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Development of forward collision warning system using laser scanner with camera to detect and estimate object headway distance

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Abstract. Rear end collision is the significant road accident scenario one among others. Such accident always occur when driver estimate an improper distance between his vehicle and the leading one and, therefore, perform an unsuitable driving. This sort of accident can be prevented by introducing an additional active safety system to the vehicle. This system is called a forward collision warning (FCW) system. Such system has been developing for a while and some difficulties arose in distinct processes. Hence, this research aims to improve a headway distance detection, i.e. distance between host and leading vehicle, which is considered as one significant process of the whole FCW system, by introducing a laser scanner and a camera. The process of the developed FCW can briefly explained by the followings. First, the camera is used to classify the headway object if it is vehicle or not, by adopting Haar cascades method in object detection process. Then, the laser scanner will determine the headway distance, in case the leading object is a vehicle. Eventually, the measured headway distance will be used by a processor for warning driver. The system evaluation experiment was conducted to determine the performance of the system, including delay, sensitivity, accuracy, linearity and offset, at the velocity below 30 km/h, hence, verifying the operational velocity below 30 km/h. The result shows significantly fine sensitivity linearity but quite deviate from actual of accuracy at a given speed.

1. Introduction

The report from (WHO) in 2015 estimated a number of road death in Thailand is about 36.2 per 100,000 of populations [1]. By this report, this figure gets ranking number 2 from the entire world. Furthermore, the information collected by the Royal Thai Police which arranging and reveal by the National Statistical Office [2] inform that for the nationwide from 2006 to 2015, 43,643 from the entire 633,198 reported cases are rear end collision which caused by driving too close to a leading vehicle. This figure is not including other cases that can be prevented by introducing some features to driver in order to perform better surveillance and more adequate driving. The more in detail about this figure is shown below in Figure 1.

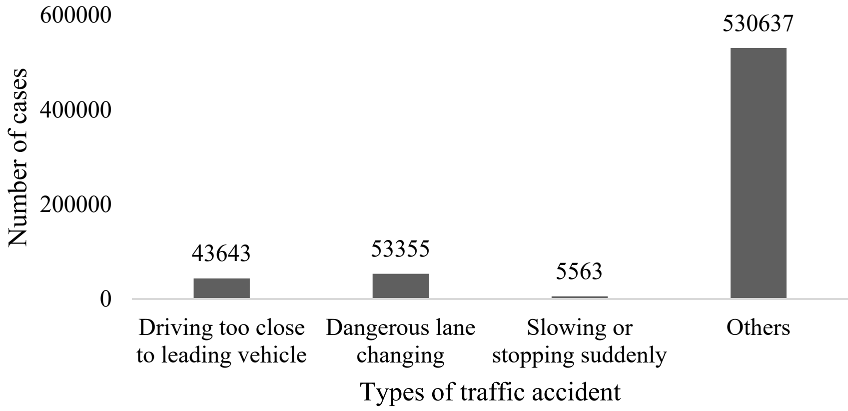

Figure 1. The Situation of Traffic Accident Cause of the Accident by a Person and Environment Causes of the Equipment Used in Driving, Whole Kingdom: 2006 - 2015

Not only happens in Thailand, the United States of America faces the same problem. According to a report from the National Highway Traffic Safety Administration, 1,966,000 from 6,064,000 crashes, of which percentage is about 32.4, are rear end collision [3]. These evidences shows that the rear end stands one of the majority type of accident happen on earth. Consequently, the solution here is to reduce accident, or at least reduce its severity. From above WHO's report, factors that lead to traffic accident can be classify into 3 class, namely human, vehicles and equipment, and environment. Since human plays the main role in controlling vehicle. Hence, in order to reduce the collision possibilities, human, i.e. drivers, should be aided by machine in order to make a better decision while driving in various condition. The method for doing so, one is to adopt the collision warning system. However, a former forward collision warning developed by numbers of department still have some disadvantages due to an inaccurate measuring process, mostly by optical vision, e.g. stereo vision, single camera. For instance, one pervious research adopting a single camera method [4] provides a mean error of -50 millisecond. Consequently, for more effective system, the measuring system should be improved.

From all mention above, this research is therefore aimed to redesign and develop the forward collision warning system in measuring part by introducing the laser scanner or LIDAR in order to provide a more accuracy measurement method to the system.

Finally, the evaluation of the system is conducted to investigate some of characteristic figures which indicate the performance of the system.

2. System Algorithm

Figure 2 shows the process flow of the developed forward collision system. The algorithm in this system begins with an object detection, a process which determines the obstacle in front of the host vehicle if it is a vehicle. Next, the laser scanner will then measure a distance, hence velocity, to the leading vehicle relative to the host vehicle if the obstacle is confirmed to be a vehicle by the object detection process. Eventually, the measured data from the former process will be used to determine the time to collision which is a key parameter of warning criteria for the system to warn driver.

