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Is stereo vision a suitable remote sensing approach for motorcycle safety? An analysis of LIDAR, RADAR, and machine vision technologies subjected to the dynamics of a tilting vehicle.

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Abstract

Tilting vehicles, such as electric bicycles, motorcycles, and scooters, are increasing in popularity as a means of personal transport. From a safety viewpoint, the development of Advanced Rider Assistance Systems (ARAS) for two-wheeled vehicles is lagging behind the Advanced Driver Assistance Systems (ADAS) for other road vehicles (e.g. autonomous emergency braking implemented for passenger cars and trucks). This study is the first analysis of three remote sensing technologies adopted by ADAS, such as RADAR, LIDAR and machine vision, but from a point of view significantly different to the used in the car industry. Essentially, the dynamics study of a four wheelers vehicle cannot be used because it does not take into account a tilting dynamics. Our findings indicate that the lack of technology transfer from ADAS to ARAS can be explained by sensor design considerations, which limiting the application of the existing automotive remote sensing approaches to tilting vehicles. We propose how to tackle these limitations in terms of both hardware and software, by presenting related experiments on a scooter.

Keywords: tilting vehicle; two-wheeler; ADAS; ARAS; stereo vision; machine vision; LIDAR; RADAR

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1. Introduction

Smart vehicles need to be able to interpret and predict the immediate future location of other vehicles and road users in the context of advanced safety systems and autonomous driving. The remote estimation of car pose and in particular its heading angle is key to predict its future location. This paper explain why automotive remote sensors are not currently used in vehicles that present a tilting dynamics behavior. Once identified the technical reasons of the safety gap between cars and motorcycles, we propose a solution based on a custom 3D perception system based in stereo vision only.

The use of artificial stereo vision systems allows to get the 3D information of a scene from a couple of 2D sensed projections of the same scene. The ground truth in this specific context is associated with referential information about the depth, shape and orientation of the objects present in the traffic scene. The creation of a 3D ground truth is a complex measurement and data fusion task that is typically obtained by combining of different kinds of sensors. More conveniently, we used a new method (Gil et al., 2017b) to generate ground truth car pose from the stereo video data, which enables the quantitative evaluation of machine vision solutions.

In our case-study, we focused on accurate car heading angle estimation of a moving car in real road environment. This allows us to deal with realistic imagery challenges for stereo vision systems like texture-less and non-lambertian surfaces (reflectance and transparency). Tests conducted are presented.

2. Motorcycle safety needs

In motorcycle several terms and acronyms are commonly used to identify sets of vehicles with given legal requirement or features associated with their dynamics behavior. For example, single-track vehicle, Powered Two-Wheeler (PTW), and Narrow Track Tilting Vehicle (NTTV) among others. In this paper we will use two expressions: motorcycles and tilting vehicles. The term “motorcycle” will refer to pedelecs (electric bicycles), mofas, moped, scooters and motorcycles, while “tilting vehicle” will add to “motorcycle” three- and four-wheeler vehicles characterized by tilting dynamics behavior. Another preliminary consideration deals with the expression “advanced safety systems”. In the car industry these are called Advanced Driver Assistance Systems (ADAS), whereas the motorcycle industry they are called Advanced Rider Assistance Systems (ARAS).

A previous motorcycle safety study (Gil et al., 2017a) analyzed a large traffic accident dataset (ISTAT, National crash database in Italy, period 2000-2012, >1,000,000 motorcycle crashes) to develop and test a methodology to estimate the effectiveness of several safety systems for motorcycles. Part of the data is summarized in Figure 1. One of the outcomes of the data analysis is that most of the motorcycle crashes occurred in clear visibility conditions. Therefore, ARASs can contribute to protect motorcycle riders without the need to operate in difficult visibility conditions, such us rainy, foggy, and snowy conditions.

