Articles

Virtual reconstruction in traffic: a review of techniques

Reconstrucción virtual en materia de tránsito: una revisión de técnicas

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ABSTRACT

Virtual reconstruction of traffic scenes is an increasingly useful tool for investigators and experts in the field. It allows investigators to obtain a clearer picture of the events surrounding a traffic accident, allowing for a more accurate assessment of the data and a better understanding of accident mechanisms. This qualitative research under a systematic review presents the techniques and methods of virtual reconstruction in traffic that have been developed in recent years. As a result, eight articles published between 2020 and 2023 that are part of high impact repositories were obtained. It is concluded that virtual reconstruction technology for the analysis of traffic accident situations continues to make progress.

Keywords: Virtual reconstruction, forensic techniques, accident analysis, 3d reconstructions, reconstruction technology.

RESUMEN

La reconstrucción virtual de escenas de tránsito es una herramienta cada vez más útil para los investigadores y expertos en el campo. Permite a los investigadores obtener una imagen más clara de los hechos que rodearon un accidente de tránsito, lo que permite una evaluación más precisa de los datos y una mejor comprensión de los mecanismos de accidentes. Esta investigación de corte cualitativo bajo una revisión sistemática presenta las

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técnicas y métodos de reconstrucción virtual en materia de tránsito que se han desarrollado en los últimos años. Como resultado se obtuvo ocho artículos publicados entre el 2020 y 2023 que son parte de repositorios de alto impacto. Se concluye que la tecnología de reconstrucción virtual para el análisis de situaciones de accidentes de tránsito sigue teniendo avances.
Palabras clave: Reconstrucción virtual, técnicas forenses, análisis accidentes, reconstrucciones 3d, tecnología de reconstrucción.

INTRODUCTION

Road traffic accidents are one of the leading causes of death and injury in the world. Recent statistics show that more than 1.35 million people die each year in road traffic crashes, and between 20 to 50 million are injured or disabled, moreover, this figure has increased significantly in recent years. (World Health Organization (WHO), 2018).. In Ecuador, in the year 2021, 2131 people were killed and 17 532 injured in traffic accidents, which represents an increase of 33, 9 % and 33.8 % respectively compared to 2020. The number of traffic accidents in Ecuador is worrisome, especially because of the number of human lives lost as a result of these accidents. This situation has become a social problem for various reasons (Saltos Salgado et al., 2005).(Saltos Salgado et al., 2020).

In the report published by INEC (2022) on traffic accidents details the most common causes, where the driver's carelessness and recklessness with 43.5% is the main cause, followed by disrespect for traffic signs with 21%, speeding with 14.3%, drunkenness or drug use with 8%, pedestrian recklessness with 4.6% and other causes with 8.8%.

In addition, violators of the Organic Law of Land and Roads in Ecuador receive sanctions, but this does not prevent the occurrence of these acts. This is due to the lack of responsibility of those involved. As an example, Article 106 of the same Law determines that "traffic infractions are those actions or omissions that, being able and should be foreseen, but not wanted by the cause, are verified due to negligence, imprudence, or inexperience, or due to non-observance of the laws, regulations, resolutions and other traffic regulations" (Asamblea Nacional Constituyente, Asamblea Nacional Constituyente, 2001). (National Constituent Assembly, 2008).

Therefore, in any traffic accident it is important to determine the cause and responsibility for an accident, which is possible through forensic techniques because they allow determining the speed of the vehicles involved, the direction of travel, the location of the impact, any damage to the vehicle, evidence of reckless driving, and any other relevant information to determine the cause of the accident.

In addition, accidents include the collection and analysis of physical evidence, the collection and analysis of tire tracks, pavement marks, vehicle damage, steering and speed tests, alcohol or drug tests, and other relevant tests. Once the physical evidence

is collected, forensic experts conduct an analysis to determine the cause of the accident. This involves observation of the physical evidence, flight line of objects related to the accident, accident reconstruction, and vehicle trajectory reconstruction. The analysis also involves studies of the braking and acceleration patterns of the vehicles involved. They also collect and analyze documentary evidence. This evidence contains police reports, witness reports, statements, ticket tickets, vehicle maintenance records, information on the condition of the vehicles before the accident, and other documents related to the accident to determine cause and liability.(Montes Loaiza et al., 2013; Tian et al., 2010).In the same sense, Rodriguez (2017), states that there are major deficiencies in the technical documentation related to the investigation and reconstruction of traffic accidents and other forms of violent death.

