NOTES ON VEHICLE-BASED VISUAL TRAFFIC SURVEILLANCE FOR CRASH-PREDICTION

Péter GÁSPÁR, Zoltán FAZEKAS, Alexandros SOUMELIDIS

Abstract: Though some sections of motorways and multi-lane roads have been built in the last few years in Hungary, a good portion of the domestic and transit road traffic is still served by two-lane roads. Some of these roads are burdened with intense and relatively slow truck and lorry traffic. The traffic safety situation is aggravated by the impatience and carelessness of a sadly high number of drivers. These factors render the mentioned roads extremely unsafe. It is questionable whether the conventional measurement approaches – including also the fixed-camera measurements – are adequate for traffic safety monitoring purposes and whether they can provide sufficient insight into the traffic safety situation. Building upon the experience with camera-based traffic lane tracking systems, relying on reports on the applicability of surrogate safety measures for crash-prediction, and on the application of omni-directional vision systems in road vehicles, a mobile omni-directional camera-based approach of assessing the safety of the mentioned roads is outlined and motivated herein.

Keywords: Traffic safety, traffic surveillance, dynamic surround map, surrogate safety measures, catadioptric cameras, omni-directional vision systems.

1 INTRODUCTION

A large body of statistical data on traffic accidents is available from the EU countries and from OECD member states [15]. Comprehensive research studies analyze the causes, the fatalities, and the locations of the road accidents, as well as their perceptible trends [12], and estimate their economic consequences [17]. In Hungary, fatal traffic accidents number approximately 1000 per annum with about 7,000 traffic accidents per year resulting in serious injuries. With only a relatively small portion of the budget being spent on building new motorways, and in general on the maintenance and reconstruction of the existing road infrastructure which is in a fairly poor shape already, it is of utmost importance to use the available moneys in a sensible way.

Building upon the authors’ experience gained during the development of a wide-baseline stereo vision-based traffic lane tracking system [2], [3], [4] and upon their experience in modelling free-form specular surfaces [6], furthermore, relying on reports on the surrogate safety measures [10] and particularly on the Surrogate Safety Assessment Model (SSAM) [11], and finally relying on the domestic and international experience with omni-directional vision systems [7], [8], [9] a viable approach of assessing the traffic safety of these roads is outlined herein. In this approach, the imaging device is an omni-directional camera mounted on a probe-vehicle that moves with the road traffic. In the present paper, the viability of this approach is considered for the particular road type and the main processing steps of this approach are outlined. It is probably worthwhile to mention why the aforementioned experiences are relevant to the present topic. First of all, the application field (i.e., road traffic related measurement) and the sensing modality (i.e., video-stream from camera) are common with those of the traffic lane tracking system mentioned above that was implemented in MATLAB. Although, the real-time implementation of traffic lane tracking system is still under development, the real-time FPGA-based early-vision processing carried out in smart cameras has already been reported [4]. In the present application, both a real-time implementation, and an offline (i.e., slower) implementation would be meaningfully, though obviously the real-time implementation would facilitate a wider range of safety-related intervention into the traffic. In Figure 1, the cameras of the mentioned wide-baseline stereo lane tracking system is shown with its cameras mounted on the side-mirrors of the host vehicle.

Another experience that comes handy in developing the mentioned vehicle-based traffic safety measurement system is to do with the mathematical modelling light-reflection at free-form surfaces. This is because non-spherical – in cases custom-designed – mirrors are often used in catoptric and catadioptric omni-directional systems.

Figure 1. The cameras of the stereo lane tracking system – mentioned in the text – mounted on the host vehicle
The structure of the paper is as follows. In Section 2, the most important traffic surveillance approaches are summarised, then the use of the surrogate safety measures for assessing dynamic traffic scenes is motivated and the traffic situation on the roads to be assessed are described. Still in this section, the relevant features of the omni-directional cameras are summarised. In Section 3, the main processing steps involved in the vehicle-based traffic safety measurement are outlined. Finally, Section 4 concludes the paper and further work leading to realization of this traffic safety measurement is summarised.

2 BACKGROUND

2.1 Traffic Surveillance Approaches

Though, herein the safety related aspects of the traffic surveillance systems are emphasised, traffic surveillance systems are also used for other traffic related purposes, as well. These include traffic management, and travel time collection. The collected data could then be forwarded either in an offline, or an online manner to data collecting centres. The mode of data management obviously affects the way the collected data can be utilised. There are two main types of traffic surveillance systems, namely road-based and vehicle-based traffic surveillance systems.