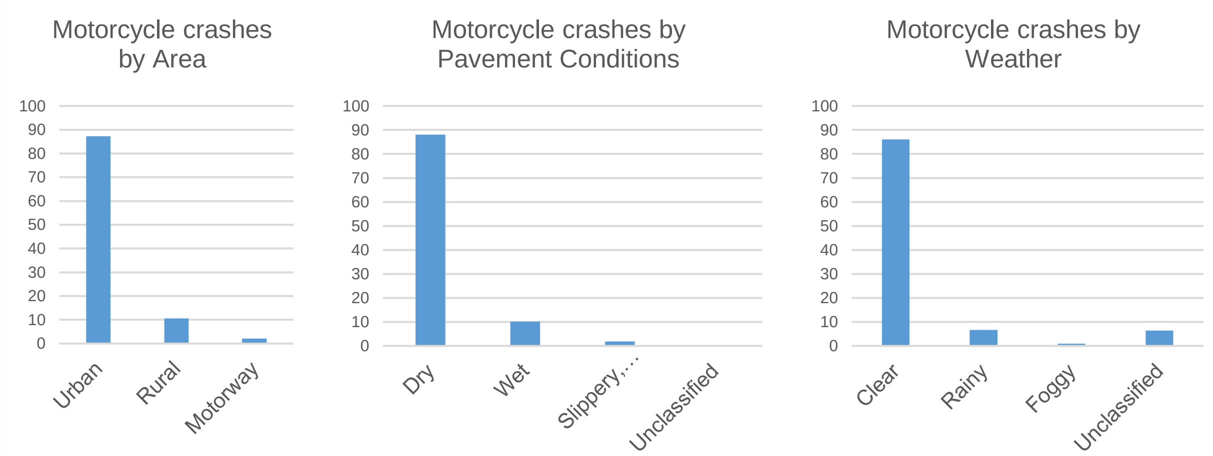


Figure 1. Circumstances of motorcycle crashes in Italy, more than 2 crashes every 15 minutes (percentages for the period 2000-2012). The left chart indicate where the crashes happened, totalizing more than 87% in urban areas. The center chart indicate the pavement conditions at the moment of the crashes, resulting in more than 88% over a dry street. The right cart present the weather at the moment of the crashes, indicating that more than 86% of the crashes occurred in clear visibility conditions.

For a more up-to-date insight, (Gil et al., 2017a) focused in the last three years of data (2010-2012), which comprise more than 200,000 motorcycle crashes. We use the information reported and the classification of crash scenarios proposed by the Knowledge-Based system of Motorcycle Safety (Appendix A - Gil et al., 2017a) to create Table 1. In this table we make explicit that more than 70% of motorcycle crashes in Italy took place from ahead of the motorcycles. Therefore, installing in the frontal part of motorcycles an artificial perception system for ARAS presents a great potential.

This finding justified our analysis of automotive remote sensing technologies employed for ADAS, in the perspective of possible applications to motorcycles and tilting vehicles. However, ADAS sensors would fail on tilting vehicles due to the large roll angles reached by the motorcycle, even in normal riding conditions, thus motivating the new approach proposed in this paper.

Table 1. Overview of motorcycle crash scenarios in Italy (period 2010-2012)

Scenario	Description	Crashes	Crash from ahead of the motorcycle
A	Intersection and angle collision	24.80%	Yes
H	Straight street and angle collision	12.16%	Yes
F	Rear-end collision	11.41%	Yes
C	Straight street and sideswipe collision	8.91%	Yes
B	Intersection and sideswipe collision	7.66%	Sometimes
D	Single-vehicle accident	7.35%	Sometimes
G	Hit obstacle + hit pedestrian	7.16%	Yes
E	Head-on collision	6.47%	Yes
I	Roundabout	4.67%	Sometimes
Z	Unclassified	9.41%	Unknown

3. Automotive remote sensing technology

Remote sensing sensors provide the inputs for artificial perception systems. Typically, camera sensors are reliable to identify objects or targets to look at, RADAR sensors provide targets velocities, and LIDAR sensors measures distance to targets. However, machine vision has allowed velocity and distance estimation from more than a decade ago but with limitations of robustness and accuracy.

These automotive technologies provide smart vehicles with information about their surroundings, e.g. to monitor safety gaps between vehicles or to detect imminent collisions and react consequently. Examples are in the form of warnings, to early alert the car driver about an action to be executed, or performing automatic actions even without human intervention, such as maintaining the vehicle position in the lane or executing an emergency stop.

Automotive remote sensing is based on powerful remote sensing technologies employed in earth observation from satellites, aeronautics and military applications. However, the high cost of these technologies do not allow for a massive adoption in vehicles to accomplish the safety tasks. This economic constraint originates a *de facto* standard of the automotive industry, in which safety devices must cost less than 100$ mass-produced to be considered for adoption. Manufacturers were forced to tailor remote sensing technologies to accomplish the minimal needs of the automotive application.

The tailored remote sensors of today's automotive industry have achieved a great maturity level. As expected, the high degree of tailoring of a sensor to fit in a specific application makes the sensor less flexible to be used in a different application. Therefore, the following analysis aims to assess whether these tailored sensors can operate properly under a vehicle dynamic (tilting dynamics) they were not specifically designed for.

