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3D Computer Vision and Wireless Sensor Applications in an Experimental Study on Electric Vehicle Driving in Roundabout Negotiation Scenarios

David González-Ortega[1*], Helen Scott[2], Francisco Javier Díaz-Pernas[1], Mike Knowles[3]
[1]*Department of Signal Theory, Communications, and Telematics Engineering,*
School of Telecommunications Engineering, University of Valladolid, Valladolid, Spain
[2]*Institute for Automotive and Manufacturing Advanced Practice (AMAP)*
University of Sunderland, Sunderland, UK
[3]*Department of Computing, Engineering and Technology (CET)*
University of Sunderland, Sunderland, UK
[*]*Corresponding author, Email: davgon@tel.uva.es*

Abstract

In this paper, a 3D computer vision application and a wireless sensor application are presented. They were used in an experimental study on electric vehicle driving to analyse the influence of age on driving style in roundabout scenarios. The 3D computer vision application uses the Kinect device to achieve face tracking of the driver. From the pith, roll and yaw angles of the face, the gaze can be estimated. Thus in each processed image, the region, from the predefined ROIs, where the driver is gazing at can be estimated. Gaze patterns and transitions in driving situations, particularly while negotiating roundabouts, can be determined. The wireless sensor application uses the gyroscope included in a 9DoF (Degrees of Freedom) sensor from the Shimmer platform. The gyroscope was placed on the steering wheel. The signal corresponding to the turn axis of the steering wheel is obtained so that the direction and speed of any turn can be detected. Besides, the heart rate was monitored and the electric car used in the experiments was equipped with an extensive telemetry system. 28 people took part in the experiments. They drove on the same 13-kilometer on-road route in Sunderland (UK) using a Smart Fortwo electric vehicle and on a route with a Forum 8 driving simulator. Only a brief description of the experiments is included. Results and analysis will be presented in the future. Experimental studies with electric cars are needed to support their progressive penetration in the market.

Keywords: EV(electric vehicle), safety, simulation

1 Introduction

Electric vehicles (EVs) are increasing their presence on the road in the last years. Governments worldwide are eager to see increasing penetrations of EVs due to the environmental, economic, and energy security benefits generated by these vehicles. Demand is increasing among both fleet operators and consumers. It is estimated that by 2045, the combined number of Plug-in Hybrid electric vehicles (PHEVs) and electric vehicles (EVs) on the road will be 49.5 Million [1]. The range of most fully EVs is limited compared to that of conventionally fuelled equivalents, being in the region of 90 miles in most instances. However, little is known about driving style, combined driver-vehicle characteristics, and their effect on EV range performance, particularly in the absence of the requirement to manually select gears, the added dimension of regenerative braking within the driving task, and the requirement to process additional information from in-vehicle range indicators and real-time feedback on regenerative braking performance [2]. Driving style has been shown to have a major impact on the fuel efficiency of conventional internal combustion engine (ICE) powered vehicles. Unlike the wealth of evidence present in literature demonstrating clear social and economic benefits to modifying elements of driving style when driving ICE vehicles, there has been a lack of research about the impact of specific aspects of driving style for power consumption in EVs. Drivers' problems at junctions have been largely studied [3]. Both drivers and young novice drivers have more problems negotiating road junctions. Unlike research about junctions in general, there have been few studies about roundabout negotiation although roundabouts are increasingly presents in roads all over the world as they have replaced traditional four-legged intersections to decrease traffic congestion and accidents [4].

A 3D Kinect-based computer vision application was developed to monitor driver attention. It uses the Kinect device and the Kinect SDK for Windows [5]. Kinect gives rise to applications robust to drastic illumination and environmental changes that can be present in real driving conditions without compromising computation performance. The Kinect device is placed in a car's dashboard in front of the driver. Thus the application achieves face tracking through the extraction of a large number of facial points. From this tracking, gaze estimation of the driver can be obtained.

