Tailigator: Cooperative System for Safety Distance Observance

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***Abstract*—A driver's inattention to or disregard for the minimum safety distance creates a hazardous situation in which avoiding a rear-end collision is nearly impossible. In a joint effort to implement safety and decision-making processes at an individual level, we present in this paper a cooperative approach to increase the driver's visual awareness of safe distances. Our Tailigator system garners information through the stereoscopic capturing and processing of images by rear cameras to calculate the distance from the leading to a following vehicle. Visual data related to the safety distance is provided to the rear vehicle in real-time, relying on an asynchronous collaborative process. Results from the system qualitative evaluation are discussed.**

***Index Terms*—Cooperative Systems, Tailgating, Safety Distance, Image Capturing**

I. INTRODUCTION

According to [1] driver behavior is dependent upon the driving actions performed in relation to the driver's skill, knowledge, perceptual and cognitive abilities. The behavior of each driver affects other road users and reciprocally they affect the driver. In a joint effort to increase safety and enhance the decision-making processes at an individual level, a cooperative driving environment makes it possible to accomplish the driving task in a safe manner. In the context of cooperative systems, according to the definition of cooperative ITS from a point of view of vehicle active safety, information has to be broadcast relying on the use of 5.9GHz 802.11p communications for V2V and V2I [2]. In a scenario where the penetration rate of vehicles equipped with V2V and V2I technologies is not 100% co-operative, systems should not only communicate and share information between vehicles, but also address their drivers. Relying on this, Advanced Driver Assistance Systems (ADAS) support the driver in challenging driving situations, specifically in data collection and analysis from other vehicles. Visual awareness of the driver can therefore be increased after having processed information that stems from nearby driver behavior.

Disregard of the rules such as the minimum safety distance makes it exceedingly difficult to stop on time in order to avoid a rear-end collision. Several findings have shown that the headway time, or the time drivers have to react to a specific event, is in most cases not enough to ensure a

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Figure 1. Cooperative driving in which visual data related to the safety distance is provided to the vehicle behind in real-time

safe driving experience [3]. This might occur in unforeseen circumstances that force a frontward vehicle to brake. In road traffic, the advice is to maintain a minimum distance of 2 seconds to the vehicle in front [4]. Forcing the leading vehicle to increase speed and disregard speed limits is very often related to aggressive tailgating behavior, which jeopardizes everyone's safety. In an effort to reduce the major cause of rear-end crashes on our roads, road marks remind the drivers to maintain the safety distance in most of European countries (i.e. Spain, France, UK). In some of these countries, tailgating is punishable by law [5].

In order to contribute to the law observance for the sake of safety, we developed in this work a system that warns the rear driver in an unobtrusive manner when the distance to the frontward vehicle become dangerous. Visual data related to the safety distance is provided to the rear vehicle in real-time, relying on a asynchronous collaborative process, in which the partners involved in the collaboration are not necessarily working and communicating concurrently. Figure 1 illustrates the idea.

The remainder of this paper is organized as follows: the next section considers related work in the field of video-based assistant systems; sections III, IV and V present a detailed description of the collaborative principle and application development process followed; in section VI the evaluation process is described; and finally, section VII concludes the paper.

II. RELATED WORK

The use of video-based data to increase the awareness of a driver has been addressed in several works. The goal of the works presented in [6], [7]; for example, was to enhance the driver's visual perception of vehicles traveling in the opposite

 DOI: 10.1109/CTS.2016.0076.

lane. To this end, the authors developed a co-ADAS for the overtaking maneuver relying on VANET technology. The system shared information with vehicles traveling in the same direction, in the same lane, after the rear vehicle started the request for the transmission of a video-stream between the leading and rear vehicle.

The combination of images from several cameras to increase driver visual perception is an extended approach used in object detection processes [8], [9]. The benefits of using synchronized cameras to guarantee a smoother enhanced road detection through the combination of visual fields in comparison with approaches based on a single camera to obtain 3D information from a disparity map were elucidated in [10].