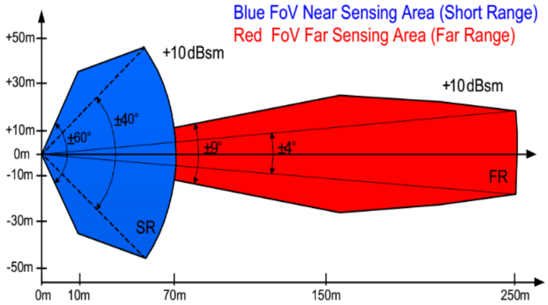
3.1. Automotive RADAR technology

RADAR (RAdio Detection And Ranging) is an object-detection system that uses radio waves to determine the distance (range) and the velocity of objects. For automotive applications in ADAS, two types of RADAR are available: Short-Range RADAR (SRR) and Long-Range RADAR (LRR). These are tailored to perform specific tasks. For example, SRRs handle the requirements of Blind-Spot Detection (BSD), Lane-Change Assist (LCA) and front/rear cross-traffic alert, whereas LRRs are responsible for Adaptive Cruise Control (ACC) and Autonomous Emergency Braking (AEB).

Advanced safety functions demand for accurate 3D object discrimination power in short and long range, that in RADAR terms translates in large Bandwidth (B). The European Union has defined the spectrum band of 79GHz (77-81GHz = 4GHz) as the most suitable for long term and permanent deployment of high resolution automotive RADARs (Verheugen, 2005). The 79GHz band offers significant benefits in terms of low power consumption, leading to a lower risk of mutual interference because of the smaller emission power required (Schneider, 2005), and lower the electromagnetics pollution in contexts of market saturation.

Valuable insights about the possibilities in terms of 3D discrimination by automotive RADARs in the 79GHz band were obtained experimentally. Experiments conducted from a static RADAR setup to static cars located 10m away (Andres et al., 2012), helped to define the maximum potential of the system in terms of discrimination from direct measurements. More recent experiments (Kellner et al., 2016), also realized from a static setup, achieved the tracking of a single moving car target turning 20 m away by combining the information measured with a math model which described the movement of a vehicle with Ackermann kinematics on a planar surface. This possibility to couple mathematical models with the sensor data, which is a common practice in automotive 3D machine vision (Barth and Franke, 2008; Barth et al., 2009), have a great potential to enhance RADAR data interpretation.

For our analysis, we made a close comparison between the technical specifications of different brands of automotive RADARs. They offer products with very similar specifications, because the RADARs are tailored for the same specific application. See Figure 2 for relevant specifications of a high-end commercial automotive RADAR (ARS 408-21 of Continental).

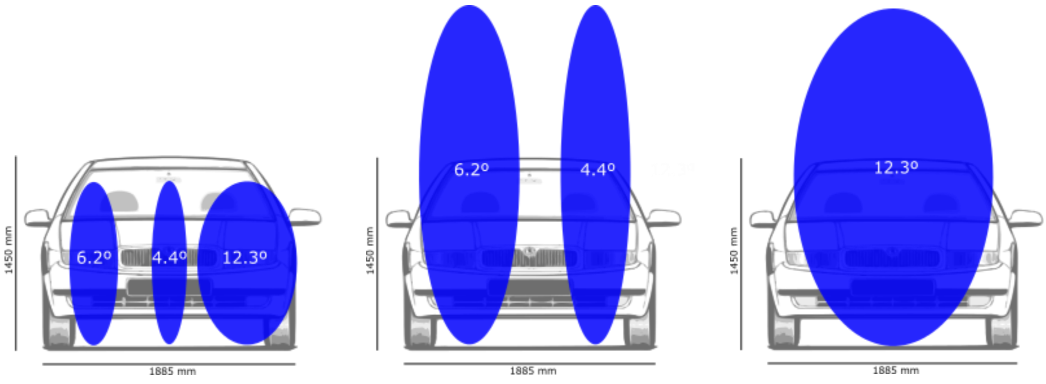


Azimuth angle augmentation (Horizontal FoV)	-60°...+60°
Elevation angle augmentation (Vertical FoV)	20°
Azimuth beam width (3 dB)	4.4°@0° / 6.2°@±45° / 17°@±60°
Elevation beam width	20°
Resolution azimuth angle	3.2°@0° / 4.5°@±45° / 12.3°@±60°

Figure 2. Top view of the 3D scanning volume of a commercial automotive RADAR and relevant specifications corresponding to the short range. Adapted from the technical datasheet of the ARS 408-21 Continental RADAR.

Our focus is on the short range part of the specification (blue section of Figure 2) because the short range has a wider Field of View (FoV). This allows the RADAR to cover more volume ahead of the vehicle using a single sensor. In the azimuth beam width specification are defined three different sizes for beam a 0º, ±45º, and ±60º. This is an expected consequence of the electronically beam steering technique, in fact, the radiation lobe of the antenna is constantly changing its 3D shape when it is moving. Therefore, the resolution and discrimination capability of the RADAR is variable according to the orientation of the measure.