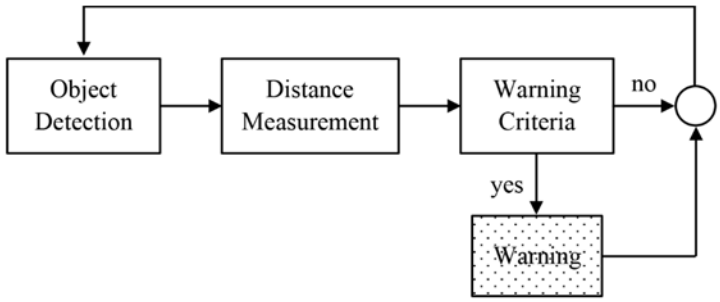

Figure 2. A forward collision warning system process flow

2.1. Object Detection

In object detection process, the machine learning method of classification is introduced, i.e. the Haar-like features or Haar Feature-based Cascade Classifiers [5]. Along with the adaptive boost or AdaBoost boosting process for machine learning, the system may classifies the obstacle and recognize if it is a vehicle.

2.1.1. Haar Feature-based Cascade Classification.

Haar-like features or Haar Feature-based Cascade Classifiers are digital image feature adopt in the object detection or recognition process. This object detection method is introduced in Rapid Object Detection using a Boosted Cascade of Simple Features. The process can briefly explain as follow.

Initially, the algorithm is trained by processing a numbers of positive and negative sample image, i.e. the image with and without the object needs to be detected. In this process, haar features windows are used in quite the same manner as a convolutional kernel in other typical image processing methods to extract features from sample images. These extracted features will later be used as basis for object detection and identification. The sample of haar features kernel are shown in Figure 3.

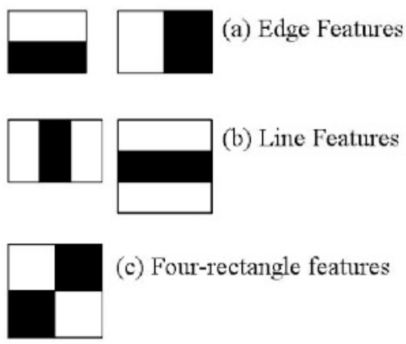

Figure 3. Examples of haar features kernel [6]

2.1.2. AdaBoost

AdaBoost or adaptive boost is a boosting process in machine learning, i.e. the process which helps to reduce error and improve machine learning algorithm. This process will focus on the area where the system is not performing well. A recursive training is the key to this process, samples used in training are introduced repeatedly to a different model whereby the misclassified samples from the previous training are weighted in order that theses samples are more likely to be used in training for the next process. Eventually, when the desired accuracy is achieved, the weighted sum of weak classifiers will be processed as a final classifier, in which these weak classifiers gathering together to perform an effective classifier.

2.2. *Distance Measurement*
In this process, the laser scanner is used as a developed system alternative distance sensor to detect the headway distance. This headway distance will later be processed for a relative velocity between host and leading vehicle.

2.3. *Warning Criteria*
After the relative velocity between host and leading vehicle is obtained, then the time to collision can be derived. This time to collision is a key parameter for system to active a warning process. A certain value of time to collision, i.e. 1 second, is set as criterion of the system. Time to collision is defined by the equation (1), where H is headway distance and V_{rel} is relative velocity between host and leading vehicle.

$$TTC = \frac{H}{V_{rel}} \tag{1}$$

3. Instruments

3.1. *Camera*
The camera used here is the iDS uEye LE. iDS is an industrial digital camera which is adopted in many fields of operation. The advantage of selecting this camera to be used in the project is that the camera itself provide a flexible configuration setting which can be set up directly by users.

The limitation of this camera is that the lens available for this camera has a narrow range of detection. This lens provides only about 30 degrees fields of view. Moreover, the sensor of this camera is quite small, therefore, the image detected by this camera is likely not widely enough for the image processing.

However, all the limitation and drawback mentioned about the camera will be strike off because in this research, the main target need to be detected is the headway or leading vehicles. Consequently, since the task to detect the sort of these object doesn’t need a wide field of view, the problem mentioned above can now be omitted.

Figure 4. iDs uEye LE camera

3.2. *Laser Scanner*
The SICK LMS291 is the laser scanner used in this project. This LMS291 communication protocol is RS232 in serial communication. The data of radial distance comes in series of package of which size is depended the user configuration. This sensor held capability to provide a data maximum speed of 38400 bits per seconds. This value is equal to roughly 10 times of detection in a second.

