (\frac{\partial \alpha_{AB}}{\partial Y_A})^2 m_{Y_A}^2 + (\frac{\partial \alpha_{AB}}{\partial X_B})^2 m_{X_B}^2 + (\frac{\partial \alpha_{AB}}{\partial Y_B})^2 m_{Y_B}^2. \quad (7)$$

5.0 Vertical angles (Vertical Plane)

From each point in the scanned object it is possible to determine the vertical angle of the laser scanner. If the coordinates of occupied laser scanner station is (0, 0, 0) then the vertical angle from point A (for example) can be determined as following:

$$\gamma_A = \tan^{-1}(\frac{Z_A}{\sqrt{X_A^2 + Y_A^2}}) \qquad (8)$$

By using the law of propagation, the accuracy of vertical angle can be determined as following:

$$m_\gamma^2 = \frac{(X_A^2 Z_A^2)m_{X_A}^2 + (Y_A^2 Z_A^2)m_{Y_A}^2 + (X_A^4 + 2X_A^2 Y_A^2 + Y_A^4)m_{Z_A}^2}{(X_A^2 + Y_A^2).(X_A^2 + Y_A^2 + Z_A^2)^2} \qquad (9)$$

Figure 3: Leica C10 3D Laser Scanner

The ScanStation C10 from Leica Geosystems is a versatile 3D laser scanning solution which rapidly photographs then measures everything at a scene, not just what may be considered important at the time. Ideal for complex environments and with a 100% acceptance record in U.S. This is one of the most useful forensic advances for processing crime scenes since the creation of photography. It allows an investigator to capture a scene totally and completely; everything is preserved from the moment the scanner is deployed.

6.0   Momentum

In classical mechanics, momentum or, equivalently is the product of the mass and velocity of an object (p = mv). Like velocity, momentum is a vector quantity, possessing a direction as well as a magnitude. Momentum is a conserved quantity (law of conservation of linear momentum), meaning that if a closed system is not affected by external forces, its total momentum cannot change. Momentum is sometimes referred to as linear momentum to distinguish it from the related subject of angular momentum [7]

Although originally expressed in Newton's Second Law, the conservation of momentum also holds in special relativity and, with appropriate definitions, a (generalized) momentum conservation law holds in electrodynamics, quantum mechanics, quantum field theory, and general relativity. In relativistic mechanics, non-relativistic momentum is further multiplied by the Lorentz factor.

The linear momentum of a system of particles is the vector sum of the moment of all the individual objects in the system [7]:

$$\mathbf{p} = \sum_{i=1}^{n} m_i \mathbf{v}_i = m_1\mathbf{v}_1 + m_2\mathbf{v}_2 + m_3\mathbf{v}_3 + \cdots + m_n\mathbf{v}_n \, ,$$

(10)

where **p** is the total momentum of the particle system, m_i and $\mathbf{v}_i$ are the respective mass and velocity of the i-th object, and n is the number of objects in the system.

The Total momentum before a crash must equal the total momentum after a crash. Therefore the inline crash is given as [8]:

$$[W1 \times S1] + [W2 \times S2] = [W1 \times S3] + [W2 \times S4]$$

(11)

The angular crash for both cars can be express as follows

$$[W1 \times S1 \times Sin\alpha] + [W2 \times S2 \times Sin\varphi] = [W1 \times S3 \times Sin\varphi] + [W2 \times S4 \times Sin\varphi]$$

(12)

$$[W1 \times S1 \times Cos\alpha] + [W2 \times S2 \times Cos\varphi] = [W1 \times S3 \times Cos\varphi] + [W2 \times S4 \times Cos\varphi]$$

(13)

The data from both cars that are involved in accident are presented in table 1

Table 1 – vehicle data

Vehicle #1	Vehicle #2 -
2002 pick up	1989 camry
Curb weight = 3112 lbs	3081 lbs
Passengers and cargo = 1413 lbs	903 lbs
Total weight = 4525 lbs	3984 lbs
Approach angle = 107 degrees	0 degrees
Departure angle = 85degrees	67 degrees
Departure speed = 20 mph	20 mph
Rotation angle = 176 degrees	47 degrees
Distance = 29.59feet	33.64 feet
Drag factor = .75	=.75
RR tire locked from impact	Both front tires locked from impact
Adjusted drag factor = .456	=.602
Impact speed = 22.3 or 22 mph	37.78 or 38 mph

