On-Road Approaching Motorcycle Detection and Tracking Techniques: A Survey

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***Abstract* — Driver Assistance System (DAS) plays a vital and promising role in most intelligent vehicles technologies by alerting the motorists about any possible collision. In such systems robustness, reliability and real-time detection are critical. This paper focused on on-road detection of approaching motorcycles, where sensor is preferably attached on the rear side of vehicle. More attention is given to the applicability of methods and technologies on motorcycle detection and recognition, as motorcycles are smaller and harder to be noticed by vehicle driver. First we discuss the problem of on-road motorcycle detection using different sensors followed by review of motorcycle detection research. Then, we discuss types of sensor to set the stage for vision-based motorcycle detection. Methods used for hypothesis generation (HG) and hypothesis verification (HV) are mentioned before the integration of detection and tracking systems. Finally, we present a critical overview of the methods discussed and assess the potential of these methodologies for the future research and applications.**

***Index Terms* — Driver assistance system, Intelligent vehicles, Motorcycle detection, on-road, Real time, Tracking**

I. Introduction

In recent years, on-road vehicle detection is gaining rapid attention in research on designing and improving driver safety system. Among the road crashes, rear end collisions are one of the most common forms of traffic accidents. The research on accident prevention and injury reduction is becoming more active among automotive manufacturers and universities. Statistics show that motorcycle riders suffer most in these accidents [1]. A motorcyclist is exposed to danger more than a normal car passenger and sharp manoeuvres further increase the risk of accident. Since human negligence is the main reason for the occurrence of accidents, developing on-board automotive driver alert system can help in overcoming the increasing deaths and injury rates. A great deal of research has been conducted on real-time detection of overtaking vehicles [2]. Most of the research is carried out for the detection of cars or four-wheel vehicles but only a few researches about detecting approaching motorcycles or a system including both categories.

This paper presents a review of recent motorcycle detection techniques using Radar, Laser, Lidar, sound sensors, optical sensors, and fusion of aforementioned techniques [5, 27,28]. Motorcycle detection is a very challenging task due to huge variability in shape, color, and size of motorbikes manufactured by different producers. Cluttered outdoors environment, illumination changes, random interaction between traffic participants, and crowded urban traffic system make the scenario much more complex for motorcycle identification. On-road motorcycle detection systems (MDS) face two main challenges; computation and reliability. Processing time is also indirectly related to vehicle speed. The more the speed of a vehicle is, the less the time available for processing a frame. Robustness is the other requirement that must be fulfilled if the ego car is on urban road and where the accident probability is greater than on rural roads or highways.

This paper is organized as follows: section 2 gives a brief introduction of existing techniques and sensors used for motorcycle detection. In section 3, a survey of motorcycle detection schemes by moving camera is given. Section 4 includes discussion on all the techniques stated in section 2 and 3. Conclusive remarks are given in section 5.

II. Current motorcycle detection techniques

Upto now there is a very few literature available for on-road motorcycle detection. Most of the motorcycle recognition systems are developed with static camera which is mounted on a pole or bridge for counting or surveillance purposes. Using active or passive sensors [3] can either do motorcycle detection. The commonly used techniques for each class of sensors are explained in the following text.

A. Active Sensors Based Techniques

The most common approach to detect motorcycles using active sensors include acoustic based [4, 5], Radar-based [6, 7], and Laser or Lidar-based [8, 9]. Based on the fact that these sensors identify the objects on the reflection of the emitted signals, they are called active. Active sensors compute the distance between the source and target by measuring the time duration between emission and detection of reflecting signal. Their key advantage is that they don’t require powerful computations for direct measurement of certain quantities (e.g., distance, relative speed etc.).

In [4], the vehicles are detected for estimating congestion on the road by using the negative feature (noise) of urban road environment. It presents the comprehensive design of an acoustic sensing hardware prototype, which has to be deployed by the side of the road to be monitored. This unit samples and processes road noise to calculate several metrics such as quantity of vehicular honks and vehicle speed distribution, with speeds estimated from honks using differential Doppler shift. The metrics are transferred to a remote server over GPRS after every minute. After certain manipulations using these metric values, the server can determine the traffic condition on the road. [5] Presents the motorcycle detection by using the microphone array through its unique low frequency signal components. There are three unidirectional microphones in the microphone array, covered with windscreens. Their locations on the sensor platform were carefully selected through a series of experiments and analytical analysis. Algorithms were developed to compensate the saturation of acoustic signals because the saturated acoustic signals have more low frequency components and could cause false detections.