With the advancement of technology it has been possible for forensic science to take steps for the benefit of the investigation and in order to present evidence based on information and communication technologies. Thus, this research presents a systematic review of ICT-based methodologies and tools in traffic forensics developed in the last decade.

MATERIALS AND METHODS

This research was based on the report of (Kitchenham, 2004) to conduct a systematic review of the literature on methodologies and ICT techniques used for traffic accident reconstruction to identify, evaluate and interpret all available relevant documentation. A source selection strategy with inclusion and exclusion criteria was carried out, as well as a predefined search to process all research related to the research question. This made it possible to obtain and evaluate the available evidence to arrive at a synthesized result.

The following research question was posed: What are the methodologies or techniques available for the reconstruction of traffic accidents based on virtual technologies?

The next step was to determine the sources of information search, considering the importance of reliable and relevant research, the use of academic articles, academic congress reports found in the repositories of Science direct and Scielo was determined. In relation to the search strategy, the keywords and terms used were "traffic reconstruction", "crash reconstruction", "virtual methods accidents", "digital techiques accidents", "traffic accident reconstructions", "3d traffic accidents". The temporality of the articles was delimited between publications and preprints from the year 2020, and articles written in English, considering that this is the language in which the journals with the greatest impact publish on the subject.

Once the documents were obtained, the abstract was reviewed for agreement with the research objective and the title search string "accident or techniques" was applied to the terms.

Inclusion criteria

Articles and conference reports published from 2020 to 2023.

Articles found in Scopus.

Open access documents.
Research and review articles.
Exlusion criteria
Articles and short communications.
Gray literature.
An article was only selected if it was found in more than one database.
Slides and books.

Table 1: *Number of studies with search criteria*

	No filters	Refined search	Search string/items.	Aligned to the objective/summary
traffic reconstruction	2214	473	86	8
crash reconstruction	455	133	45	7
virtual methods traffic	1755	540	22	11
			TOTAL	26

Source: Researchers, 2023

Twenty-six articles were obtained, which were subjected to a more extensive reading by the researchers and finally eight studies were selected that provide relevant information for this research. The results and conclusions of the documents were read in order to discover how these researchers have approached the topic of investigation and the solutions or points of view that they disseminate. Table 2 presents the articles analyzed.

Table 2: *Detail of selected articles*

Title	Authors	Magazine or main base
Using the scanners and drone for comparison of point cloud accuracy at traffic accident analysis.	**(Kamnik et al., 2020)**	**Accident Analysis & Prevention**
Method for automated generation of road accident scene sketch based on data from mobile device camera	**(Saveliev et al., 2020).**	**Proceed to**

Usage of Digital Evidence in the Technical Analysis of Traffic Collisions	**(Malinová et al., 2021).**	**Transportation Research Procedia**
Application of Close-Range Photogrammetry in Documenting the Location of an Accident	**(Stehel et al., 2021).**	**14th International scientific conference on sustainable, modern and safe transpor**
Data-driven online traffic reconstructions: Interactively optimizing in virtual reality	(Wang et al., 2022)	*Computers & Graphics*
Using the iPhone's LiDAR technology to capture 3D forensic data at crime and crash scenes	(Kottner et al., 2023).	*Forensic Imaging*
A feed-forwarded neural network-based variational Bayesian learning approach for forensic analysis of traffic accident.	(Xie et al., 2022).	*Computer Methods in Applied Mechanics and Engineering*,
Circuits, Systems, Communications and Computers (CSCC), International Conference on	(Sevcik et al., 2023).	Circuits, Systems, Communications and Computers (CSCC), International Conference on

