Collision Avoidance of Intelligent Vehicle based on Networked High-speed Vision System

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Abstract: We propose a driving safety support system (DSSS) that employs a high-speed vision system installed in the environment surrounding, for instance, highways, urban roads, and intersections. The aim of the system is to recognize potentially dangerous traffic situations, including those that are undetectable from a moving vehicle, and to use this information for supporting safe driving. The system consists of a vision network of synchronized high-speed cameras that are capable of acquiring images at one-millisecond intervals, and vehicles that are capable of communicating with this network through communication hubs. We conducted collision avoidance experiments and demonstrated that, by introducing high-speed vision, the proposed system can resolve the issue of slow reaction time, which is common to environmental vision systems.

1 INTRODUCTION

Intelligent transport systems (ITSs) have been developed rapidly in response to the increasing need for safe, economical, and environment-friendly transportation around the world. In Europe for instance, the "Europe 2020" action plan drawn up by the the Commission of the European Community, includes modernization of transport systems, utilization of information and communication technology, and so forth. Also in Japan, the government has been a driving force towards realizing the world's safest transport systems and has outlined several quantitative indicators that will be used for evaluating the efficiency of these systems.

To meet such demands, a large number of systems have been proposed for various applications, like driving safety support. We, however, do not believe that this approach, i.e. to design a system for solving existing problems, is the right one. On the contrary, we believe that a better approach is to have the design of an ITS as the starting point.

Driving safety support systems based on vision systems installed on vehicles have been proposed (Cherng et al., 2009). However, it is impractical to require that all vehicles be equipped with vision units. A more practical and feasible approach is to consider a vision system installed in the environment, for example, roadsides.

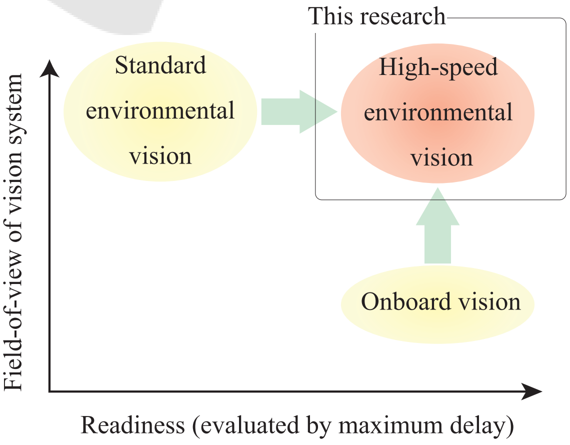

Figure 1: The purpose of this research.

It is widely considered that the introduction of driving safety support systems based on interactions between vehicles and the environment will contribute in a major way to achieving the goals mentioned above (Papadimitratos and Evenssen, 2009; Kim and Kim, 2009). For instance, studies have shown that vehicle-based vision systems are inferior to environment-based vision systems in some cases, for instance, when detecting potential dangers around

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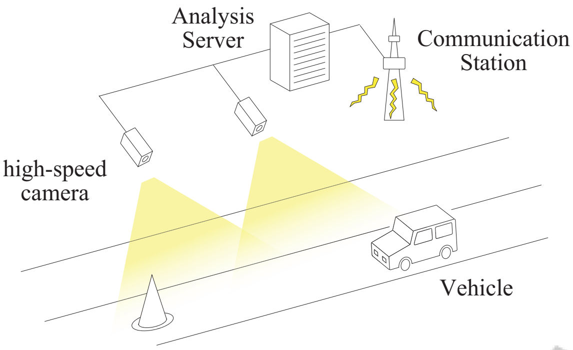

Figure 2: Proposed driving safety support system for collision avoidance.

corners, or on highways when the driver's sight is limited by large trucks (Vceraraghavan et al., 2002).

However, an environment-based system providing information about potential obstacles involves a long reaction time, which is a serious drawback in time-critical situations like collision avoidance. Considering a situation in which a pedestrian runs out in front of a vehicle from behind a parked vehicle, it is difficult to avoid a collision with the pedestrian by using an environment-based vision system alone.

We propose a novel system employing environmental high-speed cameras installed in areas with frequent traffic accidents, such as blind intersections and highways. This camera network forms a vision system synchronized for sub-millisecond communication, a system that we call the "Networked High-speed Vision System" (Noda et al., 2014). This system can overcome the deficiencies in standard environment-based vision systems, as detailed in Section 2. The concept of our study is illustrated in Figure 1.

The system used in this research consists of two high-speed cameras connected to image processing workstations, which are connected via a network. Furthermore, there is a communication station for broadcasting information to vehicles about the surrounding traffic situation, including obstacles around them and other vehicles. The cameras are installed in such a way that the field-of-view of one camera slightly overlaps with that of the other.