Another application was developed to obtain and record data from a wireless gyroscope placed on the steering wheel of a car to obtain its angular speed. Besides, the heart rate (HR) monitoring was recorded using an off-the-shelf Polar HR monitor placed around the chest of the driver. HR is important as it is related to the physical state of a person.

With these applications together with and a telemetry system included in a Smart Fortwo electric vehicle, an experimental study was conducted with a view to analysing the effects of age-related driving style on electric vehicle performance in roundabout negotiation scenarios. The experiments were carried out in a Smart Fortwo electric vehicle, a Forum 8 driving simulator, and the car of some of the participants in the study.

The rest of the paper is organised as follows. In Section 2, the 3D Kinect-based computer vision application is explained. Section 3 presents the developed wireless sensor application. The experimental study is briefly presented in Section 4. Finally, Section 5 draws the main conclusions about the work.

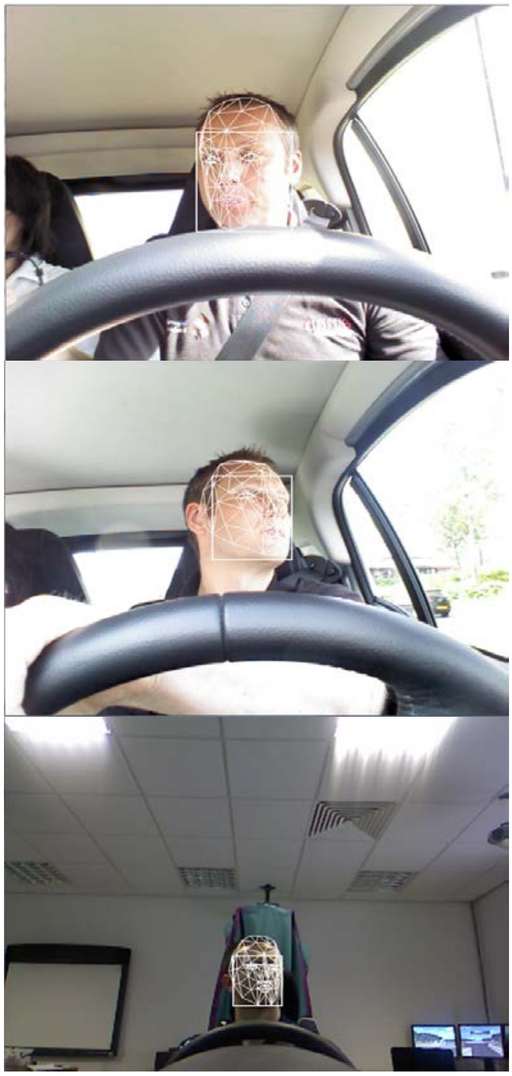
2 3D Kinect-based Computer Vision Application

Computer vision-based human body detection and tracking has required intrusive and cumbersome suits or markers in the past. The adopted capture devices determine the complexity and constraints of the image processing algorithms applied to accomplish detection and tracking. Regarding 2D cameras, occlusions between human body parts, range of motions, and drastic illumination and environmental changes are problems difficult to solve.

These problems can be approached with a capture device that provides depth information. For instance, binocular cameras [6] or multi-camera systems [7] have been proposed. The TOF (Time of Flight) cameras are another type of depth cameras. They use an infrared light beam to illuminate the scene and then they measure the phase lag between the waves sent by the transmitter to the receiver device. Although TOF cameras are very precise, they require complex hardware, are expensive, and provide a low resolution, e.g. depth image can have a resolution of 176x144. As a low-cost alternative, the Kinect sensor add-on for the Xbox 360 video game platform emerged at the end of 2010. It includes a structured light camera with a conventional RGB camera that can be calibrated to the same reference frame. The Kinect device interprets the 3D information of the scene obtained through infrared structured light that is read by a standard CMOS sensor. It was designed to enable users to interact with the Xbox 360 gaming system without needing a traditional hand held controller. Instead, the sensor can recognize the user's gestures.