The scale drawings of Figure 3 are expressing visually the consequences of the prior technical specifications. The figures depict how the beam footprint (the transversal area of the beam impacting on the target) is changing for the three different angles (±45º, 0º, and ±60º). Figure 3a represents a car located 7 m away from the RADAR and how the beam footprint change with respect to the orientation of the scanning. In Figure 3b and Figure 3c, the same car is located 14 m away and almost half part of the beam energy is passing over the car (energy not used for the detection). We highlight the coarse resolution of the 3D space at only 14 m of distance.



(a) (b) (c)

Figure 3. Representations in scale of the size of the beam impacting on a generic car. The numbers in degrees correspond to the three azimuth beam width. In the diagram (a) the car is located 7 m away from the RADAR, while in the diagrams (b,c) the car is 14 m away.

3.1.1. Feasibility of automotive RADAR sensors for motorcycle safety

The use of automotive RADARs for the implementation of advanced safety systems for motorcycles (denominated ARAS) does not seem to be a viable choice. The size of the scanning beam become considerably wide at only 14 m. Additionally, in order to be able to scan ahead of the motorcycle whit enough discrimination and a wide FoV (close to 180º) is necessary the use of at least two RADAR sensors.

Nevertheless, the major impediment for the use of automotive RADARs in motorcycles is the non-compliance with the upright assumption (Figure 4). Automotive RADARs considering that the reference coordinate system of the sensor have a fix alignment with the vertical gravity component. This consideration define the 3D space to scan, and consequently all the hardware and the software to accomplish the measurement of this 3D space.

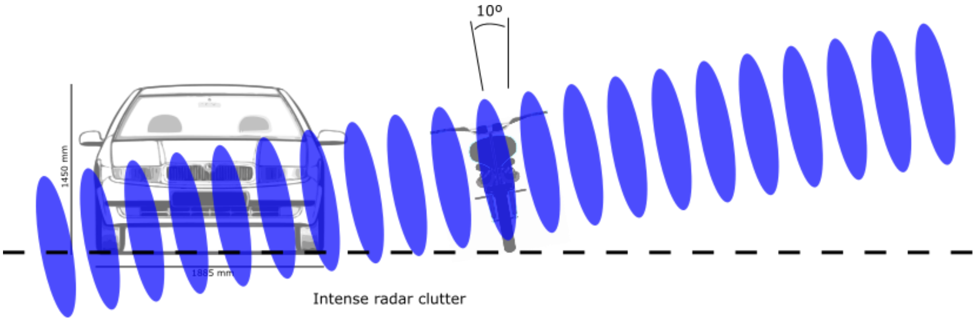


Figure 4. Example of an ideal RADAR scanning 7 m ahead when the motorcycle is tilted only 10 degrees. The increment of the clutter (unwanted echoes) coupled with the reduction of the surface radiated by the car can lead to RADAR blind.

On the right side of Figure 4 it can be seen how the RADAR measures moving away of the road plane. This reduce the net energy which will impact on the possible targets and produce weaker echoes. On the left side two unwanted effects occurs: 1) a reduction of the net energy to hit targets, and 2) a drastic increment of the RADAR clutter due to the reflections occasioned from the street, which can lead to the condition of RADAR blinded.

To conclude, novel signal processing techniques may enhance future automotive RADARs (Engels et al., 2017) but as we presented, there is the constraint in the beamforming that cannot deal with a tilting vehicle.

3.2. Automotive LIDAR technology

A LIDAR (Light Detection and Ranging) system is based on the time-of-flight (TOF) method. Our analysis focus on the ibeo LUX automotive laser scanner (Figure 5) broadly used in the automotive industry. The principle of measurement consist in slicing the 3D volume in front of the sensor in a set of stacked horizontal laser planes (4 or 8 planes depending of the model). In this way the depth of the environment sensed is expressed by simple two-dimensional representations.

When the sensor is operating in nominal conditions, it is expected similar (redundant) measures in all planes for short distances up to 14 m because these horizontal planes are almost parallel between them. A slight inclination between the planes allow to compensate changes in the coordinate reference system of the sensor when the vehicle is braking (the front of the car tilt downwards). For simplicity, our analysis consider a single plane.

Multi echo	Up to 3 distance measurements by laser pulse
Horizontal FoV	110º whit overlapping planes
Angular resolution & Scanning frequency	0.125°@12.5Hz / 0.25°@12.5Hz / 0.25°@25Hz / 0.5°@50Hz
Depth resolution	40 mm ± 100 mm (1 sigma)
Horizontal & vertical beam divergence	0.08° & 0.8°

Figure 5. Aspect of the automotive LIDAR and its relevant specifications. Adapted from the technical datasheet of ibeo LUX.