With this set-up it is possible to have a large detection range for vehicles moving at high speed and obstacles, even if they are not visible by the same camera. The high-speed vehicles are equipped to receive information about obstacles detected by the vision system, and to take appropriate action, like collision avoidance.

In the remainder of this paper, we describe the proposed driving safety support system designed for installation on a highway and present results of experiments conducted for verifying the effectiveness of this system, specifically, collision avoidance experiments using vision systems that capture images at different frame rates (30 frames per second (fps) and 600 fps).

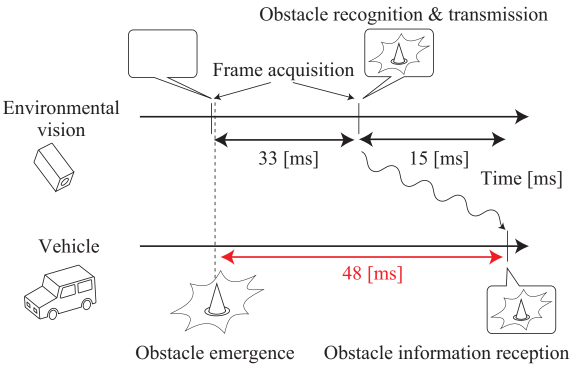

Figure 3: Timing diagram of environmental vision system using standard camera (30 fps).

2 PROPOSED SYSTEM

2.1 Networked High-speed Vision System

Networked high-speed vision systems have previously been proposed (Noda et al., 2013; Noda et al., 2014). In this subsection, we give a short overview of the system.

The networked high-speed vision system consists of multiple high-speed cameras and PCs which are connected via a network. These cameras have partly overlapping fields-of-view and observe the entire space of interest. The PCs are synchronized to sub-millisecond order by using the software-based precision time protocol (PTP). When applying this system to object tracking, the data transmitted in the network includes the position of the tracked target and the timestamp when the frame is acquired.

Thanks to the high acquisition rate, target tracking can be realized by a simple computer algorithm. This system is designed to be used in a number of situations, including highways and intersections. The main target of the system is to track objects moving in the field of view. For this purpose, background subtraction is an appropriate algorithm because it can be executed with low computational load. Since the cameras are calibrated, homography matrices for transforming the cameras' coordinate systems into a common world coordinate system can be obtained. Each target can be identified by its position in

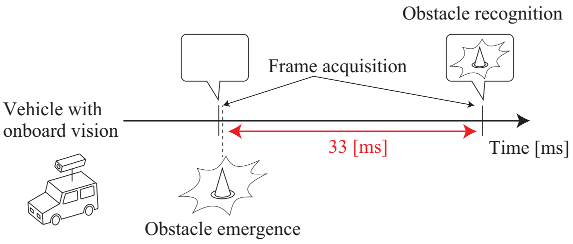

Figure 4: Timing diagram of onboard vision system using standard camera (30 fps).

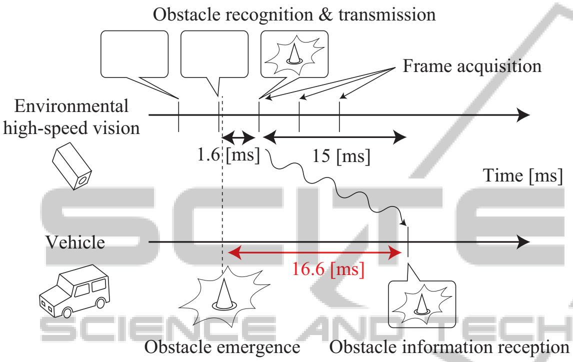

Figure 5: Timing diagram of environmental high-speed vision system using high-speed camera (600 fps).

the previous frame due to the small movement of the target during short frame interval of the high-speed cameras. The main tasks of the CPU include background subtracting, binarization, calculating the image centroid, and so on, which enables tracking to be completed within a 1-millisecond frame interval.

2.2 Proposed Driving Safety Support System

Networked High-speed Vision Systems have a broad range of applications in ITS. As a result of the configuration detailed in the previous section, the system enables us to recognize every traffic situation at a high frame rate. One of the advantages of this system is that, since it can robustly track vehicles on a highway, we can obtain abundant traffic data with high accuracy even for vehicles that are not equipped with special sensors. Therefore, this system can be applied to efficient traffic planning and control by surveillance and analysis of traffic congestion or accidents.