Although the Kinect device was developed as an add-on for the Xbox 360 platform, it can be connected to a PC via a USB port. Initially, Microsoft did not launch official drivers to use the Kinect device with a PC. Some libraries were developed to make the most of the functionalities of Kinect shortly after. Eventually, Microsoft launched a Kinect software development kit in June 2011. Since its commercial launch, many developers and researchers have used the Kinect device in their work, in different areas, e.g. head-pose and facial expression tracking, hand gesture recognition, human activity recognition, and healthcare applications [8]. Schwarz et al. [9] presented a method for human body pose estimation using depth data extracted from the Kinect device and TOF cameras. The Kinect depth images lead to higher stability in landmark locations and more robustness to noise. Clark et al. [10] proved that Kinect can validly assess kinematic strategies of postural control. The use of the off-the-shelf Kinect device in diverse computer vision-based systems can have a great impact on many people, for instance people involved in rehabilitation tasks. Chang et al. applied it for the rehabilitation of two people with motor disabilities [11]. The human body motion capture is used to determine the correct and incorrect performance of exercises in physical rehabilitation. They concluded that the Kinect device can motivate physical rehabilitation. Lange et al. [12] developed a game to train reaching and weight shift to improve balance in adults with neurological injury using the Kinect device. Chang et al. [13] used Kinect in a system to facilitate task prompts needed by people with cognitive impairments. Kinect has also been used in other varied fields. Stone et al. [14] used it to monitor and report the gait of people in their homes during normal everyday activities. Dutta [15] studied the validity of the Kinect device to assess the postural control and concluded that it provides comparable data to a 3D motion analysis system during a commonly performed clinical test. Sanna et al. [16] presented Natural User Interface (NUI) based on the Kinect device that enables users to customize the association among gestures/postures with platform commands to choose the most intuitive and effective interface.

We developed a Kinect-based C++ application using the Kinect SDK for Windows to achieve face tracking. When a user is in front of the Kinect device, this application achieves face tracking through the extraction of a large number of points. If these points are joined forming triangles, the 3D facial mesh is built, as Figure 1 shows. The application tracks robustly the face in frontal and non-frontal positions.



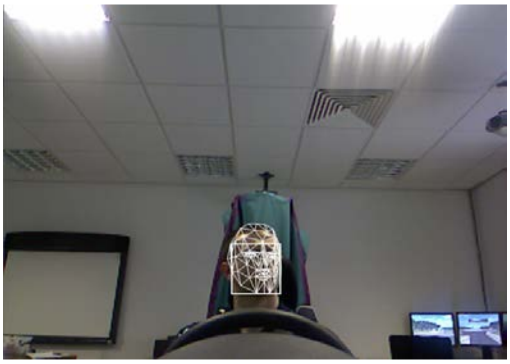


Figure 1: Face tracking achieved by the Kinect device in the Smart FortTwo EV and in the driving simulator.

With this information, the pitch, roll and yaw angles of the face are obtained. Then gaze can be estimated from the latter data [17]. From this estimation, the region of the predefined ROIs the driver is gazing at in each processed image can be obtained.

The application processes 10 frames of 640x480 pixels per second using a PC with an Intel dual core processor at 2.1GHz and 4GB of RAM, so the driver state monitoring is achieved in real time. Besides, for each execution of the application, the position of interesting facial points such as those from the eyes, nose, and mouth in each processed frame is stored in a file. An offline analysis of the driver state can be made with these data.

3 Wireless Sensor Application for Driving Monitoring

The fast development in hardware and wireless networks has provoked the emergence of small sensor devices that can obtain reliable data regardless time and place. On that point, assisted living technologies emerge to help people that need assistance in activities of daily living but wish to live independently as much as possible. Besides, the growth of Wireless Sensor Networks (WSN) in the last years has been very important due to the emergence of applications that demands the use of many nodes. In this regard, architectures for nodes in wireless sensor networks, which can be adjusted to different applications, have been proposed [18].