Pulse Doppler Radar framework [6] is used to detect and then track the obstacles in front of vehicle. The system is mounted on the front lower part (see Fig. 1) of the ego vehicle, for detection and tracking of any obstacle on the front side. The system finds out the distance between the equipped vehicle and target, and the relative speed by observing the echoes of the Radar signals. The system also worked well in different weather conditions and showed positive results for 150m. This system is unable to differentiate between the types of obstacles; it can't classify the obstacle into categories of car, motorcycle, and man etc. Radar based driver safety systems [10] have shown good results in different weather conditions e.g., in fog, rain, and low light conditions. They have larger range to detect the target/obstacle but can't give us brief information about the obstacle or vehicle to be tracked. The cost of a Radar based system is relatively higher than some of the other sensors based solution e.g., Lidar and optical sensors.

Laser and Lidar-Based systems have proven their performance to be more effective, cheaper, and real-time than the Radar-systems. These systems transmit and receive electromagnetic radiations at higher frequencies. Lidar is inexpensive in production and easier in packing than Radar. In [8], multiple vehicles were detected and classified by mounting a Laser scanner on vehicle. The classification was based on different criteria: sensor specifications, occlusion reasoning, geometrical configuration, and tracking information. The estimated confidence level was computed accounting the geometrical configuration, the classification, and the tracking time. The system was tested under several conditions (urban centers, highways) with three different Laser scanners and confirmed its strength and fulfilled the real-time requirements. Figure 2 shows some results of the above-mentioned technique. Some techniques involving the fusions of Radar and Lidar [11] have also been proposed.

B. *Passive Sensors Based Techniques*

Optical sensors are generally referred to as passive sensors [3] because they acquire data without emitting any signals manner. Optical sensors include the use of cameras which are cheaper than active sensors. Optical sensors are utilized to track the approaching and preceding vehicles more effectively as visual information gives us a brief description of the surrounding vehicles. Furthermore the visual detection and tracking is independent of any modifications to the road infrastructure. Several systems proposed in [12-14] revealed the principal practicability of vision-based DAS.

Several Vision techniques for detection of motorcycles have been proposed [15-22]. In most cases, the camera is static i.e., either it is mounted on a pole or roadside building or bridge for surveillance purposes. By using static camera it is easier to recognize and track a motorcycle among the vehicles. A simple background subtraction technique [16,23-25] is performed to remove all the stationary objects in the scene and detection algorithm is applied on the foreground objects. Based on size, aspect ratio and shape estimation, motorcycles are identified. Figure 3 shows results shown by techniques using stationary camera. Some motorcycle classification schemes [26] also use helmet presence as a key feature in classification. Since helmet is must in many countries so presence of helmet guarantees the motorcycle existence. The system utilizes support vector machines (SVM) trained on histograms of head region image data of motorcycle riders. The trained classifier is integrated with a tracking system where motorcycle riders are automatically segmented from video data using background subtraction. Heads of the riders are isolated followed by their classification into helmet and non-helmet groups by SVM.

Fig. 1. Radar system mounted on the front end [6]

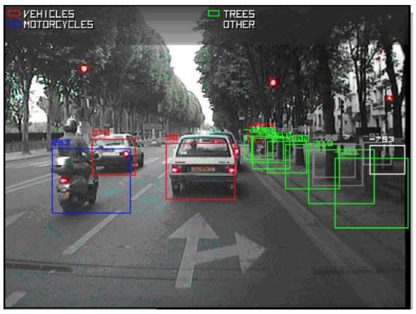

Fig. 2. Results of detection by a Laser sensor [8]

Fig. 3. Results of Motorcycle detection by Static Camera [19]

C. Fusion of Sensors

Fusion of techniques removes the shortcomings and drawbacks in individual techniques being fused while the advantages are added up to make the system more robust and reliable. Multiple sensors extract maximum possible information from the environment and provide an estimate of the important features of an obstacle. The researchers have also exploited the fusion schemes [27,28] to enhance the performance of intelligent vehicles. In [28] combination of Lidar and camera is used and a Bayesian sum decision rule is employed for the combination of results achieved by both classification techniques. Utilizing Lidar data, detection and tracking are performed and to get more reliable object detection, information from camera and Lidar is simultaneously accessed for classification. In [5] fusion of Radar, sound sensor, and IR camera is proposed to set up a system that combines the output and result of each sensor to get promising results.