Driver following behavior has also been detected and evaluated using different technologies that include cameras based on vision. For example, analyzing video-based data, the authors in [11] found that the time headways and standstill distances were dependent upon vehicle type. The average headway was around 2 seconds when a car was following and 3 seconds when a truck was following.

There are also works that focus on systems for detecting, monitoring and alerting tailgating behavior. To discourage tailgating, a low-cost Tailgating Warning Sensor (TWS) was presented in [12]. The device warned the drivers if their own vehicles were tailgating, or if a collision was imminent. It consisted of a compact optical electronic sensor mounted in front of the vehicle. In [13] a model was proposed that was based on vehicle dynamics and the perception reaction time, brake intensity, friction between tires and road surface to calculate the stopping distance of the rear vehicle. The model was tested and validated in a field experiment.

In an additional work, the authors presented an object-tracking process based on an improved Gaussian Mixture Model (IGMM) for background. The method combined the Deterministic Non-model-Based approach with Gaussian Mixture Shadow Model (GMSM) to remove shadows. The tracking strategy was improved further by computing the similarity of color histograms. The procured results showed the robustness of the approach in a complex environment [14].

Image processing, especially binocular stereo images, were used in a further work to measure distance headway in real time. The high computational cost related to this method was reduced to a combination with optical flow [15].

All the rear-end collision avoidance system presented in this section collected information by using sensors or cameras mounted in the rear vehicle. In [16] a rear-end parking assist camera located in the leading vehicle was used to collect the relevant data, as rear-end parking assist cameras are already standard in many new cars.

Figure 2. Message displayed to the tailgating vehicle

In line with this work, we contribute to the research in the field by developing a cooperative system to promote the observance of the safety distance (Tailigator) in an unobtrusive manner. The system detects the distance to the following vehicle by means of object detection and optical stereoscopy. In order to make it possible for the driver being tailgated to communicate with the trailing vehicle, our system components reside in the leading vehicle. If a certain threshold value regarding the distance between both vehicles is exceeded, the leading vehicle displays a message in the rear part reading that required safety distance has been trespassed. This message is intended for the driver of the following vehicle. Figure 2 illustrates the idea. The novelty of this approach consists of the leading vehicle indicating to the tailgating vehicle that the distance is too close, relying upon the manner in which human communication occurs.

III. System Setup

Our system runs on a Raspberry Pi B+ or Linux-based micro computer with 4 USB connectors and 40 general purpose input/ouput (GPIO) pins for hardware connection and two cameras connected through a USB port. To calculate the distance between two adjacent vehicles the following steps are performed:

- Stereoscopic capture of images for distance calculation.
- Vehicle detection on both images by building a Cascade classifier using the comprehensive library developed for image processing OpenCV.
- Distance calculation relying on a stereoscopic vision.
- Warning message display addressing tailgating vehicles.

Figure 3 depicts the location of the cameras in the rear part of a vehicle. In order to build a cost efficient system with a minimum power supply need, we used two USB Logitech HD270 web cameras with a focal length of 4 mm that guaranteed a field of view of 60°. They were compatible

Figure 3. Location of the cameras in the rear part of the vehicle.

with Raspberry Pi and ensured a smooth mounting in the rear windshield of a vehicle. The system was able to detect vehicles at a maximum distance of 100m in the same lane of the leading vehicle. To provide power to the Raspberry Pi and the connected cameras, we used a mobile battery pack that provided 30,000 mAh capacity and up to 2A output current.

IV. Image capturing and Vehicle Detection

Simultaneous image capturing was performed to prevent potential errors that could occur due to modification of the vehicles' positions during the distance calculation at a speed of 130 km/h (80.78 mph).

In order to achieve a smooth process, we divided program capturing functions into two separate threads, thereby allowing for a triggering process via a common control signal from an independent source. Figure 4 illustrates the procedure.