The networked vision system is designed to have high-speed cameras with overlapping fields-of-view in order to provide full coverage of the area in question. The function of the system is to simultaneously detect vehicles and obstacles on the road. As a result, it provides vehicles with traffic information and “obstacle maps”, which represent the locations of obstacles in relation to the target vehicle, through the communication station. The vehicles can then decide whether to take appropriate action, like sudden braking or steering, in response to the incoming information.

In general, an environment-based vision system can monitor a larger area compared with an onboard vision system. It is possible to recognize, at an early stage, different traffic situations involving surrounding vehicles and obstacles. However, an additional delay is inevitably introduced in the wireless communication. Consider for instance a situation where a child suddenly runs in front of a vehicle. In this case, the low responsiveness is a limiting factor in traditional environment-based vision systems.

Moreover, if an obstacle emerges just after a frame is acquired, there is a 33 ms delay in detecting the obstacle, assuming the standard frame rate of 30 fps for standard cameras. Figure 3 illustrates the total delay between detection and the vehicle receiving this information: 33 ms for detection and 15 ms for system-to-vehicle communication.

On the other hand, when a standard camera is installed in the vehicle, there is no delay due to communication. Therefore, as illustrated in Figure 4, there can be a delay of up to 33 ms in such a system.

In contrast, by introducing high-speed cameras capable of image acquisition at 600 fps, the detection delay can be reduced to 1.6 ms. Figure 5 illustrates that vehicles can recognize obstacles within 16.6 ms after an obstacle emerges, including the delay due to communication.

To summarize, the proposed driving safety support system for high-speed vehicles based on an environmental high-speed vision system can recognize traffic situations in the entire area of coverage, and at the same time can achieve the same high responsiveness as standard on-board vision systems.

3 COLLISION AVOIDANCE RULES

The networked high-speed vision system installed on a highway provides information about objects, like other vehicles and obstacles, to each of the vehicles in the covered area simultaneously. It generates an obstacle map from the viewpoint of each target vehicle. In the case of a highway, the obstacle map will include distances from the target vehicle to obstacles, including an indication of which traffic lanes the obstacles are in. The system generates one obstacle map per vehicle on the highway. Since the proposed system uses high-speed vision, the distances that the ve-

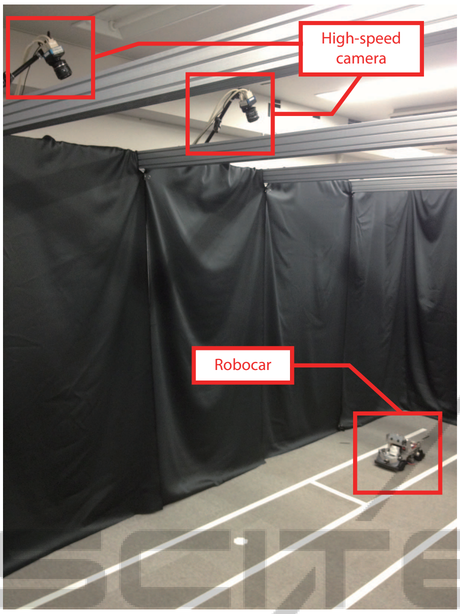

Figure 6: Experimental setup.

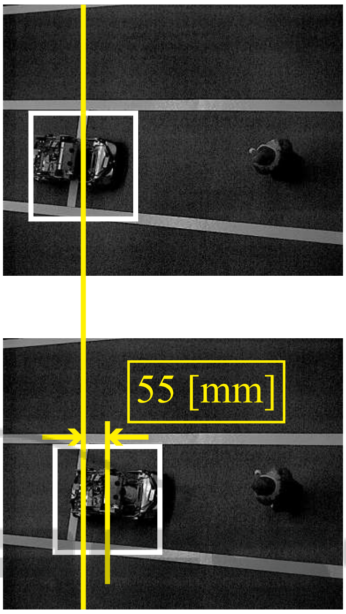

Figure 7: The upper figure shows an image captured by one of the high-speed environmental cameras when the system recognized that the distance to the obstacle fell below the threshold. The lower figure shows the same situation for a standard environmental camera.

hicles move between frames can be significantly reduced (Ishii and Ishikawa, 1999).

Obstacle maps generated by the networked high-speed vision system are distributed to the corresponding vehicles through a wireless network. Each vehicle selects collision avoidance rules from a set of pre-programmed rules, based on the received obstacle map. When an obstacle suddenly appears in front of a vehicle, it is commonly known that collision avoidance by steering is more effective than a sudden stop (Keller et al., 2011).

