ROAD SAFETY IMPROVEMENTS IN JUNCTIONS USING 3D LASER SCANNING

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ABSTRACT

Intersections are a critical part of the European road network, representing a small fraction of its overall size, but concentrating more than a fifth of the fatalities in road accidents. The effectiveness of various junction layout treatments aiming to reduce road accidents and fatalities is being actively researched. The importance of true and precise road geometry becomes very important in this context and the requirements for accurate 3D road design become so demanding that conventional 2D approaches are often insufficient. The aim of this paper is to present a practical example of implementing 3D laser scanning technology, and specifically terrestrial laser scanners and imaging total stations, as part of topographical survey for road design and road safety analysis. Accurate 3D models of the studied intersections can assist the researchers and decision makers in studying these interactions and developing more accurate evaluations of junction improvement schemes.

Key words: road safety, intersections, metric (mapping/surveying) system, 3D laser scanners, road safety measures

1. INTRODUCTION

Intersections are a critical part of the European road network, representing a small fraction of its overall size, but concentrating more than a fifth of the fatalities in road accidents (Antoniou et al., 2011, Broughton et al., 2011). Consequently, there is a clear interest for the analysis of road safety at intersections, evidenced by the large body of research on the topic. The analysis of safety at intersections is hardly a new topic (see e.g. Kulmala, 1994, and Amundsen and Elvik, 2004), though with high complexity. Macroscopic accident analysis provides useful insight to the accident characteristics at junctions. However, only in-depth accident investigation can assist the detailed identification of accident causes in junctions as well as the design of the appropriate countermeasures. In this context, the emergence of new technologies (like 3D laser scanning) has opened the road to levels of analysis that until recently might have seemed too involved and costly, often summarily referred to as metric (mapping/surveying) systems. This type of systems and geometric procedues is assumed for the remainder of this article. One of the ways in which these new technologies can contribute in the advancement of road safety is through the improvement of the decision process used to evaluate, prioritize and finally target infrastructure improvements so that they will be most effective (e.g. along the lines of efforts in Europe, such as Yannis et al., 2008, 2011, and the US such as Lu and Wang, 2005; UDOT, 2008 and FHWA, 2009, 2010).

On the other hand, human factors start to play an increasingly more central role in highway design. These advances lead to an increase in the fidelity with which the road environment needs to be known to the driver and the vehicle itself. The importance of true and precise 3D road geometry becomes very relevant in this context. The spatial, true information that can be extracted by 3D laser scanning technology can be very useful for the departure from traditional 2D plans into fully 3D road design and construction. Traditional, two-dimensional engineering drawings are not only insufficient to cover the increasing demands but cannot easily be updated according to the latest changes in the infrastructure. Advanced 3D surveying tools, such as terrestrial laser scanning, offer an attractive, affordable alternative, as they can quickly create accurate, 3D depictions of any object, including roads and intersections. Unlike a traditional plan where the choice of section cannot be changed, 3D laser scanner technology allows sections to be created through the digital model at any point according to what is required. These properties are very desirable in intersection analysis, as there are many different points of view, as well as obstructions. High-resolution geometric models can be derived from laser scanning data and 3D recordings and virtual presentations can be produced as final products.

The choice of junction design and operational features depends upon several factors, whose relative importance varies between cases and needs to be assessed. These factors mainly include traffic safety, road type and function, number of concurring legs, traffic volume, design and operating speed, priority setting, available space, adjacent land use, network design consistency, environmental factors and cost (PIARC, 2003). The type of junction has to be suited to the road type, the environment and capacity, in order to maintain good readability both of the road and of the junction, as well as a satisfactory level of safety (Bared and Kaisar, 2001; Elvik and Vaa, 2004).