From equation (12) the momentum of vehicle 2 can be calculated thus:

$$[3984 \times S1 \times Sin0] + [4525 \times S2 \times Sin107] = [3984 \times 20 \times Sin67] + [4525 \times 20 \times Sin84]$$

$$[3984 \times S1 \times 0] + [4525 \times S2 \times 0.9563] = [79680 \times 0.9205] + [90500 \times 0.9961]$$

$$[3984 \times S1 \times 0] + [4525 \times S2 \times 0.9563] = [79680 \times 0.9205] + [90500 \times 0.9961]$$

$$4327.25[S2] = 73345.44 + 90147.05$$

$$S2 = 37.78 \rightarrow 38mph$$

Also from equation (13) the momentum of vehicle 1 can be calculated thus:

$$[3984 S1 \times Cos0] + [4525 \times 37.78 \times Cos107] = [3984 \times 20 \times Cos67] + [4525 \times 20 \times Cos85]$$

$$[3984 \times S1] + -49970 = 31130.97 + 7882.55$$

$$3984 \times S1 = 39013.52 + 49970$$

$$S1 = 22.33 \rightarrow 22mph$$

From the results presented above, it can be observed that the speed of vehicle 2 (S2) was found to be 38*mph* i.e. (60.8*kmph*), while vehicle 1 (S1) was found to be 22*mph* i.e. 35*kmph*. The results indicate that vehicle 2 (S2) approach the bent at an excessive speed thereby lost control.
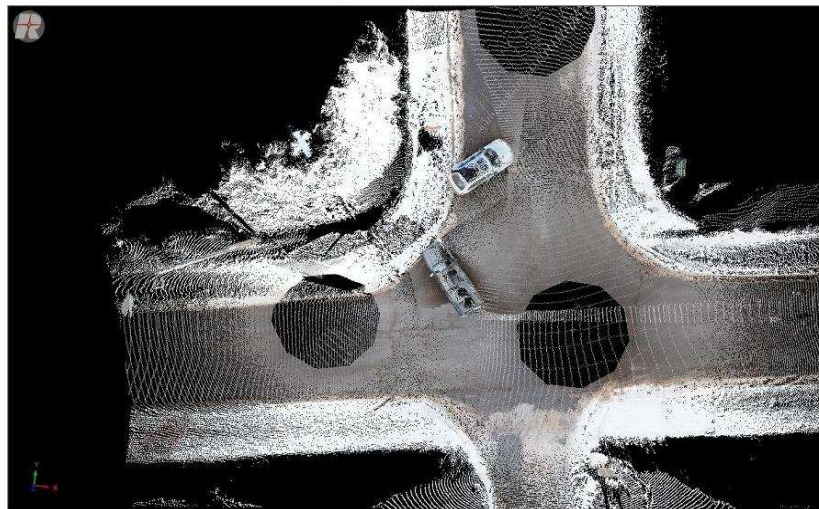

Figure 4: 3D Laser scanner crowd points of Accident Scene

Figure 5: 3D cloud points of Accident Scene

7.0   Conclusion

With the growing interest in national and international road safety programs, there is a requirement for reliable, accurate, and timely data to make decisions about traffic safety problems and countermeasures. The aim of these programs is to document and evaluate the characteristics of traffic accidents and the interaction of various components in order to support analysis on traffic safety. In the field of traffic accident reconstruction, a number of measurements tools have been adopted with terrestrial laser scanning being a promising technology in this field. The greatly reduced on-scene time, resulting to shorter traffic disruption periods, and a permanent 3D visual detailed record of the accident scene are the notable advantages of terrestrial laser scanning.

With the intersection-related crashes making up a high proportion of total fatal crashes, there is a need for recording their current status in order to improve the design and operation of road intersections. Terrestrial laser scanning provides the capability of recording such infrastructures in a fast and reliable way, where a number of different information, including traffic control features, volumes, accident characteristics and detailed spatial data, can be easily obtained. This information can then be integrated within traffic management integrated systems and be used for accident prevention purposes.

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