The development of physiological and kinematic sensors of small size, which do not bother the user, at an affordable price and reliable, facilitates their intensive use. For instance, inertial sensors can be used to monitor human body motions precisely [19]. For wearable applications, size and execution time have to be well balanced against other features. The approach adopted in the development of Shimmer^{TM} wireless sensor platform was to increase the application of sensor technology in healthcare by focusing on commercially feasible features valuable to engineering researchers, biomedical researchers, and clinicians. As a result, the Shimmer wireless platform has found users in leading universities and corporate research and development organizations all over the world [20]. The Shimmer platform comprises of a baseboard which provides the sensors computational, data storage, communications, and daughterboard connection capabilities. The core functionality of Shimmer is extended via a range of daughterboards which provide various kinematic, physiological, and ambient sensing capabilities. This range of contact and non-sensing capabilities can be reliably used both in clinical and in home-based research scenarios. Burns et al. [21] compared sensors of the Shimmer platform with known commercial systems. The Shimmer sensors provided reliable signals and compared well with the commercial systems. They concluded that low-cost, modularity, and small form factor of the Shimmer platform makes it an ideal option for monitoring applications. The platform provides flexibility in terms of data capture and storage as well. Besides, the sensor fusion can help reduce noise and guarantee certain level of robustness [22].

We developed an application that uses the 9DoF sensor from the Shimmer platform. It combines a gyroscope with a magnetometer to provide a powerful solution to the kinematics detection. The gyroscope measures the speed of the orientation changes with respect to the three axes. It obtains the angular speed, which can be useful for the driving monitoring. The LabVIEW tool was used to develop the application. LabVIEW (Laboratory Virtual Instrument Engineering Workbench) [23] is a design and development platform with a visual programming language from National Instruments. LabVIEW has rich GUI widgets and hardware drivers. Besides, LabVIEW is a graphic dataflow programming language based on virtual instruments (VIs), which are virtual representations of hardware equipment. We used the Shimmer library of LabVIEW to develop the application, especially the ShimmerECG virtual instrument (ShimmerECG.vi), which incorporates all the sensor functionalities and allows a configuration of their inputs and outputs.

The gyroscope is placed on the steering wheel of car in a place that does not bother the driver. The gyroscope signal corresponding to the turn axis of the steering wheel is obtained so that the direction of any turn can be detected. A position indicator of the steering wheel was included. A threshold has been fixed to distinguish between a turn due to a normal manoeuver and a sharp turn. The latter is characteristic of an unsafe driver state. The gyroscope signal is shown in the application and is store for offline processing. Figure 2 shows the gyroscope window of the application. It includes the orientation changes in the steering wheel axis, two buttons indicating the turn direction, the angular speed, the position of the steering wheel, and the time spent without changes in the position of the steering wheel.

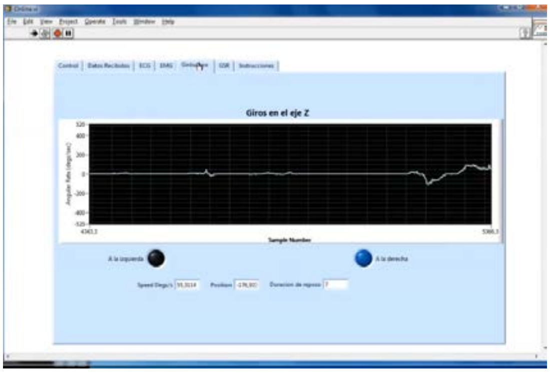


Figure 2: Gyroscope window of the wireless sensor application.

The heart rate (HR) monitoring was recorded using an off-the-shelf Polar HR monitor placed around the chest of the driver. HR is important as it is related to the physical state of a person. The Polar HR monitor has been used previously in other research studies [24].

4 Experimental Study

The two presented applications has been used in an experimental study on Electric Vehicle Driving in Roundabout Negotiation Scenarios to analyze the effects of age, years of full driving license, and average annual mileage on driving. 28 people took part in the trials. They drove on the same 13-kilometer on-road route in Sunderland (UK) using a Smart Fortwo electric vehicle and on a route with a Forum 8 driving simulator in the laboratories of AMAP (Institute for Automotive and Manufacturing Advanced Practice) in Sunderland. Figure 3 shows the position of the Kinect in the dashboard and the gyroscope on the steering wheel of the electric car and Figure 4 shows both in the driving simulator.