The road-based traffic surveillance systems, such as inductive loops, have been a principal means of road surveillance and incident detection for many years mainly because of their reliability and inexpensive operation. However, the camera-based and other recent roadside vehicle detection technologies are now used extensively to measure high-volume road traffic [8], [9].

The technological advances seen in vehicle sensors [18] and the increase in speed and reliability of detection algorithms [1] make it possible to implement vehicle-based surveillance. Vehicle-based traffic surveillance systems involve probe-vehicles – equipped with some tracking devices – that allow the vehicles to be tracked by a central computer facility. Although, vehicle-based traffic surveillance systems are not yet in wide use, these systems show promise of providing rich data on travel times and as a means to detect incidents. They can also be used to estimate flows and origin-destination patterns. Recently, a visual vehicle-based traffic surveillance system, interestingly, but not surprisingly using an omni-directional vision approach, was proposed for the above outlined applications [7]. The paper’s most relevant aspect to the particular safety assessment approach suggested herein is the generation and the use of dynamic panoramic surround maps by the described system. These surround maps can be used to calculate the surrogate safety measures [10] covered briefly in Subsection 2.3. In the present paper, the visual vehicle-based traffic surveillance approach – such as the one described in [7] – is considered for certain types of roads.

As an illustration, a bird’s eye view of the traffic scene is shown in Figure 2. It was derived using an inverse perspective mapping of the traffic scene shown on the left. This bird’s eye view can be taken as an instantaneous surround map with a car – shown as a fairly large green region because of the inverse perspective mapping applied – in front of the host vehicle. The dynamic surround map is used to describe the movement and the trajectory of the host car and other vehicles with respect to the road surface.

Figure 2 A traffic scene with lane marking detected (a) and its bird’s eye view (b)
The distance between the host car and the car followed is marked.
2.2 Target Roads for Visual Vehicle-based Traffic Surveillance

Though some sections of motorways and multi-lane roads have been built in the last few years in Hungary, a good portion of the road traffic is still served by two lane roads. Lengthy sections of the national main road network belong to this road category. Some of these sections are burdened with intense and relatively slow truck and lorry traffic; these sections are frequently oversaturated. The situation is aggravated by the impatience and carelessness of some drivers. All these factors contribute to make these sections extremely unsafe. In the following, such roads will be referred as target roads.

There is a growing governmental intention to monitor, regulate and control the traffic on these roads, e.g. by deploying speed cameras and other traffic surveillance equipment, and by using traffic-dependent traffic light control regimes that optimise the throughput of junctions. However, as frequent users of these roads, the authors’ opinion is that there is much to be done in respect of accident prevention on these roads.

Indeed, the drivers’ irresponsibility has reached an astonishing and frightening level, manoeuvres such as risky and life-threatening overtaking has become the ‘norm’ on these roads. In many cases, it is not the speed-limit though that is violated, but the prohibition, or the safety rules of overtaking. In view of this ranking traffic safety situation, it is questionable that viable measurements and preventive measures – with any hope of success – can be solely stationary in respect of the target roads. In our view, under the mentioned circumstances, some measurement devices should move together with the traffic. Therefore, we propose the use of some mobile visual vehicle-based traffic surveillance system – such as described in [10] – for the target roads. The data collected in this manner could be processed, analyzed and data-mined with the aim of identifying non-trivial unsafe geographic locations (i.e., road sections other than junctions) and other conditions, where and under which unusual vehicular and driver behaviour frequently occur. This can be done in a similar manner to the validation of the crash-prediction potential of micro-simulations of intersections reported in [11]. This way, potential non-trivial accident hotspots could be identified and appropriate preventive actions could be taken.

2.3 Applying the SSAM Approach for Dynamic Traffic Scene Evaluation

The Surrogate Safety Assessment Model (SSAM) was developed and validated in the United States [11]. This assessment method augments the analysis of the expensive and unreliable field measurements and actual crash data and uses runs of appropriately tuned micro-simulations of the road traffic at junctions or road segments to assess traffic safety in these locations. Though, some traffic volume-based accident-prediction models – e.g., [20] – show better correlation with factual crash data than the SSAM-based predictions [11], the micro-simulation-based models provide a good insight into the underlying traffic patterns and accident types. The importance of micro-simulation-based models is evident in case of uncommon road geometries and arrangements, and in case designs, i.e., junctions not yet built. Furthermore, there is a wide range of differences between countries in the usual/local behaviours on roads. E.g., in the SSAM projects the American researchers were hesitant to use accident prediction models from other countries. They only did so in the case of some recently introduced traffic layout. Micro-simulation-based modelling seems to be more tuneable toward these local behaviour patterns. As declared in [11], the SSAM is expected to be used on real data acquired from visual traffic surveillance systems. So, as the camera coverage of the busiest intersections in Hungary increase, it is foreseen that surrogate safety measures can be collected via automated video processing methods at least for research and experimental purposes. Note that in case of vehicle-based traffic safety surveillance opted for in this paper, the surrogate safety measures need to be adapted to non-stationary measurements, i.e., when also the ego-motion of the vehicle hosting the surveillance camera must be considered.