III. MOTORCYCLE DETECTION BY MOVING CAMERA

On-road motorcycle detection requires the camera to be mounted on the car that leads to scenario where the background is changing with time. Motorcycle recognition, classification and tracking become very challenging in this case. This task is highly demanded in systems used for accident prevention systems because motorcycles have higher probability to face accidents as compared to car users. Limited research has been conducted in this mode of motorcycle detection due to level of difficulty and complexity in development of the algorithm. There are several issues in designing robust, real-time, cost effective and reliable motorcycle accident prevention systems using optical sensors.

Major challenges for system designing are,

- Elimination of Complex and variable background
- Computation in real-time
- Robustness in urban traffic and
- Cost efficient solution

While the algorithm development requires,

- Choice of best features for shape matching
- Classifier Selection for recognition
- A large database for training the Classifier
- Fast and accurate Tracker

The techniques proposed in [29,30] showed successful classification tracking of motorcycles on urban roads. The whole system is divided in three main blocks: Hypothesis Generation (HG), Hypothesis Verification (HV) and Tracking [31]. A detailed review of different HG methods and HV approaches is given in [2]. Prior information about the motorcycle was used to find out the possible candidates for potential motorcycle. The system used large database for training of SVM Classifier, which in the later stage classifies the candidate region into motorcycle and non-motorcycle objects. Once the motorcycle is located, a tracker like Kalman filter tracks it. The proposed system also detected multiple motorcycles in a single frame as shown in Fig. 3. However, the proposed algorithm doesn't detect the motorcycle during the nighttime since the shadow information used by the system is no longer available in darkness.

Vehicle cueing or HG step requires a previous knowledge or information about the target to be identified in the upcoming frames. The appearance based cueing technique locates the regions in which there is a possibility to find target (motorcycle). These regions termed as Region of Interest (ROI) are determined on the basis of some specific features. There are many clues which can be very useful in ROI extraction for vehicle detection e.g., shadow under the vehicle [32,33] horizontal and vertical edges [34], corners [35], symmetry [31, 36-40], texture [41], color [42], the vehicle's lights [43,44].

Several vehicle detection systems [43-45] have deployed the above-mentioned features to find ROIs for car, truck, jeep etc. but in case of motorcycles, almost all of these characteristics lack to give any promising result. Due to small size the measurement of symmetry property is very difficult and may not give actual ROI location. Use of color, corners, edges and texture characteristics also become ineffective due to variation in shape, size and color of motorcycle. In [30], shadow and black color of tyre was utilized to determine the possible locations of motorcycles. It showed positive results but the system may lose its robustness in the case where motorcycle is far from camera or in different illumination condition.

HV step takes the input ROIs generated by HG step and performs classification to identify the target. Using either a template matching technique or a classifier can perform the classification. In template matching [46] a correlation is calculated between the template image and ROI images. Based on correlation value, ROI is classified into positive (including target) or negative (image without target). On the other hand a classifier [47-50] is first trained on a large database of target images for learning purposes. Once trained, classifier categorizes ROIs images into positive and negative group.

Time and accuracy of vehicle detection can be significantly improved by making use of the temporal continuity present in the data. This can be accomplished by using a tracking model which predicts the location of target in upcoming frames. A tracker trained on past history of vehicle motion can predict the new location using state estimation which reduces the extra computations for target localization.

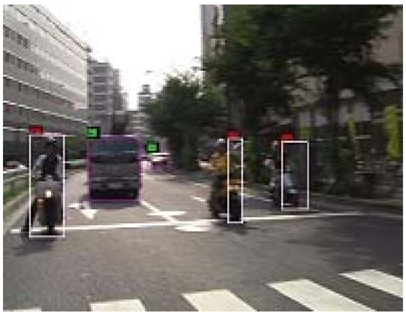

Fig. 4. Motorcycle detection by SVM Classifier [30]

Tracking involves locating the target in next video frames after it has been recognized and classified by the HV step. The most commonly used tracker is the one developed by using Kalman Filtering [51]. With the advancement and availability of fast computational machines, particle filters [52] are also gaining popularity in tracking applications. Majority of existing on-road vehicle detection techniques [29,30] use *detect-then-track* approach (i.e., vehicles are detected before being tracked). Performing detection and tracking sequentially requires more time for computation.

IV. Discussion

Various methods have been reviewed in previous sections. Unfortunately, none of these can completely solve the complex challenges of on-road motorcycle detection. Based on the prevailing conditions, different sensors, devices and methodologies need to be considered and utilized by the system. New and improved algorithms should be proposed to further overcome the overall reliability and robustness problems.