Figure 3: Kinect device and gyroscope inside a Smart Fortwo EV.

Figure 4: Kinect device and gyroscope in the driving simulator.

The mean time of the trials per person was about 2 and a half hours and included questionnaires before and after the routes together with training trials so that drivers were able to get used to the electric car and the simulator. As the electric car has automatic gears and most of the drivers had cars with manual gearbox, the training trials was necessary to obtain correct data during the recorded trials. The research was focused on analysing the drivers' behaviour while negotiating roundabouts. There are many roundabouts in all the different types of roads and driving style can have a big influence on the performance in routes with many roundabouts. That is especially important in electric cars due to the regenerative braking, which makes speed decrease turning the kinetic energy into electric energy, thus recharging the battery. The on-road route included three consecutive roundabouts in a section with one lane in each direction with a speed limit of 30 miles per hour (mph) (R1-30, R2-30, and R3-30 in Figure 5) and another three consecutive roundabouts in a section with two lanes in each direction with a speed limit of 70 mph (R1-70, R2-70, and R3-70 in Figure 5).

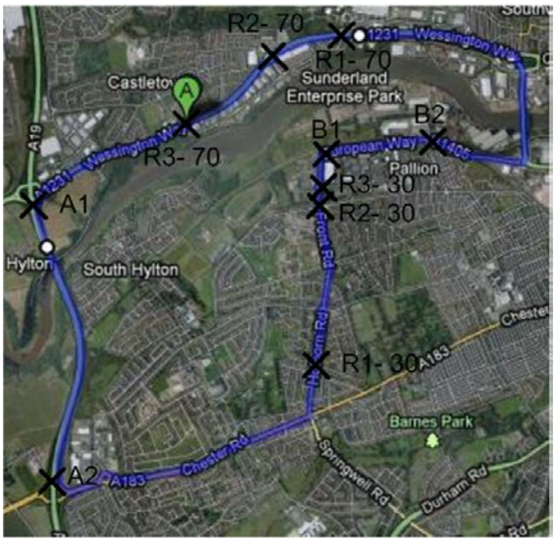


Figure 5: On-road route of the experimental study in Sunderland.

The simulator route was designed as similar as possible to the on-road route with three consecutive roundabouts with a speed limit of 30 mph and three consecutive roundabouts with a speed limit of 70 mph. Besides, the simulator was configured to have a behaviour typical of an electric car. During the routes, a hundred facial points were extracted using the Kinect-based application with a processing rate of 15 fps to achieve driver's face tracking. With this tracking, the time spent by the driver looking at the different regions of interest (ROIs) together with the transitions between them can be estimated. These ROIs for the Smart EV were: (1) straight ahead, (2) instrument panel (speedo), (3) charge level and energy status gauge dials, (4) rear-view mirror, (5) left half of the windscreen, (6) left mirror, (7) left door glass (excluding the left mirror), (8) the right part of the windscreen close to the right pillar, (9) right mirror, and (10) right door glass (excluding the right mirror), as Figure 6 shows. For the simulator, whose images were projected onto three big screens, the ROIs were: (1) straight ahead, (2) instrument panel, (3) Speedo (down right side of the front screen), (4) Rear-view mirror, (5) Left side of the front screen, (6) Left screen, (7) Right side of the front screen, (8) Right screen, as Figure 7 shows.

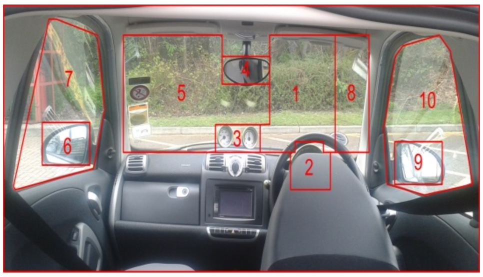


Figure 6: ROIs in the Smart FortTwo EV.