The aim of this paper is therefore to demonstrate a practical example of implementing terrestrial laser scanning and imaging total station as part of topographical survey for road safety analysis and evaluation of candidate infrastructure investments for urban and suburban intersections. The remainder of the paper is structured as follows. Relevant background is presented, including existing methodologies and equipment, as well as applications in transportation infrastructure management. A summary of safety measures assessment results is presented next. The practical application setup is presented next, followed by the development of the 3D model that can support the process of safety measures evaluation. Finally, a concluding section provides further insight and discussion, including other applications and prospects of these technologies in highway engineering and transportation in general.

2. BACKGROUND

Recently, laser scanning is gaining great interest for its relevant simplicity and speed. Laser scanning analyzes a real-world or object environment by measuring thousands of points with high accuracy in a relatively short period of time. For small-scale applications, terrestrial laser scanning has emerged as a valuable resource for highway engineering and surveying applications, offering a multitude of advantages over conventional approaches. Different laser scanner principles exist, i.e. triangulation based, time-of-flight based and phase-difference based, with all based on the same idea of computing distances by measuring the timeframe between sending laser pulse or wave and receiving its reflection from an object (e.g. Vosselman et al., 2004; Teizer and Kahlmann, 2007).

Most of the published work in the field of terrestrial laser scanning deals with the extraction of surface models and very few consider the extraction of geometric parameters of existing road infrastructure. This can be attributed to the fact that many parameters can affect the accuracy in various road engineering applications. For example, Hiremagalur et al. (2009) note that while “in many 3D laser scanner applications, high relative precision […] is sufficient, […] DOT applications require good relative precision and high absolute accuracy”. The specific characteristics of highway engineering projects create a set of challenges dealing with long distances, obstructions from various structures, as well as different materials (concrete, asphalt etc.). One practical approach to overcome some of these challenges is the integration of LIDAR and photogrammetry, e.g. as presented by

Veneziano et al. (2003) for highway location and design applications. Teizer et al. (2005) present a framework for real-time 3D modeling of transportation infrastructure, which could have a multitude of applications, including “condition assessment, maintenance, operations and construction activities”.

A major application area of laser scanning in road engineering is pavement condition assessment and testing in highway facilities, as well as structural integrity of special-purpose structures, such as bridges (e.g. Wang et al., 2008, Meegoda et al., 2003 and Li et al., 2011). In the area of road safety, laser scanning seems a promising technology. For example, Zhao et al. (2008a) use laser scanners set on the road site to profile an intersection from different points of view in order to allow the tracking of location, speed and direction of moving objects, Szurgott et al. (2009) scan speed bumps in order to assess vehicle behavior and Antoniou and Tsakiri (2012) use 3D laser scanning for the calculation of sight distances in complex urban and suburban intersections.

Yannis et al. (2011) present an assessment of the effectiveness of road safety measures at junctions. In particular, the authors investigate the effectiveness of various junction layout treatments (conversion of junctions to roundabouts, redesigning of junctions, changes of the junction angle, staggering of junctions, reduction of gradients on approach, increase of sight triangles and channelisations) or traffic control interventions (implementation of ‘yield’ or ‘stop’ signs, the implementation or the upgrade of traffic signals) aiming to reduce road accidents and fatalities. The results suggest that road safety measures implemented at junctions are among the most promising road safety measures, and that they are generally associated with very satisfactory cost-benefit results. The authors also recommend that cost-benefit ratios and safety effects should always be examined in conjunction and not in isolation and that transferability of results among different settings or countries should be examined with particular caution.

In this research, the use of 3D laser scanning technologies is proposed as a tool to support the evaluation of the effectiveness of road safety measures at intersections. This includes obtaining more detailed representations of the junction geometry and conditions, than what was previously available, and also the ability to evaluate combinations of measures in conjunction. Since the 3D laser scanning approaches result in a full 3D model of the intersection, it is evident that the ability to assess the benefits of each approach become more pronounced.