The range that can be provided by this sensor in a normal condition can be up to 80 meters. This figure may be reduced due to inappropriate operation condition. The field of detection for this sensor can be set to 100 or 180 degree, depends on the user configuration.

Figure 5. SICK LMS291 Laser Scanner

4. Test Experiment

Test experiment is performed by operating this developed forward collision warning system, i.e. driving the test vehicle straight to target vehicle, in a constrained condition, i.e. only single leading vehicle available in the experiment, to obtain the time to collision detected by the developed system. Another vision system of measurement, which provide more precise measurement of actual time to collision, is perform in parallel by recording a reference indicator frame size which will be used to calculate its rate change to obtain an actual time to collision. The test experiment takes place in 60 meters straight test course, test velocity is constrained to the lower than 30 km/h, the scenario is set as shown in Figure 6.

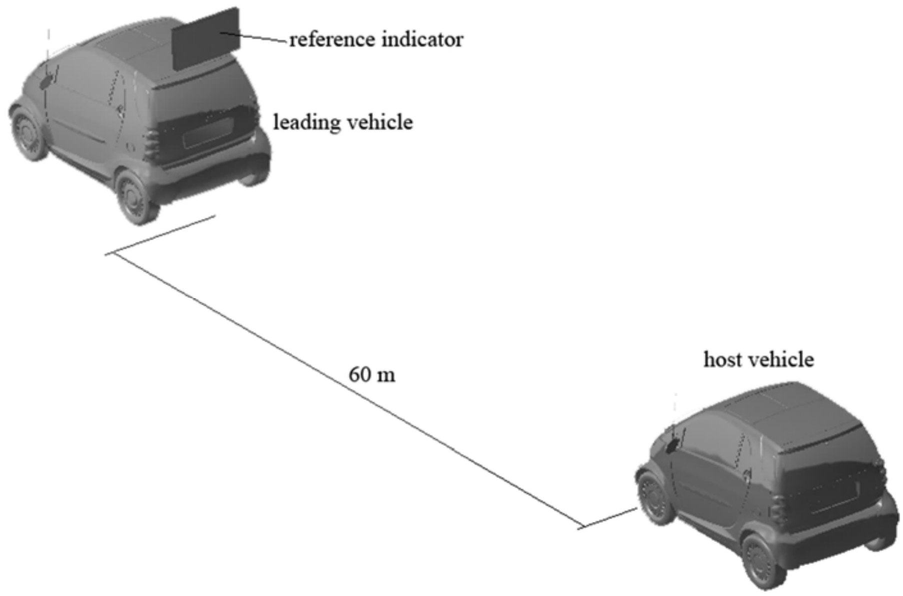

Figure 6. Test experiment scenario

4.1. Actual Time to Collision Measurement

Video recorded from frontal camera of the host vehicle is used in determine the actual time to collision, each frame form this video may look like a frame shown in Figure 7. It can be shown that the time to collision can be determined from a pixel length of reference indicator by the equation (2).

$$TTC = \frac{w}{\dot{w}} \tag{2}$$

Where w and $\dot{w}$ are pixel length and its rate change, respectively.

Figure 7. Example of video frame used in calculation

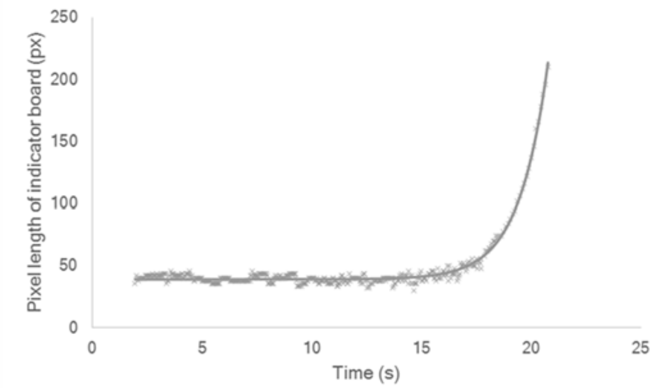

Figure 8. Example of pixel length data

In order to refine the measured actual time to collision, the regression analysis is applied to pixel length data. The fitting equation is shown in equation (3). Also, from this equation, it can be shown that time to collision is expressed as equation (4).

$$w = c_1 e^{c_2 t} + c_3 \tag{3}$$

$$TTC = \frac{c_3}{c_1 e^{c_2 t}} + \frac{1}{c_2} \tag{4}$$

Pixel length data from one of single test run is shown in Figure 8.

5. System Evaluation

Evaluation of system is done after conducting a test experiment. The recorded time to collision from the system will be taken to be compared with another set of reference record derived from another method which is assume to be an actual time to collision. Numbers of characteristic parameters indicate the performance of the system in sense of sensor device, e.g. linearity, sensitivity, accuracy, is then determined.