The capturing itself was done relying on the OpenCV library algorithm shown in Algorithm 1. By using two threads to capture the images, we reached a time difference of 0.2 seconds between the two cameras. The time frame we used to detect all the vehicles and calculate their distances was every 3 to 6 seconds with an image resolution of 640 x 480. Higher rates resulted in damaged or incomplete camera images. Additionally, a buffer clearance of the Linux camera driver was regularly required to prevent access errors and damaged images. The following subsections describe the process of building the cascade classifier.

A. Collecting training material

For training the classifier we collected positive and negative images with the following characteristics:

- Positive images consisting of the target detection object. We captured over 600 positive images of front-views of cars by recording them from the rear windshield of a vehicle on a variety of roads. We ensured that captured images were made in a variety of light and weather conditions, and that they featured different types of vehicles. Figure 5 shows an example of positive images acquired.

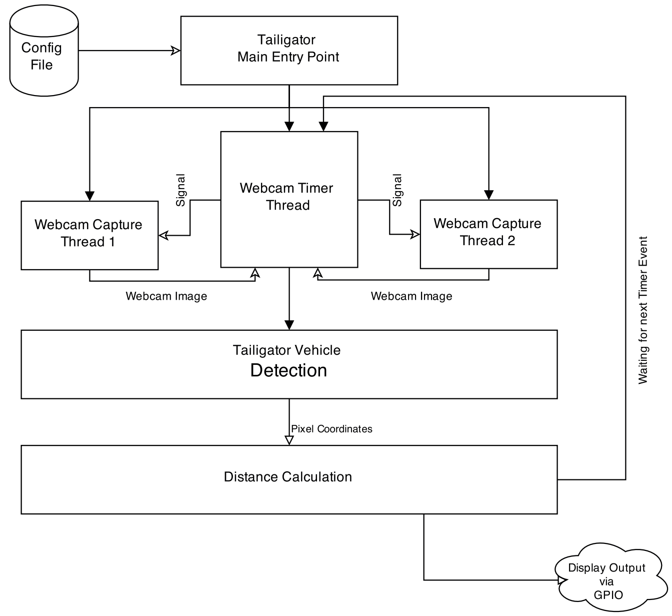

Figure 4. General structure of the software implementation of the Tailigator system

Algorithm 1: Capturing a picture within the camera thread

Input: Camera name and position (left or right)
Input: Hardware reference of the camera

Open Camera(Selected hardware reference)
if *!camera.isOpened()* **then**
| ▷ Error while accessing the camera Errorhandling
end
else
| camera.read(image-raw)
end
camera.release()
▷ Releases the needed system resources for the camera
return *Return captured Image*

- Negative images consisted of images of different objects that were resized to fulfill the same conditions as the positive images. Our final sample consisted of around 2100 negative images.

B. Training the classifier

To train the classifier we created two reference text-files in order to indicate the relative path to the negative and the positive images respectively. The file also contained the number of objects on the image, the position (x,y coordinated) of the objects located on the image and the size of an imaginary square containing the object. Both files were used by OpenCV to create the main source of information for the training algorithm in the form of a vector-file.

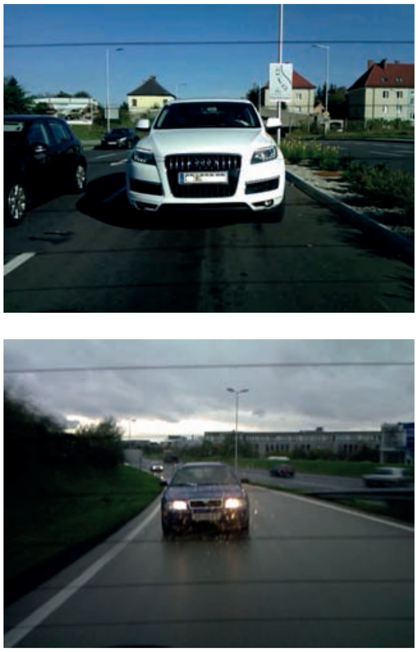

Figure 5. Example of positive images.