A critique of the active and passive sensor based methods is provided below followed by critique of HG, HV and tracking steps. The aim is to emphasize on their leading strengths and weaknesses as well as to propose promising solutions for enhancing their performance. The aim is to make these techniques more reliable, robust and fast to deal with the challenging and complex conditions arising in traffic scenes.

A. Critique of Active Sensors Based Methods

Active sensors are very useful in giving the real-time detection and show robustness during rainy and foggy conditions. Their main advantage is that some specific quantities (e.g., relative speed, distance etc.) can be measured without any powerful computations. The long range of detection (150m approx.) of Radar based systems result in designing a reliable accident prevention system. Lidar is less expensive than Radar but their range is relatively shorter. Radar is more reliable in snow, foggy and rainy conditions than Lidar. The accuracy of Laser based systems is better than Radar but cost is on higher side. Active sensors are hardly able to acquire shape and classify the target vehicle into car, bus, truck and motorcycle etc. As compared to optical sensors, active sensors collect less information about the target (e.g., shape, size, color etc.) and are more exposed to interference issues due to the dynamic and noisy environment of road traffic. Noise removal and signal recovery may require complex signal processing techniques. Fusion of active and passive sensors has achieved significantly better results in terms of classification and robustness. Active sensors are relatively expensive than simple CCD or CMOS camera that makes them a secondary choice for DAS manufacturers.

B. Critique of Passive Sensors Based Methods

The main advantage of optical sensors i.e., cameras is their cost. With the development and advancement in technology, high performance and inexpensive cameras can be used on the rear and front side to cover full 360 degrees view. Static camera based algorithms are useful only in counting or monitoring of motorcycles therefore such techniques are of less interest for developing on-road motorcycle detection systems. The results shown in [29,30] are satisfactory but further improvements are required. The disadvantage of using passive sensor is their robustness as compared to active sensor based techniques. Visual information is greatly influenced by weather and illumination changes. Generally, systems lose their classification during night time, rainy and foggy conditions. Furthermore, separate algorithms are required for the night and daytime environments.

Motion based approaches use the optical flow methods to find the moving vehicles. The optical flow fields are determined by matching feature points or pixels between two image frames. Dense optical flow method mentioned in [53] matches each pixel in the image based on their intensity. This technique requires huge computational effort and therefore is not so suitable for real-time application.

In knowledge or learning based approaches, HG is more difficult phase than HV step for motorcycle recognition. Nearly all characteristics used for HG for cars are unable to locate the proper ROIs for motorcycles. If any of these works; it fails during nighttime or in fog. In case of template matching algorithms, it is very difficult to get proper motorcycle template that can fit all variants of motorcycle. On the other hand, classifier based HV step has proved its performance and has given good results as compared to template matching methods. The only requirement for a good classifier is a large image database for training.

Tracking remains an important step in motorcycle localization and positioning in future frames. Mostly *detect-then-track* approach is employed for on-road motorcycle detection techniques. This approach performs detection and tracking sequentially which requires more time for computation. Using detect-and-track scheme in which detection and tracking are performed simultaneously can save time. This approach can be utilized to improve the detection results as tracking predicts the target position in future frames and searching in the predicted regions not only saves the time but also improves detection.

V. Conclusions

In this paper we have conducted a state of the art on on-road motorcycle detection systems because motorcyclists are exposed to danger more than other road users. On-road motorcycle detection is especially challenging and several practical issues must be kept in mind for the development of system that can yield highest level of robustness and reliability in real-time. Acoustic methods are inexpensive but suffer sound signal interferences due to noisy traffic and therefore require skillful signal processing. Radar gives robustness but it's expensive and lacks classification. Laser gives better accuracy but relatively expensive and need complex methods for shape detection. Lidar is a cheaper solution but is short ranged as compared to Radar or Laser. Optical devices are cheaper than active sensors but visual based solutions have high computational load and may require longer time for processing. Camera based solution also requires careful selection of templates, features, classifier and tracker. This field needs a great deal of research work to be done. Depending on the requirements different methods seem to be more suitable under certain conditions.

We have witnessed the introduction of vision based vehicle detection systems launched by Volvo cars [54,55]. In [54] fusion of camera and radar is practiced in which camera detects the type of vehicle and Radar determines the distance, location and speed of the target. Judging from the progress in this area, it will surely be among the appealing research fields in near future. For further advancement in this research field, relevant government agencies, motorcar manufacturers, and research institutes, should collaborate and work collectively. Rapidly falling prices of processors and availability of high resolution image sensors lays down the foundation for the continuous development of this field.

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