3. AN OVERVIEW OF INTERSECTION ROAD SAFETY IMPROVEMENT MEASURES

In order to provide some context for the concluding section, this section includes some main observations about road safety improvement measures (Yannis et al., 2011). Important safety effects are associated with the development of roundabouts (Brenac, 1994). In particular, statistically significant results indicate that converting stop-controlled junctions to roundabouts may result in 31% reduction of injury accidents for T-junctions and 41% reduction of injury accidents for crossroads, while converting traffic-signal-controlled junctions to roundabouts may result in 11% reduction of injury accidents for T-junctions and 17% reduction of injury accidents for crossroads (Elvik and Vaa, 2004). Converting stop-controlled single-lane urban and rural junctions to roundabouts may reach around 75% reduction of injury accidents and around 85% reduction of all accidents (Persaud et al., 2001). Converting traffic-signal-controlled single-lane rural junctions to roundabouts may result in around 35% reduction of injury accidents and 75% reduction of all accidents (Persaud et al., 2001).

Redesigning the junction layout can have mixed effects. However, based on meta-analysis results summarized in Yannis et al., 2011, an angle of less than 90 degrees gives the fewest injury accidents and the opposite appears to be the case for material damage only accidents. Re-designing a junction of an angle less than 90o to an angle of 90o, may increase injury accidents by 80%. On the contrary, re-designing a junction of an angle of 90o to an angle of more than 90o, appears to bring a reduction of injury accidents by 50%. Furthermore, meta-analysis results (Elvik and Raa, 2004) indicate negative safety effects of improving sight triangles at T- junctions (30% increase of injury accidents), and positive safety effects at 4-leg junctions (50% reduction of injury accidents). On the other hand, in the Highway Safety Manual (AASHTO, 2010), a safety benefit of 73% is associated with increases of sight triangles.

The information presented above represents the state of the art in the evaluation of road safety improvement measures. The figures obtained through the analysis of a large number of intersections represent an important body of research and analysis and on average provide an indication of the expected benefits. However, the availability of an accurate 3D model of the specific intersection that is being considered can be a valuable tool in the hands of designers, allowing them to fine tune and optimize the design and thus obtain the maximum benefits from a customized solution.

4. PRACTICAL APPLICATION SETUP

In this research, 3D laser scanners have been used for the development of accurate and detailed 3D models of intersections for the purpose of road safety assessment and evaluation of improvement measures. The main equipment used for the data collection was a terrestrial laser scanner- TLS (Leica Scanstation 2) and an imaging total station (Topcon IS-203).

The advantages of the Total Station include:
- Absolute point accuracy of TS sub-mm
- Inexpensive
- Scanning and image taking facilities available in widely used equipment
- One person operation
- Long range (non prism) up to 2000m
- Robotic capabilities

while on the other hand the following properties can be considered as disadvantages:
- Scanning operation slow (in the order of 20 points/sec)
- Scanning field of view (FOV) in the order of 60° x 60°

Similarly, for the terrestrial laser scanner, the advantages include:
- Absolute point accuracy <10mm (three-fold better for modeled surfaces)
- Fast (100K. points/sec) and high-density data
- Simple data acquisition
- Ranges up to 1000m (depending on TLS type).
- Field of view (FOV) 360o
- Combination with other devices (e.g. GPS, external cameras)

while the following can be considered disadvantages:
- Requires technical knowledge for data processing
- (Still) relatively expensive
- Heavy/ bulky

One urban and one suburban intersection were selected for the application. The criteria for the selection of the urban intersection included the reduced sight visibility due to road geometry, obstructions from buildings, vehicles and plants, reduced visibility in the secondary approaches, suboptimal pavement surface, high traffic flows and known high occurrence of traffic accidents.