According to the parameters above and the number of entered stages, the training time depends on the complexity of the object. The number of stages must be precise, as an inaccurate classifier can result from too few stages, and an over-trained classifier from too many stages. The training was performed with a total of 30 stages and around 10 hours computation time. As a result, we obtained an xml-file as input for the OpenCV's detection-function.

C. Locate tailgating vehicle

As our application is only relevant for a scenario where two vehicles are following each other in the same lane, multiple vehicle detections in motorways or other multi-lane roads will not apply. We implemented a location algorithm that started to scan for information from the middlepoint of the image, and then from left to right. Afterwards, the algorithm compared the coordinates from each current step coordinates with the ones from the object, obtained as output from the OpenCVs detection. Algorithm 2 denotes the followed procedure. Figure 6 shows the vehicles detected. The vehicle in the same lane is tagged with a green circle. The X-coordinate corresponding to this vehicle serves as input for the stereoscopic function.

V. DISTANCE CALCULATION

Stereoscopic vision sensors enable the calculation of the distance to a certain object using the relative pixel-position difference of the object on both pictures (shown in figure 7).

To be able to calculate the distance to a certain object by stereoscopy the following conditions need to be fulfilled.

Algorithm 2: Tailgating vehicle location in the same lane as the leading vehicle

Input: Processed image after detection
Input: Set of detected vehicles coordinates
Input: $middlepoint = \frac{imageWidth}{2}$

```
while !located do
    for currentStep=middlepoint;currentStep−− do
        if currentStep==xCoordinates then
            ▷ A hit as scanning left located=true;
        end
        else
            if (currentStep+addStep)==xCoordinates
              then
                ▷ A hit as scanning right located=true;
            end
        end
        else
            addStep++;
        end
    end
end
return xCoordinates of tailgating vehicle
```

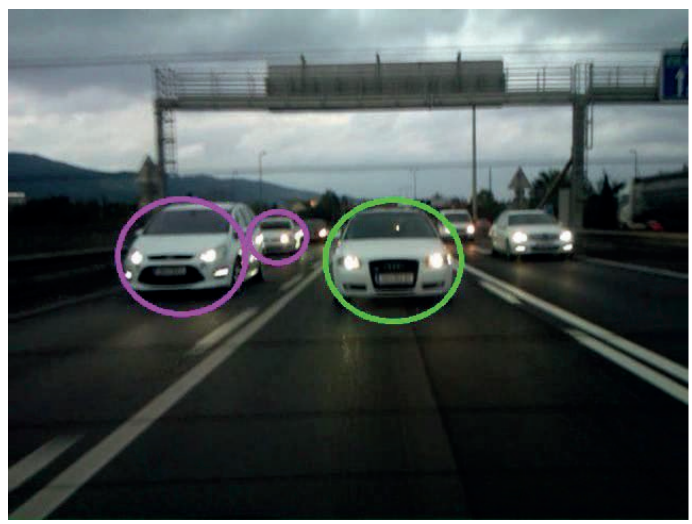

Figure 6. Vehicle detection and location of the vehicle on the same lane (green).

- 2 cameras with the same specifications for sensor size, focal length and picture resolution.
- Perfect horizontal (and in certain cases vertical) alignment of the cameras to prevent miscalculations due to angular errors. (These miscalculations could lead to a wrong value of the pixel coordinates and therefore a wrong distance. If a proper alignment can not be guaranteed, calculation adjustments need to be made to compensate for the difference.)
- The distance between the two cameras must be properly