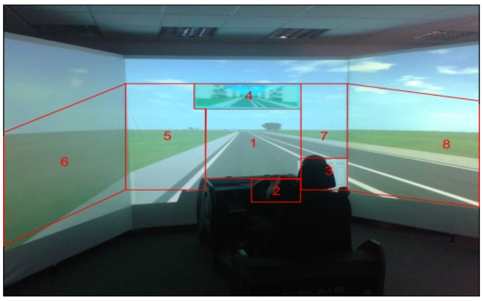


Figure 7: ROIs in the driving simulator.

The Smart EV was equipped with an extensive telemetry system. In addition to recording position, speed, and electrical parameter during driving, the data logger also records battery voltage and state of charge during charging cycles. New data were obtained each second while the car was in motion. The simulator was configured to obtain the same data than the Smart EV telemetry equipment.

A subset of 12 participants drove again on the same 13-kilometer on-road route in Sunderland but using their own car instead of the Smart Fortwo electric vehicle so that comparisons can be made between the data obtained in both routes. All the information has to be processed and analyse to extract relations and conclusions about the eye gaze pattern of the drivers, variations of HR, speed and driving styles in the routes, and in the roundabout negotiations.

5 Conclusions

Two applications have been presented in this paper. A 3D computer vision application makes it possible to monitor driver attention as gaze can be estimated while driving. Gaze patterns and transitions can be studied in driving situations such as roundabout negotiation scenarios. The wireless sensor application records the angular speed of the steering wheel, which is very interesting in the analysis of the driver behaviour. Besides, an extensive telemetry system was used to record position, speed, and electrical parameter and a HR monitor was used to record the heart rate of the driver. A profound analysis of the data has to be fulfilled to reach significant conclusions.

Experimental studies with electric cars such as the briefly presented in this paper are needed so that their performance, consumption, and security can be deeply analysed. If the environmental economic benefits of EVs are to be fully achieved, it is necessary that the reactions of their systems to different driving styles are understood. Thus driver training can be optimized alongside the continuing development of the technology.

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Authors

David González-Ortega received his M.S. and Ph.D. degrees in telecommunication engineering from the University of Valladolid, Spain, in 2002 and 2009, respectively. Since 2003 he has been a researcher in the Imaging and Telematics Group of the Department of Signal Theory, Communications and Telematics Engineering. From 2005 and 2009, he was an assistant professor and since 2010 he has been an associate professor in the School of Telecommunications Engineering, University of Valladolid. His research interests include computer vision, image analysis, pattern recognition, neural networks and real-time applications.

Helen Scott. Background – Psychology (MBPsS). Specific area of expertise – Age-related visual search in driving. Current position - Research Fellow/Lecturer in Engineering Human Factors, University of Sunderland. Current research activity - Human Factors in Low Carbon Vehicles, driver training and evaluation methods. Active member of the Low Carbon Vehicles Group within the Institute for Automotive and Manufacturing Advanced Practice (AMAP).

Francisco Javier Díaz-Pernas received the Ph.D. degree in Industrial Engineering from the University of Valladolid, Spain, in 1993. From 1988 to 1995, he joined the Department of System Engineering and Automatics, University of Valladolid, where he has worked in computer vision systems for industry applications as quality control for manufacturing. Since 1996 he has been a professor in the School of Telecommunications Engineering and a Senior Researcher in the Imaging and Telematics Group of the Department of Signal Theory, Communications and Telematics Engineering. His main research interests are applications on the Web, intelligent transportation systems, and neural networks for computer vision.

Dr Mike Knowles is a Senior Lecturer in Engineering at the University of Sunderland. He holds an MEng in Electronic and Electrical Engineering and a PhD in Computer Vision, both from the University of Birmingham. His research interests include Electric Vehicle Technology, Condition Monitoring, Video analysis in Automotive Applications and New Product Development. Dr Knowles is a Member of the Institution of Engineering and Technology and is a Chartered Engineer.