Concerning to the laser beam that produce scanning planes, from the horizontal (0.08º) and vertical (0.8º) beam divergence it can be understood that the laser operates in a high Transverse Electromagnetic (TEM) mode to fit the needs of the automotive application (see Figure 5 for the specifications). As a result, the laser footprint (the transversal area of the beam impacting on the target) is better described as a thin rectangle because it was engineered to provide high horizontal discrimination power. The scale drawings of Figure 6 express visually the technical specifications of the sensor, showing the rectangular footprints of the automotive LIDAR.

The numbers over the laser footprints (Figure 6a) represent the distance between the target car and the LIDAR (14 m, 29 m, and 57 m). Consequently, the laser footprint grows due to the beam divergence. The dashed lines surrounding the laser footprints represent the movement of the laser over the car surface when the sensor is under a hypothetical vibration (angular deviations about ±0.05°). In Figure 6b, the car is 57 m away from the sensor and a single laser pulse is able to sense different parts of the car, denominated in the example from P1 to P5.

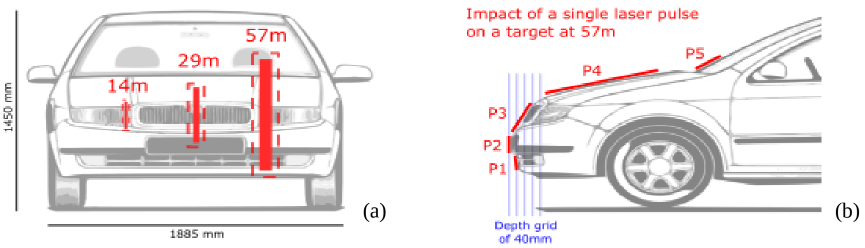


Figure 6. Representations in scale of the size of the beam impacting on a generic car. In the diagram (a) the numbers above of the laser footprints are the distance car to LIDAR. For example, the rectangle below the number 57 have the size of the impacting laser footprint on a car 57 m away from the LIDAR. In the diagram (b) the multi echo effect is depicted for a target car at 57 m from the LIDAR.

3.2.1. Feasibility of automotive LIDAR sensors for motorcycle safety

The use of automotive LIDARs for the implementation of advanced safety systems for motorcycles (denominated ARAS) does not seem to be a viable choice. In the technical specification there is indicate the number of bounces back allowed for a single laser pulse by the term “multi echo”. This feature is related with the TOF measurement principle, therefore the sensor will not be able to measure if the target impacted generates more than 3 bounces in the same laser pulse. Thus, in case of more than 3 bounces per laser pulse the LIDAR get blind.

Analysis of Figure 6 (b): due to the beam divergence the laser footprint impact in several parts of the frontal part of the car. In the example, the impacts are described in 5 parts corresponding to the same laser pulse. The impact in different parts of the car present different depths for the same pulse (multi echo), due to the depth resolution of the laser (40 ± 10 mm). The surfaces P1 and P2 backscatters one bounce each, while the part P3 present two or three bounces and the LIDAR gets blind, even without counting the bounces from P4 and P5.

Therefore, the car is invisible for the automotive LIDAR at 57 m of distance, independently of the laser beam maximum range (200 m). This undesired effect shorten the range of detection. An example of range shortening is found in a previous experiment that has involved 140 tests (Savino et al., 2012) using the same automotive LIDAR. In the experiment, the sensor started to detect a fix obstacle from distances about 58.3 m (sd. 14.5 m).

Nevertheless, the main impediment for the use of an automotive LIDAR in motorcycles is the non-compliance with the upright assumption (Figure 7), for the same reasons mentioned in the analysis (3.1.1).

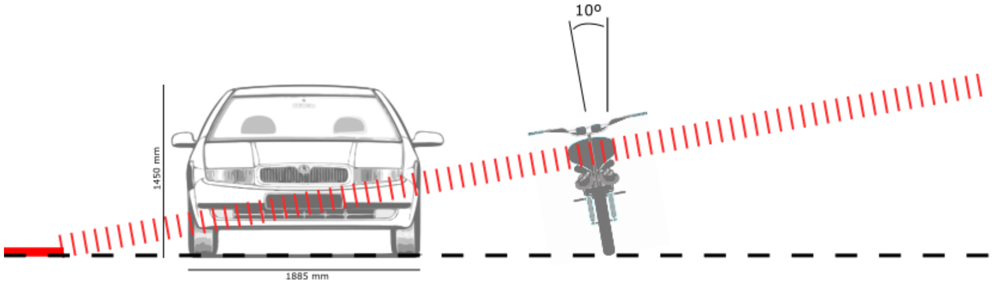


Figure 7. Example of an ideal LIDAR scanning 14 m ahead when the motorcycle is tilted only 10 degrees. Problems: on the right side, part of the scanning plane will not intersect possible targets, whereas on the left side, part of the scanning plane will impact on the floor.