The fieldwork included initially surveying measurements to establish the reference coordinate system of all the data and to georeference the TLS measurements. For this purpose, a control traverse network was established around the intersection and measured with accuracy at the centimeter level, using the total station Topcon IS-203. Then followed the scanning of both intersections in order to create the 3D models as well as ground plans and sections. A total number of 3 scans for the urban intersection and 2 for the suburban intersection were acquired using the scanner Leica Scanstation 2. The specific scanner has a measurement range of 5-350m and a quoted accuracy of 6mm. The TLS was set up over known points of the established traverse and the scanning resolution was set up to 1cm. Finally, the imaging total station was used to capture photographic images along with grid scanning functionality for the defined areas in the same way a scanning is performed. At the two selected intersections, the Topcon IS 203 total station was used with various resolutions (from 5 to 30cm) depending on the extent of the scan. The main aim of this experiment was to compare the scanning products of the laser scanner and the imaging total station.

5. DEVELOPMENT OF THE 3D MODEL

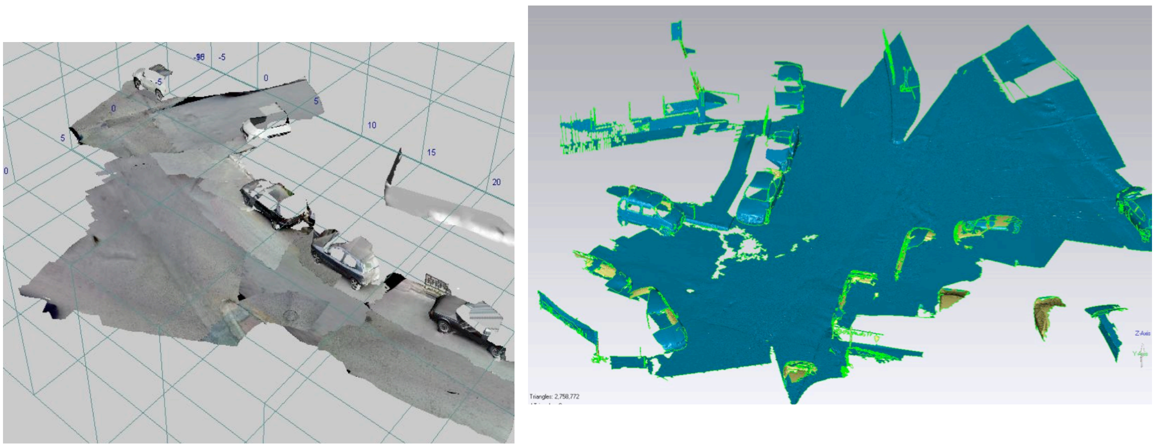
Due to visibility constrains from single laser scanner acquisition, it is often necessary to combine multiple overlapping point clouds into a single data set to fully cover the object being surveyed. This procedure is usually referred to as "registration" and involves determination of the transformation parameters between the local coordinate systems of the point clouds such that all can be transformed into a common coordinate system. This procedure is performed when at least three common points can be identified on the overlapping area. The common practice is to use signalised targets placed at selected locations on the surface of the objects to be scanned and estimate their coordinates either using the terrestrial laser scanner or an external total station instrument. This is due to the fact that the registration algorithms used in proprietary laser scanner software recognise the special targets automatically and with the aid of external surveying measurements they perform a rigid body transformation in order to convert all scans into a common coordinate system.

However, in many applications related to scanning inaccessible objects in high automation, the registration process must be performed without using signalised targets. The automatic registration of point clouds without the use of targets is an active area of research. The majority of commercial software that deals with point cloud registration tries to achieve correspondence between two clouds through local search algorithms, e.g. Besl and McKay (1992), which works well if good a priori alignment is provided, otherwise it may not converge. In this work, a methodology for registering overlapping point clouds without the use of targets but with the use of external information, has been implemented which has been developed by Tournas and Tsakiri (2007). For this purpose, a sufficient number of common points located in the overlapping area are used. These points are identified automatically on photographic images taken during laser scanner data acquisition from a high resolution CCD camera.

