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ABSTRACT

In this paper, we introduce evaluation methods for vehicle speed detection and license plate recognition using vision-radar conversion systems. The vision-radar sensor systems can be applied to automatic speed enforcement systems and traffic information surveillance systems. Thus, the accuracy of speed detection and license plate recognition is important for evaluation metrics. In this study, two different data are individually collected by vision cameras and radar sensors respectively, which are converted into speed data by our conversion algorithm. We propose new evaluation methods for vehicle speed detection and license plate recognition by comparing the speed data of vision-radar sensors with reference speed data. Two different evaluation methods have been used for automatic speed enforcement systems and intelligent transportation systems. The proposed methods have different evaluation methodologies in installing equipment, producing reference data, analyzing data, and collecting data. We expect that the proposed evaluation methods will be suitable for other similar systems.

Keywords: Vision-radar sensor, speed enforcement system, evaluation method, speed detection accuracy, license plate recognition accuracy

1. INTRODUCTION

The one primary goal of road safety policies in developed countries is to eliminate mortality. Thus, many governments have employed automatic speed enforcement systems on roads. In particular, the Korea government will install over 10,000 speed enforcement systems until 2017. Generally, an inductive loop detector is used for a speed enforcement system, which provides accurate and reliable speed detection. However, traffic congestion can occur during the detector installation in the road pavement. Moreover, a loop detector cannot be embedded over any bridges owing to the metal structure and thin covering pavement. For instance, an inductive loop needs at least 300mm of space to any ferrous metal object and at least 100mm of covering pavement.

In August 2014, anti-corruption and civil rights commission (ACRC)in Korea encouraged Busan city to install automatic speed enforcement systems on Gwangan Bridge in order to reduce roadway noises from illegal street racing. However, Busan city announced that automatic speed enforcement systems cannot be installed on Gwangan Bridge because a valid technology was not developed.

Many sensors were tested in order to replace the inductive loop detectors to non-intrusive detectors such as laser-based detectors and radar-based detectors. The two detectors provide easy installation and accurate speed detection. However, they also have some disadvantages.

The laser-based speed detector has limited detection area if it is installed on the side of a road. The vehicles moving on the inside lane will not be detected if another vehicle is moving on the outside lane at the same time. The radar-based speed detector is interrupted by weather conditions such as fog, rain, and snow. Moreover, if it is installed on a bridge, reliable data collection will not be satisfied owing to the bridge vibration. The two speed detectors cannot be applied to a bridge because of the limitations mentioned earlier.

In this paper, we introduce a novel non-intrusive speed detector that uses a vision camera and a radar sensor. Moreover, we propose new evaluation methods for the proposed system for providing more reliable speed detection on multiple lanes. The vision camera and radar sensor produce speed data individually, and then final speed data is calculated by combining the two speed data.

The speed data of the two devices have their own error rate and limitation. The speed detection accuracy of a vision camera is declined by weather conditions. On the other hand, a radar sensor produces constant speed data regardless of the weather conditions. However, the accuracy of a radar sensor is dropped by signal reflection and dispersion on multiple lanes.

This paper introduces the concept of data conversion methods collected from a vision camera and a radar sensor. In addition, analysis results and discussion are presented in order to explain the prospects of our systems.

The remainder of this paper is organized as follows. In the next section, we review the existing evaluation methods. In Section 3, we describe our proposed evaluation methods. Finally, our conclusions and ideas for future work regarding this study are provided in Section 4.
2. RELATED WORK

2.1 Evaluation Methods for License Plate Recognition Systems

In Korea, standard evaluation metrics for vehicle speed detection are described in the evaluation criteria of intelligent transportation system (ITS) which is published by Ministry of Land Infrastructure and Transport (MOLIT). The criteria are to maintain the performance quality of devices, systems, and services in ITSs. In addition, methods and procedures for a reliable evaluation are presented for ITS devices [1].

The device evaluation of ITS can be classified into 4 different types of evaluations; essential, completion, regular, and relocation evaluation. In the essential evaluation, the performance of ITS devices is compared with reference devices, where the evaluation is performed once before the installation of devices. The completion evaluation is performed after the installation of devices in order to maintain the device performance quality. Repairing and correcting of devices are performed at the regular evaluation to restore device aging and performance drops. In the relocation evaluation, calibration and correction of devices are performed based on the relocated road environment.

The performance evaluation for ITS devices can be divided into 4 steps as mentioned earlier. In this study, we will analyze the accuracy of speed detection and license plate recognition. The criteria of national police agency describe the detailed evaluation metrics such as speed detection accuracy, license plate recognition rate, and vehicle detection rate.

In this study, we analyze the difference between the criteria of national police agency and ITS, where we will produce improved evaluation methods that can supplement each other. Table 1 elaborates the performance criteria for automatic vehicle identification (AVI) systems.