3.3. Automotive Machine Vision technology

Machine Vision (MV) is the ability of a computer to see. It can employ one or more video cameras that can be of different types. MV involves a large number of technologies, software and hardware elements to perform the processing, and involves the Computer Vision (CV) discipline. In particular, CV deals with algorithms for gaining high-level understanding from digital images or videos. Some of these algorithms seeking to automate tasks that the human visual system can do in terms of 3D perception and understanding, or object identification and classification.

Automotive Machine Vision concerns to the real-time application of MV in road vehicles, which is currently booming due to the development of autonomous cars. In our study, we are interested in to identify possible automotive MV systems that can be used as a remote sensor for the development of ARAS. Our focus is CV algorithms for 3D perception and road traffic understanding that only use of camera sensor information. In this way, the strength of stereo vision techniques relies in that heavy dense calculation of the disparity map is a pixelwise operation that can be achieved by hardware in real-time (Gehrig et al., 2009). Thus, the visual and depth information can be given to a high performance embedded system to implement an Obstacle Detector (OD) system.

Most of OD algorithms needs certain assumptions about the ground in the image, such the ground is parallel to the orientation of the camera (Hu and Uchimura, 2005; Xia et al., 2014), or planar ahead of the vehicle (Suganuma and Fujiwara, 2007; Zhang et al., 1997). An example is presented in Figure 8.

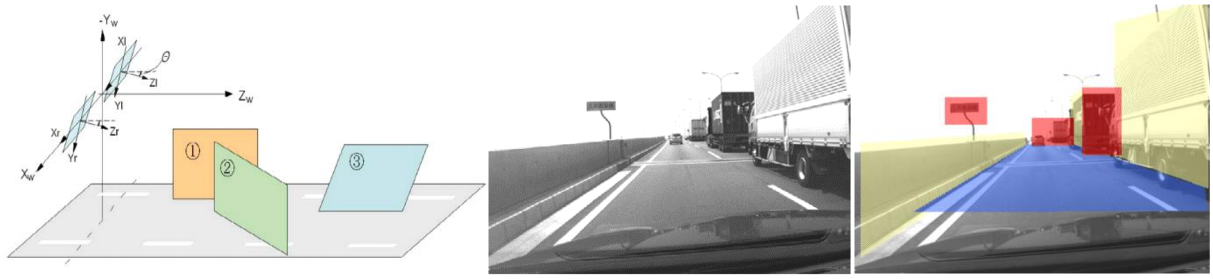


Figure 8. Representation of the stereo camera and the different 3D plane projections of the traffic scene using the “U-V-Disparity” concept. On the right image is overlaid the identification of the street and other big surfaces. Adapted from Hu and Uchimura, 2005.

Strategies for non-planar roads (Suganuma et al., 2008) relies in the importance of the physical camera setup and calibrate the system in order to use less software transformations to rectify the images (Nedevschi et al., 2004; Broggi et al., 2006) and to save computing. Other approaches, instead to localize the road attempt for approximate free space in the 3D volume. The free space is expected to be over the road (Badino et al., 2007; Broggi et al., 2013; Oniga and Nedevschi, 2010).

In recent review of the most evolved OD approaches for the car application, (Bernini et al., 2014) analyzed and categorized the approaches in four categories: a) probabilistic occupancy grids, b) digital elevation map, c) scene flow segmentation, and d) geometry-based cluster. Most of these approaches showed to be deterministic (important for real-time), possible to implement high performance embedded computers, and robust in a variety of clear visibility conditions at very different hours of the day. The “stixel” world (Badino et al., 2006, 2009) is presented in Figure 9 as example of mature OD system.

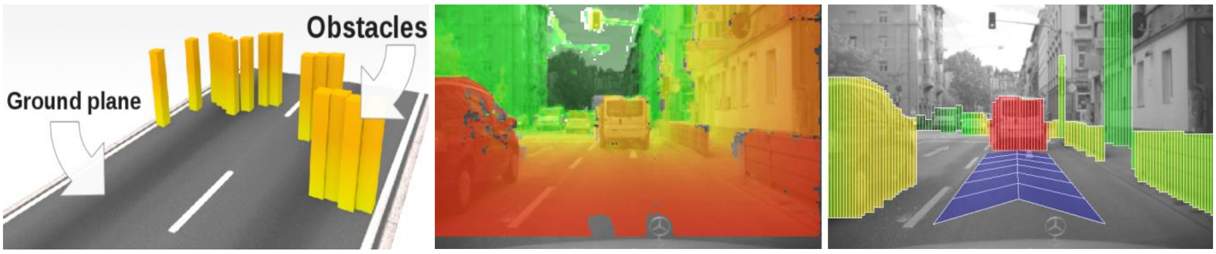


Figure 9. Left: conceptual representation of the stixel world. Center: the Disparity Map of the stereo vision system as interpretation of the depth of the traffic scene. Right: the stixel representation of the different obstacles. Adapted from Badino et al., 2009.