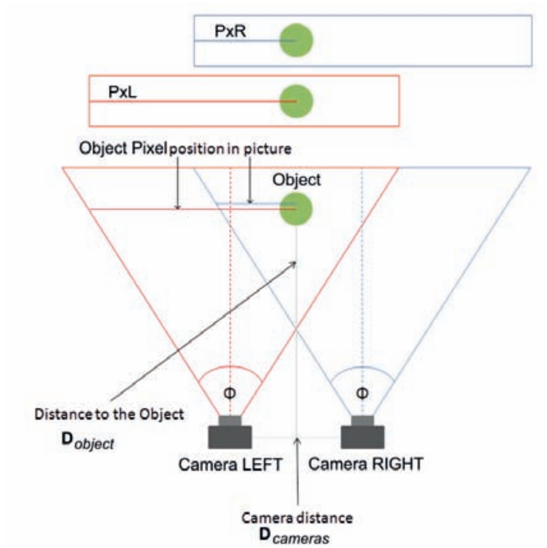

Figure 7. Camera setup for stereoscopic distance calculations. Adapted from [17]

set, as it influences the pixel offset between the two pictures. This could lead to inaccuracy if the offset is too small and the blind spot is located directly in front of the set-up (generated by the camera distance and the field of view of both cameras).

- Synchronous capture of the images is essential to be able to prevent pixel shifts due to the movement in the calculation of distances between dynamic objects.

As depicted in figure 7, the distance calculation is only possible in the area where the images of both cameras overlap. We measure the distance to an object D_{object} placed in front of the cameras using in the formula 1 by [17] parameters such as the distance between the cameras $D_{cameras}$, the horizontal field of view φ_0, the horizontal image resolution Px_h and the horizontal pixel difference to the same object in both pictures in pixels $Px_L - Px_R$.

$$D_{object} = \frac{D_{cameras} * Px_h}{2 * \tan(\frac{\varphi_0}{2}) * (Px_L - Px_R)} \quad (1)$$

VI. Visual Data Evaluation

Visual data related to a safe driving distance is provided to the rear vehicle in real-time by relying on an asynchronous collaborative process. In order to evaluate the developed system by potential users, we performed a qualitative evaluation with a focus group. To this end, 8 persons who were interested in Intelligent Transport Systems were selected by a non-random method to share their experiences relevant to the evaluation. A group facilitator posed open-ended questions in order to foster discussion.

We aimed at investigating the feelings, attitudes and user satisfaction that were derived from the manner of communication that occurred in our system: from the perspective of the driver being tailgated, i.e. the one communicating with the rear vehicle. To this end we showed the functioning of the system to the focus group using a simulation platform that reproduced the system (Figure 8).

Figure 8. Simulation platform showing the functioning of the system

Results indicated that the persons had a more positive response to this method of communication, as opposed to a method wherein the driver in the rear vehicle receives warnings to keep the safety distance within their own car. They argued that a message directly transmitted from the leading vehicle itself provides a clearer message that better reflects the intimidation which the driver might feel because of the aggressive driving behavior of the tailgating vehicle.

VII. Conclusion and Future Work

A cooperative approach to mimic human communication in a situation in which a vehicle is tailgating another one was proposed in this paper. Tests performed in a real scenario with several vehicles delivered good results in terms of simultaneous image capturing, recognition of following vehicles and the distance calculation to those vehicles. However, we detected some issues related to a buffer overflow after capturing more than 20 images. We solved this problem by clearing the driver buffers automatically every minute. As Linux drivers are updated to work with the ARM architecture provided by the Raspberry Pi, we used them in this work. However in the future we will rely on a different micro-controller with Intel architecture, for better driver support.

The technology presented in this paper could be helpful in situations where the tailgating driver is not paying attention to the distance to the leading vehicle. On the other hand if tailgating is intentional on the part of the rear driver this technology begins a “dialogue” that might remind some tailgaters to be rational. Further research will focus on the driving response to the received message.

ACKNOWLEDGMENTS

This work was supported by the "KiTSmart Project - City of Vienna Competence Team for Intelligent Technologies in Smart Cities", funded by national funds through the MA 23, Urban Administration for Economy, Work and Statistics, Vienna, Austria and the "Photonics Project: Foundations and industrial applications".

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