The processing of the various scan clouds collected from various sensor positions requires the use of a common reference coordinate system, i.e. geometric alignment or georeferencing. In this project the reference system was defined by the total station measurements whereby geodetic control information was transferred onto the special targets. The georeferencing of the laser scanner data was achieved at an accuracy of 0.01m. With TLS data, registration and georeferencing are usually carried out in a combined procedure. Prior to registration, noise reduction of the data was performed to ensure the registration is performed with good accuracy. The final step was the creation of the mesh and 3D model, which were then used to perform the road surface and road visibility analysis.

The data from the imaging total station required a different processing. The individual digital images that were recorded contextually with the scan in the field have to be aligned. This is performed by ensuring that the model's surface points are identified and made to correspond with the same ones on the images. In this way a point cloud is created, where every pixel of the image is associated with a numeric value and colour. The following step was the creation of the orthoimagery. This is performed by selecting the point cloud that represents the image and converting it into a mesh (grid of triangles), which corresponds to the surface of the object. The projection of the image onto the surface of the façade using appropriate photogrammetric software produces the orthoimage which then is used to perform the road surface and visibility analysis.

An example about the difference in the immediate digital products that can be obtained using the two different instruments is shown in Figure 1. Specifically, in Figure 1(a) a view from the orthoimage model of the intersection using the digital images and scanning of the total station is shown. On the other hand, the 3D model of the same intersection part using only the point cloud data from the laser scanner is shown in Figure 1(b). Figure 2 shows a detail showing the level of granularity obtained by the final 3D model from the laser scanner.



(a) (b)

Fig. 1. Examples of the data products

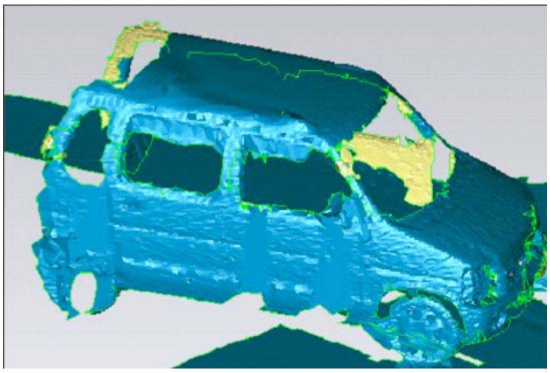


Fig. 2. Detail of the 3D model showing the obtained level of granularity

With the 3D models created as discussed above, it is possible to have also an infinite number of two-dimensional projective models (plans, sections and elevations), which are not dependent on the viewpoints established a priori. The possibility of having available the total coverage of a road intersection, changes the very idea of a survey and its scale of reference. For example, visibility analysis can be performed using either the 3D derived models or the 2D models in a CAD environment.. In the example shown below, the point cloud data acquired from the intersection (Fig.3a) are processed as explained in section 3, to produced the 3D model (Fig. 3b). This model can be used to extract any type of information such as road geometry, 2D plans, or perform visibility analysis using proprietary software for point cloud processing (Fig. 3c).