Low light and nighttime situations requires totally different algorithms, because the performance of ordinary CV algorithms is seriously affected. Vehicle front and rear lights are the only characteristics which can be used to detect other vehicles at nighttime, but they suffer from distraction of shops lights and other bright regions.

3.3.1. Feasibility of Automotive Machine Vision for motorcycle safety

Cameras, differ from RADAR and LIDAR sensors in cost, size, power consumption, and FoV (Field of View). The imaging sensor can have wide horizontal and vertical FoV, providing enough information of the environment even with large roll angles (±30º). Camera-based driver assistance was intensively developed in the 1990s and nowadays are standard ADAS in several vehicles. Thanks the advances in algorithm developments, today is possible to combine the depth information of the stereo vision system and visual data allowing distance and velocity estimation at pixel level.

Nevertheless, most of these approaches contain algorithms that requires certain alignment between the camera sensors and the 3D space to sense, due to the upright assumption inherited from ADAS. Therefore, to cope with the tilting dynamics is necessary adapting existing algorithms or develop new ones that accomplish the same thing.

4. Application example: Materials, Methods and Results

The research methodology defined pursuit two objectives:

- Assess the potential of the Machine Vision (MV) technology to cope with a tilting dynamics.
- Evaluate the potential of stereo vision as a remote sensor approach for ARAS, which can be designed to avoid crashes or mitigate them. One example is the Motorcycle Autonomous Emergency Braking (M-AEB) which present an encouraging potential (Savino et al., 2015, 2012).

As a consequence, we engineered a multi-focal stereo vision system to install it in and instrumented scooter for ARAS (Advanced Rider Assistance Systems) assessment. An early stage of the system were introduced (Savino et al., 2017), for which several test from a fixed and moving setup were presented.

The most important technical specifications of our imagining system are the wide horizontal and vertical Field of View (FoV), because it provides adequate 3D spatial discrimination power in all directions, allowing the operation in a tilting dynamics. The system is composed for sets of camera pairs with fixed lenses arranged in camera rigs in the frontal part of an instrumented scooter. The four different pairs of lenses chosen define different zones of interest to sense ahead of the vehicle, which is the same strategy used in autonomous cars but with the difference that they use information from different type of sensors, such as RADARs, LIDARs and cameras.

On the algorithms side, we use Semi-Global Matching (SGM). Additionally, we used a recent method called “satellite markers”, which allows: to generate 3D ground truth, quantify camera decalibration (vibrations in the vehicle transferred to each camera modifying its poses differently), and algorithm benchmarking (Gil et al., 2017c).

In brief, we evaluate the MV system performance in real traffic conditions similar to those that led to a real motorcycle crash in the past. To do this, we employ instrumented vehicles to emulate pre-crash conditions at the same place (public roads) where the accident took place. The instrumentation were presented in (Gil et al., 2017b).

The information of the kinematic and circumstances of motorcycle crashes were extracted from InSAFE database (Piantini et al., 2012, 2013), the in-depth crash investigation database active in the area of Florence, Italy. From the cases extracted, we selected only the cases for which M-AEB performed well in virtual simulations. In this way, we seek to know if the MV system is able to provide reliable information to trigger the M-AEB. The protocol employed during the crash emulations was thoroughly explained in (Savino et al., 2017).

Results are favorable to the possibility to sense target location and pose from an imagining system installed in a scooter. For example, the 3D reconstruction of Figure 10 was obtained from the Disparity Map of the stereo vision system. It corresponds to the 3D space from 7 m to 14 m ahead the scooter. As it can be seen, the imagining system can offer enough 3D discrimination power to detect small and narrow targets, like the unusual photographer wearing a straw hat on the left side of the scene imaged.