6. Results and Discussion

6.1. Results

Figure 9 illustrates the calibration curve of the system, i.e. the plot of the developed system measured against the actual time to collision, the linear regression from of this curve is defined by equation (5). Another characteristic parameters of this system is shown by Table 1.

The error distribution, i.e. probability density function (PDF) is also shown in Figure 10. A mean and variance of this error distribution are -17.5 millisecond and 0.0914 square second, respectively.

$$TTC_{sys} = 1.01 TTC_{actual} + 0.03 \tag{5}$$

Where TTC_{sys} and TTC_{actual} are system measured and actual time to collision respectively. Also note that all data points use in determining calibration curve equation (5), shown in Figure 9, are obtained by performing multiple test runs.

Table 1. System characteristic parameters

Parameter	Value	Unit
Sensitivity	1.01	-
Accuracy	0.90	Seconds
	57.30	%FS
Linearity	0.30	Seconds
	1.87	%FS
Offset	0.03	Seconds

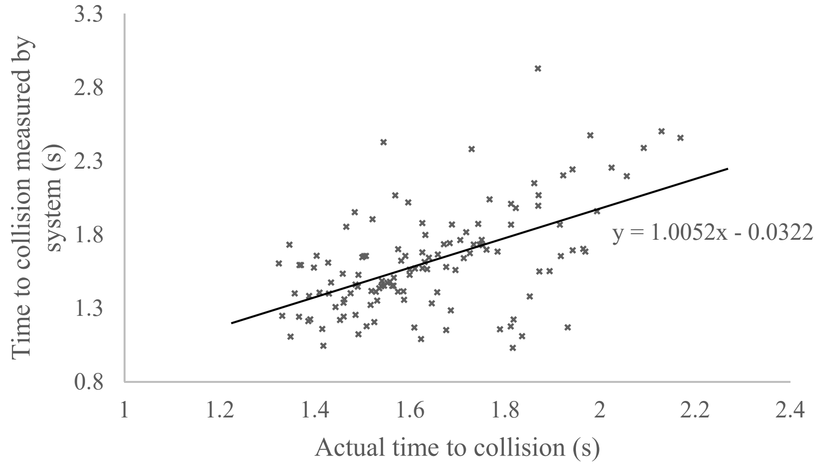

Figure 9. Calibration curve of the system

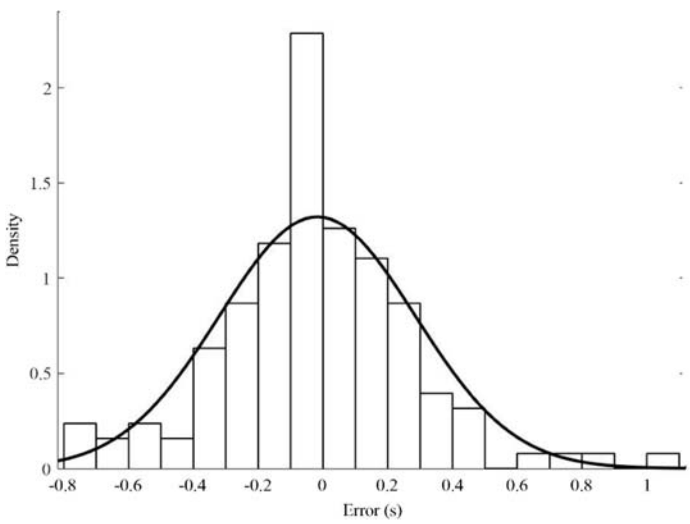

Figure 10. Error distribution of time to collision

6.2. Discussion

After evaluation test experiment is perform, the develop system seem to provide a proper distance measurement information for being used in this develop system, under a constrained condition. However, from a calibration curve in Figure 9, there appear some points of data which largely deviate from the main cluster of points which appear closely to the calibration line which indicate an inaccuracy of the system. Although, the error distribution shows its mean of -17.5 millisecond. This negative value imply that even an inaccuracy measurement occur, the error of the system still effects in safety characteristic of the system, i.e. the error lead to a lower in measured time to collision than the actual one which effects in early warning in warning criteria process. This can be seen by a right-skewed error distribution in Figure 10. Finally, most errors occur in very low value about 20 milliseconds, which may be considered as a satisfactory characteristic of the system.

7. Conclusion

This alternative method of measuring time to collision by introducing the laser scanner as distance measurement tool can provide a fair accuracy. By comparing the mean error occur in this method to that stated in a previous research mentioned in the introduction section, it appears that the mean error of this propose method is only 0.35 times of that mentioned research. In addition, characteristic of error distribution in this method indicate a false-safety behavior of the time to collision detection system.

Acknowledgement

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