In the work described in this paper, we assumed such a situation and adopted collision avoidance by steering. More precisely, the vehicle was programmed to start the avoidance maneuver by steering in a certain direction when the distance to the obstacle is less than a pre-defined threshold. The vehicle then drives in a straight line for a fixed time period and finally steers back in the opposite direction, which will place it in the neighboring lane.

4 EXPERIMENTAL SETUP

We conducted an experiment to show the effectiveness of the proposed driving safety support system. The system used in this experiment consisted of a 1/10-scale vehicle, two networked high-speed cameras attached to workstations, and a communication station. The system is shown in Figure 6. The vehicle used in this experiment was a robotic car research platform called “RoboCar 1/10”, provided by ZMP (ZMP, 2014). RoboCar has a realtime operating system (a customized version of Linux), controlling its steering and communication modules. It communicates with the communication station via a Wifi connection (IEEE 802.11g).

The obstacle map contained two 32-bit integer variables per obstacle, where one represented the distance from the vehicle to the obstacle, and the other represented the number of the lane that the obstacle resided in. We limited one obstacle map to containing at most 50 obstacles, meaning that the size of one packet (including header and payload) was 512 bytes, since the payload was 4*2*50 bytes = 400 bytes.

We conducted a preliminary experiment to measure the round-trip time of a 512-byte packet between RoboCar and the communication station. The measured times ranged from 5 ms to 30 ms, indicating a one-way time of 2.5 ms to 15 ms. This result is in agreement with the assumptions made in Section 2.

5 EXPERIMENTS

We conducted an experiment to validate the effectiveness of the proposed system. The setup is illustrated in Figure 6. In this experiment, we assumed a situation where a person suddenly jumps out in front of the vehicle from the roadside onto the highway. Since

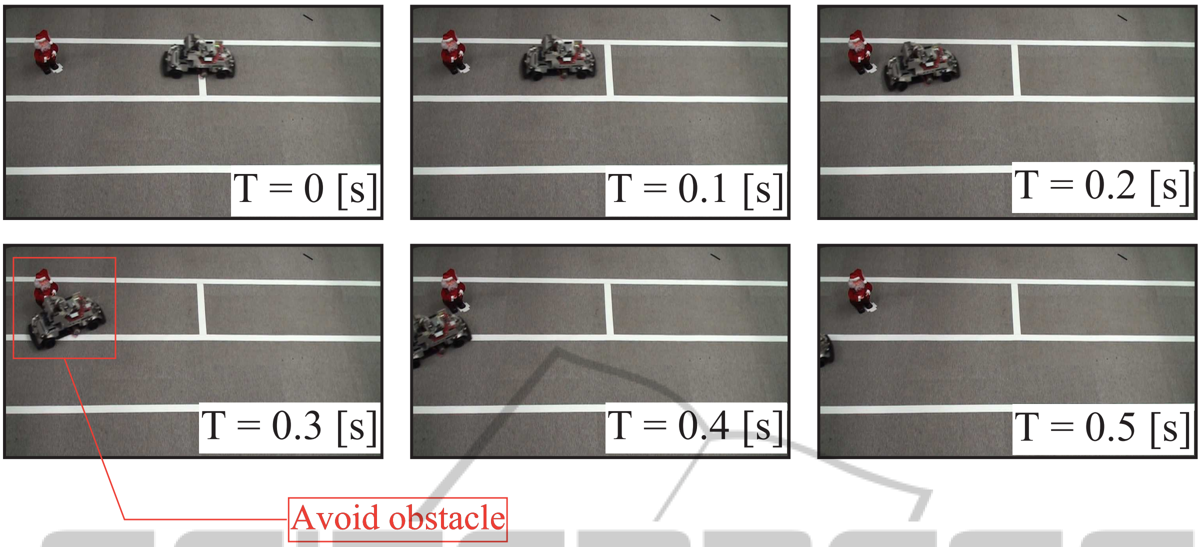

Figure 8: Experimental results for the high-speed environmental vision system.