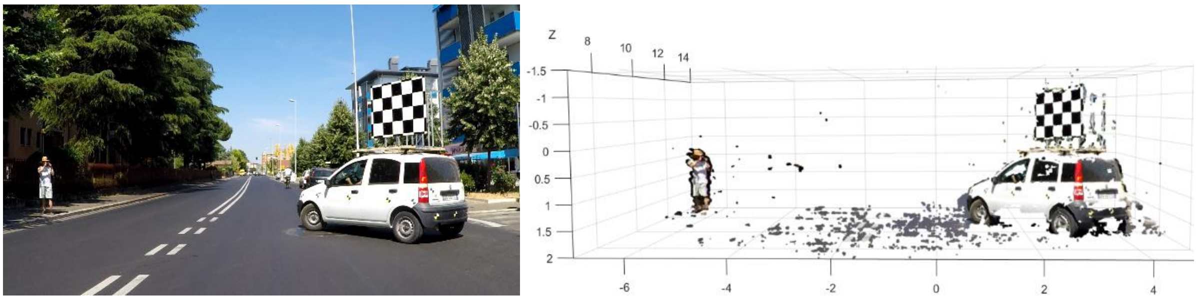


Figure 10. Image from the left camera of the stereo system and its respective 3D reconstruction of the traffic scene from the scooter point of view. In this emulation a parked car initiates a U-turn crossing the lane (crash id84 – InSAFE crash database).

5. Discussion

This study described the technical fundamentals of automotive remote sensing technology and their potential as measurement instruments in simple terms, for the application in road vehicles. The analysis performed allowed us to unveil the reasons why high-end automotive RADARs nor LIDARs have not been applied to tilting vehicles. Proper understanding of the root of the problem is key to propose effective solutions.

In motorcycles, simple change lanes and traffic filtering requires a counter steering maneuver and roll angles up to ±10º. This vehicle dynamics is completely inexistent in four-wheeled vehicles. In addition, when a motorcyclist negotiates a curve the circumstances, such as layout of the road, current traveling speed, other vehicles in the street, and rider skills among others, may require that the motorcycle exceed the ±10º of roll angle mentioned before. Therefore, we explicit that the vehicle dynamics present in tilting vehicles are the challenges to surpass for the future ARAS, and new remote sensing sensors will need to cope with this dynamics.

As a solution for tilting vehicles, such as motorcycles and scooters, we introduce the idea to engineer perception systems purely based in camera sensors, and we justifying our statement based in statistical motorcycle crash data of more than 13 years (see Figure 1). Thus, contrary to other vehicles, such us cars, buses, and trucks, the expected intervention of the safety systems in motorcycles is very often in good visibility conditions, because bad weather conditions may discourage the riders to employ this mean of transport at these moments.

6. Conclusions and future work

In this study we highlighted the great potential for smart tilting vehicles as a personal means of transport for urban areas, for which a preventive safety approach will play a key role in making this type of mobility safer. Our three main contributions are: 1) a first feasibility assessment of three automotive remote sensing technologies for its applicability on advanced safety systems for tilting vehicles; 2) the description of a 3D remote sensing approach able to operate properly under the dynamics of tilting vehicles; and 3) presentation of experimental results of the system in realistic traffic conditions.

Accordingly, we have identified two main barriers for the transfer of technology of state-of-the-art remote sensing devices to tilting vehicles. These two barriers led to the current situation for which ARAS are much less developed than ADAS, even if motorcycles are more dangerous that cars (Sekine, 2014; Nicol et al., 2012; The EU, 2016; NHTSA USA, 2015). The first barrier is technological and lies in the fact that the actual sensors were designed to operate for non-tilting vehicles. When these sensors are tilted they fail in properly detecting objects in road environment. The second barrier is a misconception in the scope of the application of ARAS (Advanced Rider Assistance System) inherited from the more constrained scope of ADAS. For example, while for an automotive remote sensing strategy is requested to operate in reduced visibility conditions, such us rainy of foggy, it is not the same for motorcycles. In motorcycle safety, such requirement can be relaxed because the intervention case of advanced safety systems for motorcycles is broadly expected under clear visibility conditions (Figure 1). This open new possibilities in terms of artificial perception systems for ARAS.

As a consequence, remote sensing approaches based on camera sensors (that maybe not be the best choice for car application) can be employed in ARAS. Additionally, camera sensor systems are low-cost perception systems and better suit motorcycle constraints, such as low consumption (the power budget is reduced than in cars due to the smaller batteries) and light weight, so as not to affect the load distribution of the vehicle.

The stereo vision based experiment we presented is part of a larger research on advanced safety systems for motorcycles. The aim is to assess the stereo vision technology in traffic conditions similar to those that led to motorcycle crashes in the past. To this end, motorcycle crash accidents were analyzed and virtually reconstructed to obtain detailed data of the kinematics of the vehicles involved, therefore the circumstances of the crash and its precipitating event. This, allow us to employ instrumented vehicles to perform an emulation of the motorcycle crash at the same location were the crash happened. In the information collected during the emulations is contained stereo video sequences acquired from the tilting vehicle. Additionally, the satellite marker method employed during the tests allows to including 3D ground truth of the traffic scene, which is needed to assess several computer vision algorithms. After the data analysis, the elaboration of a public dataset to speed up the development of ARAS technology is planned.

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7. References

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