RESULTS

The eight selected papers were re-read taking into consideration how they answer the research question. In the first paper that is part of this review it was determined that the authors sought to test whether sketches obtained from different 3D point clouds can be produced faster and more accurately than sketches obtained from classical police measurements. To do so, they compared classical police work and sketching with terrestrial laser scanners Riegl VZ-400i, Faro Focus S70, Geoslam ZebRevo 3D and data collection from a Topcon Falcon 8 drone, all of which were used for 3D modeling and sketching. They compared the accuracy using a graphical approach. For the subsequent visual inspection of the traffic accident scene, the most suitable source is an orthophoto obtained using the Surface from Motion (SfM) method, which is the result of processing a series of georeferenced photographs taken from the UAV. They conclude that the digital data provides the opportunity for a second look at the accident scene, whether it is a quiet street or a busy road. The use of an accurate 3D representation of the scene, such as a compilation of the crash data, can be helpful in addressing questions and doubts that arise. This also provides the option to import directly into crash simulation tools, such as PC-Crash or Analyser PR. (Kamnik et al., 2020)

Thus, for the authors Saveliev et al. (2020) describe in their study that despite government efforts to reduce the road fatality rate, road traffic accidents still occur frequently and that accident scene sketches are performed manually in most countries, which affects the quality and quantity of data collected. This poor quality of sketches contributes to the return of cases for investigation. To improve this situation, the use of an automatic RTA scene sketch generation system using mobile devices is proposed. This will enable traffic officers to perform their work faster and more efficiently, increase the accuracy and precision of traffic accident registration, and eliminate the subjectivity of data presentation. The proposed method requires only a mobile device with a camera to operate, which automatically generates sketches of road scenes. The process consists of video recording vehicles and surrounding environments with a mobile device; building maps and reconstructing the camera path using the SLAM method; reconstructing the 3D scene and classifying objects with convolutional neural networks; calibrating the scale of the generated 3D scene and sizing the location of other objects; converting the 3D model into a 2D RTA scene sketch. The developed system provides users with recommendations on how to record video from different angles to capture all required components, including the relative location of vehicles and static objects, vehicle damage and surroundings within a 10 m radius. The video collected by the user will be compressed on a mobile device and sent to a cloud for further processing. To generate ATR scene sketches in an automated manner, we consider the basic stages of video processing.

The ORB SLAM2 algorithm that is used offers faster initialization and operation, higher model quality, and open source. It converts the video recorded by the user into a sequence of frames, identifying features (key points) in each frame and positioning them in a 3D space. The algorithm also generates an unoriented weighted visibility graph using the keypoints and frames (Saveliev et al., 2020)

In the following research published by Malinová et al. (2021) they state that there are 3 ways to get data from the ECU: the first uses regular diagnostic tools, the second uses the CDR (Crash Data Retrieval) system and the third uses the GIT Tool co. system. Using diagnostic tools, maintenance and service related data can be read through the OBD / OBD II socket. These records, known as freeze frame data, can be very useful for accident analysis, although they are usually encrypted and only accessible to car manufacturers. Thus, with this background, the authors state that the use of CDR (Crash Data Retrieval) extracts and decodes the information stored in

The CDR system allows to extract and decode the information stored in the ACM (Airbag Control Module). And that the data once downloaded can record up to 5 seconds before and after the accident, in addition to data on the speed difference, engine speed, whether braking is taking place, the ignition cycle at the time of the collision, the state of the seat belt and the state of the airbag. In addition, they specify that the data must be stored securely to prevent tampering and be available to national authorities for accident analysis. It must also be possible to accurately collect the model, version and variation of the vehicle, as well as the active safety and accident prevention systems

installed in the vehicle. The authors conclude that 15-20% of EDR (Event Data Recorder) equipped cars are on the roads of the European Union and that these vehicles leave behind digital evidence after an accident, which can be evaluated like any other forensic evidence. The CDR (Crash Data Recorder) system allows the police, experts and forensic scientists to do a thorough job. This tool is capable of recording 5 seconds before a crash, the moment of the collision and another 2 seconds of displacement, which provides an objective reconstruction of accidents(Malinová et al., 2021)..

Another technique presented in this research is the use of short range photogrammetry where the position of the camera is generally stationary, placed on the ground and used for objects ranging in size from 0.5 m to 200 m. This technique is based on the creation of a point cloud in space where one condition is that all light rays should be at the same point on the measured object without appreciable scattering. In addition, it is essential to evaluate the lighting conditions at the accident site to ensure the quality of the images and documentation obtained. Direct sunlight and lack of visibility without the use of lighting equipment can cause degraded results of the site documentation. In so far as under the accident analyzed by (Stehel et al., 2021) which had adverse conditions the result obtained was inaccurate due to insufficient illumination of the scene and, consequently, difficult triangulation of the points in the captured images because they were not identifiable in sufficient number in the individual images.