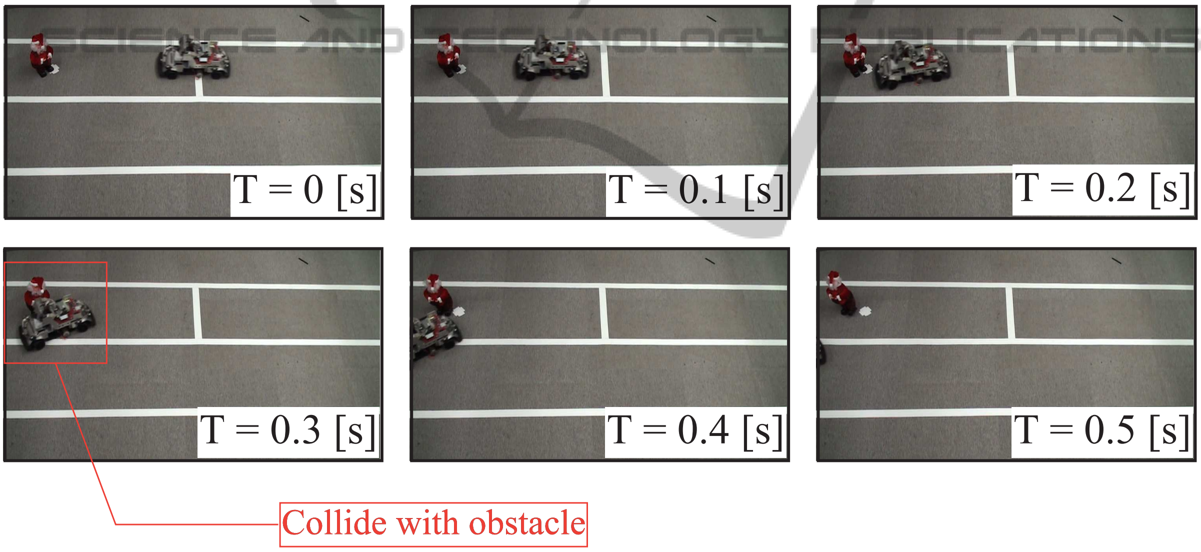

Figure 9: Experimental results for the standard environmental vision system.

the speed of a person on the highway can be considered to be considerably lower than the vehicles on that highway, we modeled the person as a static obstacle. In the experiment, we assumed a situation in which the person (obstacle) that suddenly appeared was detected by the system around 800 mm in front of the vehicle.

To illustrate the effectiveness of the proposed system, we conducted two experiments. In the first experiment, we used standard environmental cameras with standard frame rates of 30 fps. In the second experiment, we introduced a high-speed environmental vision system with a frame rate of around 600 fps.

The results of the experiments are shown in Figures 8 and 9. The vehicle received the obstacle map transmitted by the networked vision system, after which it took action based on a preprogrammed collision avoidance rule. The collision avoidance rule adopted in this experiment was as follows:

1. Start steering at an angle of 30 degrees when the distance from the vehicle to the obstacle falls below the threshold (800 mm) and keep that heading for time T_1.
2. Keep going straight for time T_2.
3. Steer at an angle of -30 degree for time T_1 in order to come back to the neighboring driving lane.

Considering the time required for an evasive maneuver, it is even more important to detect the obstacle at an early stage. The standard environmental vision system could recognize the vehicle when it overshot the threshold by 55 mm. In Figure 7, this threshold is indicated with a white line drawn 800 mm from the obstacle. In contrast, the proposed system could recognize the vehicle just after it reached the line.

When a collision occurred in the case of the standard environmental vision system, the vehicle had a velocity of 7.2 kilometers per hour (km/h) (=1.8 millimeters per millisecond (mm/ms)). Therefore, the delay for recognition in the standard vision system can be estimated to be $55/1.8 \simeq 30.5$ ms. For this reason, collision avoidance fails with the standard vision system, whereas it succeeds with the proposed system.

In this experiment, the vehicle started the evasive maneuver when the distance from the vehicle to the obstacle fell below 800 mm. This distance is equivalent to 8 m at actual scale. It is known that vehicles must maintain at least 58 m intervals between them for safe driving, which is around 7 times longer than 8 m.

6 CONCLUSION AND FUTURE WORK

In this research, we aim to construct a driving safety support system based on networked high-speed vision cameras. We constructed a system employing two high-speed environmental cameras attached to workstations, which were connected via a network and synchronized to sub-millisecond order, and a communication station. We also conducted comparative experiments of collision avoidance. One experiment using standard cameras (30 fps) failed to avoid a collision with an obstacle. In contrast, the other experiment using high-speed cameras (600 fps) succeeded in avoiding a collision with the obstacle. Through fundamental experiments, we demonstrated the effectiveness of the proposed system when applied to a driving safety support system and showed that such a system can overcome the low responsiveness that is common in standard environmental vision systems.

To further reinforce the effectiveness of the proposed system, we are planning to carry out additional experiments to compare it with an onboard vision system for collision avoidance. We also aim to introduce the proposed system in other situations. For instance, it should be possible to apply it to intersections in urban areas. Although vehicles generally drive at lower speeds in urban areas, the speed relative to vehicles driving in the opposite direction is twice as fast as that of the vehicle in question. We expect that our proposed system will be effective even in such situations where the driving speed is not high.

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