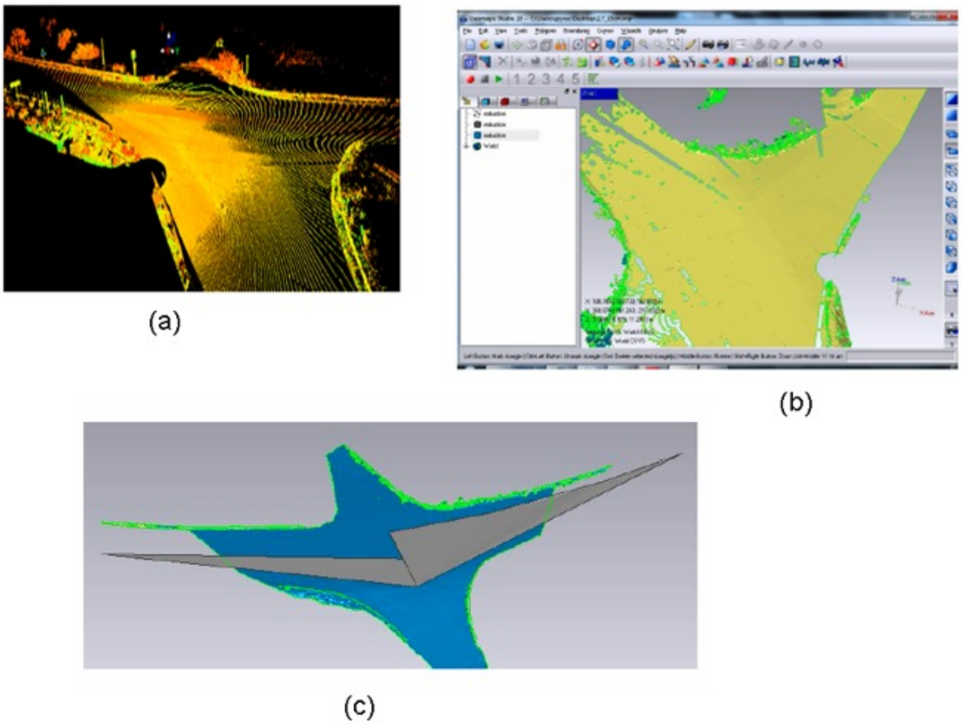


Fig. 3 Example of data processing from the point cloud to the visibility analysis

6. DISCUSSION AND CONCLUSION

3D laser scanning is a powerful tool, which can have several applications in highway engineering and design. The ability to construct a highly detailed model of the infrastructure at its actual current state is valuable as it can be used to monitor its condition. This can be particularly relevant in specialized structures, such as bridges and tunnels, but also in the remaining of the roadway, as it can provide an accurate means for the monitoring of the evolution of the physical structures (e.g. barriers) and plants. Pavement condition monitoring is another interesting field, since not only is one thus able to assess the quality of the pavement, e.g. via monitoring of the cracks and level changes, but one is able to construct a complete 3D model that could be useful in determining e.g. where water might be deposited, potentially resulting in dangerous situations such as aquaplaning.

3D laser scanning technology can be very useful in in-depth accident investigation, assisting not only the detailed identification of accident causes but also the design of the appropriate countermeasures. The development of practical, quick and reliable 3D models for each intersection through the techniques presented in this research, it becomes practical to take into consideration all possible particularities of setting, context, and implementation features of a specific junction that may produce results with varying degrees of difference. Thus, the use of 3D laser scanning technology in junction analysis, including in-depth accident investigation, on a case-specific basis will allow the detailed identification of accident causes and respective countermeasures but also the subsequent monitoring and optimization of the effects of these measures in different intersections. This would actually make it much easier to transfer knowledge and expertise from other regions or countries, by taking into account the extent of the implementation, the implementation period, and specific national or local requirements.

Finally, accurate 3D models would allow the examination of the combined effect of geometric and traffic control treatments at junctions. An even increased effectiveness would be expected, as a result of the combination of two cost-effective treatments. The existence of a 3D model would allow the designers to design in three dimensions all the possible considered treatments (even converting a junction to a roundabout or an interchange, Amundsen and Elvik, 2004, De Brabander and Vereecka, 2007) and be able to drive through the new layout (using available 3D techniques). This would not only allow the designers and planners to assess the feasibility and possible constraints of the new layout, but it would also allow the drivers to experience the new layout with striking accuracy, thus also allowing human factor assessments of the new layout prior to its construction.

While it is recognized that mobile mapping is the emerging and most promising technology that offers many more capabilities and features, the presented tools are affordable and accessible and cover the requirements of the static applications presented in this research. Using mobile mapping for these applications would not only be inefficient use of the expensive equipment, but could also lead to an overwhelming amount of data with the associated data management implications and difficulties.

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