2.4 Image Acquisition with Omni-directional camera

The advantage of using an omni-directional camera in the given context can be verified by considering e.g., the monocular lane detection approach depicted in Figures 2. In the figure, a traffic scene with detected lane markings is shown; the distance between the host car – equipped with the camera – and the leading car is also marked. The original unprocessed image was taken with a normal, relatively narrow-angle monocular camera, as it can be verified from the bird’s eye view of the scene shown in Figure 2b. With similar objectives and cameras eight or more synchronized cameras would be necessary to cover the 360 degree field-of-view – required in this dynamic traffic safety assessment task – in a monocular fashion. To cover this field-of-view in a stereoscopic fashion, (i.e., doubly to enable point correspondences), further cameras would be necessary. Using a fisheye stereo vision system as suggested in [9], still at least four synchronised cameras would be necessary.
Note that the cameras would need separate mountings, connections, and possibly separate calibration procedure.

Various omni-directional vision systems are known from the literature. The dioptric systems and catoptric systems are based on special lenses and on non-planar mirrors, respectively; while the catadioptric systems use both of these optical elements. Some of these systems are reviewed in [7], [18]. Using such optical systems, non-customary, strongly distorted images – similar to the one shown in Figure 3a – are taken and recorded. In Figure 3b, a possible arrangement of a catadioptric vision system is sketched for the car appearing in Figure 1. The upward looking conventional camera and the non-planar mirror of the vision system are rigidly mounted on a rod. Figure 3c illustrates how a mapping is generated via reflection of light at a free-form surface. By choosing an appropriate non-spherical specular surface for the catadioptric vision system, a better use of the image sensor area could be achieved. Such a catadioptric arrangement is shown in Figure 4.

Figure 3 A spherical mirror reflecting a lab environment (a). The sketch of a catadioptric vision system mounted on the host vehicle (b). The mapping created by a non-planar specular surface reflecting a marked plane into a camera (c)

Using two or more appropriately designed and placed specular surfaces – facing a single camera, or a number of cameras – stereo imaging can be achieved, that is, a stereoscopic reconstruction of the scene is possible.

3 VEHICLE-BASED TRAFFIC SURVEILLANCE FOR CRASH-PREDICTION

Though, the main processing steps of the vehicle-based traffic safety assessment task are not markedly different from the general scheme of the lane detection algorithms – based on cameras and on additional sensors – given in [3], some additional processing steps must be included in the mentioned scheme. From the image data – in this case taken by the omni-directional imaging set up – the road and vehicle features are extracted.

Based on the road features and considering the road surface model (e.g., planar road) and the sensor model (in this case the model describing the rigid arrangement of a known specular surface and a calibrated camera), the outliers are removed from the road features. Then a lane model is fitted on the blobs representing the inlier road features.

Then taking ego-vehicle dynamics into account, tracking is carried out with respect to the road and – after proper filtering – to other vehicles. The surrogate safety measures are calculated based on these tracking results.

Figure 4 The sketch of a catadioptric vision system – mounted on the host vehicle – comprising a non-spherical mirror

4 CONCLUSION

In this paper, a particular visual vehicle-based traffic surveillance approach was proposed for
certain types of roads (referred herein as target roads). Two modes of use were considered: with online and offline data collection.

For evaluating the safety risk of the traffic events extracted from the image sequences and to use these categorised incidents for crash prediction, the surrogate safety assessment measures and approach was proposed. The use of a single omni-directional camera with an on-board computer equipped with appropriate video, navigational and vehicle dynamics data recording capabilities is suggested.

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References


Prof. Péter GÁSPÁR, MMEng., PhD., DSc.
Computer and Automation Research Institute
Hungarian Academy of Science
Kende u. 13-17
H-1111 Budapest
Hungary
E-mail: gaspar@sztaki.hu

Dr. Zoltán FAZEKAS, MEng. PhD.
Computer and Automation Research Institute
Hungarian Academy of Science
Kende u. 13-17
H-1111 Budapest
E-mail: zoltan.fazekas@sztaki.hu

Dr. Alexandros SOUMELIDIS, MEng. PhD.
Computer and Automation Research Institute
Hungarian Academy of Science
Kende u. 13-17
H-1111 Budapest
E-mail: soumelidis@sztaki.hu