The authors of the research entitled "Data-driven online traffic reconstructions: Interactively optimizing in virtual reality", proposed in their paper a 3D online traffic reconstruction method based on video data and traffic simulations. The method consisted of two parts: data preprocessing to obtain structured vehicle trajectories and trajectory reconstruction to obtain complete and smooth vehicle trajectories. Specifically, they first used the online MOT method to extract the vehicle trajectories from the videos and transform them to the geodetic coordinate system using an inverse projection transformation (IPP). Second, they introduced a traffic simulation method to predict the vehicle trajectories and implemented the Kalman filter to optimize the vehicle trajectories according to the extracted trajectories and the predicted trajectories. Then, they iteratively optimized the traffic simulation parameters based on the optimized trajectories using the Covariance Matrix Adaptive Evolutionary Strategies of Adaptation (CMA-ES) algorithm when needed(Wang et al., 2022).

The following published paper aimed to evaluate the use of Recon-3D through example scenarios to determine if this technology could be applied to record incident or crime situations. The researchers used an iPhone 13 Pro along with the Recon-3D application to record two indoor environments, a simulated crime situation and a garage, and an external one of a parked car. Each location was captured multiple times and they concluded that Recon-3D for iOS, which is equipped with Apple's latest LiDAR technology, offers a simple and fast workflow for documenting in 3D with an iPhone or iPad. Results from three test scenarios show that the imaging process is very straightforward and allows forensic investigators or police officers to document a crime

or accident within minutes. While more validation studies are needed, Recon-3D appears to be a useful application for forensic pathologists(Kottner et al., 2023). A published paper that, while not specifically describing a 3D reconstruction method or technique, focuses on the development of an algorithm that vastly improves the computation for 3D reconstructions. The researchers developed a computational algorithm based on variational Bayesian learning that allowed them to inversely identify the deformation field of a crashed car, calculate the residual deformation fields from the final damaged structural configuration, and evaluate the strength of the crashed vehicles. This technique allowed for greater computational efficiency by reducing the number of iterations and improving the accuracy of the registration results, since the location of the nodes was largely maintained during the registration process. These unique features of the developed machine learning algorithm were found to be essential for forensic analysis of traffic accidents and strength assessment of crashed vehicles(Xie et al., 2022).. With respect to their perspective they state that for 3D reconstruction under a sophisticated approach to crime scene documentation and in-depth forensic analysis the quality of the results is strictly dependent on the source data, thus they propose an evaluation triangle to assess the applicability of the method where they identify the feasibility, critical requirements and individual factors for 3D reconstruction of crime scenes. They further focus their proposal on an evaluation methodology that makes use of the feasibility identification and evaluation triangle to address the existing dependency. They presented a crime scene in a virtual reality workflow to show the connection between the process and the individuals(Sevcik et al., 2023).

DISCUSSION

The first conclusion presented by this research is based on the methodology applied for this systematic review, where the choice of the source of information allowed an approach to everything that researchers have developed in recent years with respect to crime scene reconstructions and provides a clear perspective on the subject and its progress, especially in the European Union and the Asian continent, which have published the most information. However, despite this, it is important to emphasize the use of the resources as part of prototypes that can be used and are expected to be adopted in research after being perfected and improved with the support of public and private institutions.

As a second conclusion, traffic accident reconstruction technology has the potential to significantly improve road safety. This technology has proven to be a useful tool for recreating and analyzing the events surrounding a traffic accident, allowing traffic authorities and investigators to better understand how accidents occurred and help prevent future incidents. Technological advances also allow investigators to track vehicle information, better understand impact dynamics, and obtain high-quality images for better results. This contributes to a better understanding of traffic accidents and helps develop better prevention methods.

Finally, technology for traffic accident reconstruction also offers the possibility of improving road safety through accident prevention. This is achieved through the use of sensors, driver assistance devices and warning systems. These devices can detect warning signs and alert the driver before an accident occurs. This helps prevent accidents by reducing vehicle speed, providing greater road user awareness, and ensuring greater safety for all road users. Traffic accident reconstruction technology also helps improve road safety by collecting data for informed decision making and improved traffic signaling.

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