<table>
<thead>
<tr>
<th>Evaluation Items</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After December 2010</td>
<td>Before September 2010</td>
</tr>
<tr>
<td>Highest</td>
<td>≥95</td>
</tr>
<tr>
<td>High</td>
<td>95 &gt; .≥85</td>
</tr>
<tr>
<td>Middle</td>
<td>85 &gt; .≥80</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; 80</td>
</tr>
</tbody>
</table>

The accuracy of license plate recognition and the number of passed vehicles should be collected at every analysing interval when we evaluate target devices. In order to validate the objectivity of performance evaluation, various data should be collected from different experiment environments where continuous video data is necessary for verifying the experiment.

The accuracy of license plate recognition can be generated by comparing the detected results with the results of manual recognition. For calculating the accuracy of license plate recognition, essential evaluation is applied on weekdays with 4 different times; for instance, sunrise (15 minutes before and after sunrise), daytime (from 30 minutes after sunrise to 30 minutes before sunset), sunset (15 minutes before and after sunset), and nighttime (from 30 minutes after sunset to 30 minutes before sunrise). The evaluation is performed for at least 3 days (more than 100 vehicles) with 30 minutes analyzing interval. On the other hand, the three other evaluations are performed on weekdays with two different times; for instance, daytime (from 30 minutes after sunrise to 30 minutes before sunset) and night time (from 30 minutes after sunset to 30 minutes before sunrise). The evaluation is performed for 1 hour (more than 200 vehicles), and its analyzing interval is 1 hour.

In the regular evaluation, all AVI devices that are more than 2 years old are evaluated during the daytime. Moreover, the 50% of all devices are evaluated by rotation every a year. If we perform the regular evaluation at nighttime, the 20% of devices are randomly selected. The number of devices for evaluation at nighttime can be calculated as follows:

\[ S_n = N_d \times 0.2 \]  

Where \( S_n \) is the number of devices for nighttime evaluation, \( N_d \) is the number of all devices in case of completion evaluation and relocation evaluation. \( N_d \) can be the number of selected devices for a current year.

Threatening location should be avoided during a performance evaluation. The items of evaluation include vehicle detection time, lane number, license plate number, and video data.

As mentioned earlier, evaluation during the daytime is performed from 30 minutes after sunrise to 30 minutes before sunset, and evaluation at nighttime is performed from 30 minutes after sunset to 30 minutes before sunrise. Both evaluations in daytime and at nighttime should be processed for 1 hour with at least 200 vehicles. However, we can complete the evaluation if more than 500 vehicles are passed for 30 minutes. If the number of passed vehicles is less than 200, we can extend the evaluation period to more than 1 hour. However, the extended period can be over 1 hour. All vehicles passed on multiple lanes should be included.

2.2 Evaluation Methods for Speed Enforcement Systems

In Korea, speed enforcement systems are installed based on Road Traffic Act Article 2, and the functions and standards are described on the standard specification of national police agency [2]. The performance criteria of automatic speed enforcement systems are the detection rate of violation vehicles, the error rate of license plate recognition, the error rate of
vehicle speed detection, and speed enforcement error rate. The detection rate of violation vehicles can be calculated as shown in Equation (2), and it should be over 80%.

\[
\frac{\text{the number of detected violation vehicles}}{\text{the number of violation vehicles}} \times 100
\]  

(2)

The error rate of license plate recognition can be calculated as shown in Equation (3), and it should be less than 2%.

\[
\frac{\text{the number of wrongly recognized vehicles}}{\text{total number of recognized vehicles}} \times 100
\]  

(3)

The error rate of vehicle speed detection can be calculated as shown in Equation (4), and it should be less than ±5%.

\[
\frac{\text{measured speed} - \text{reference speed}}{\text{reference speed}} \times 100
\]  

(4)

The speed enforcement error rate can be calculated as shown in Equation (5), and it should be less than 2%.

\[
\frac{\text{the number of wrongly detected vehicles}}{\text{total number of detected vehicles}} \times 100
\]  

(5)

In the license plate recognition systems, the recognition accuracy and error rate should be over 80% and less than 2% respectively. All characters and numbers in the license plate should be recognized.

Moreover, current license plates, general plates, and specially-equipped vehicle license plates are should be classified. The minimum width of lanes is 3.2m. The license plate recognition accuracy should be calculated using the images that are clean enough form annual recognition. The other abnormal plates should be removed such as diplomat official vehicle plates, military official vehicle plates, and temporary plates, damaged plates, and covered plates. Table 2 shows evaluation metrics and methods for speed enforcement systems.

**Table 2: Evaluation metrics for speed enforcement systems**

<table>
<thead>
<tr>
<th>Error rate of speed detection</th>
<th>Error rate (%) = (\frac{\text{measured speed} - \text{reference speed}}{\text{reference speed}} \times 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed error (km/h) = measured speed − reference speed</td>
<td>average speed error (km/h) = (\sum \frac{</td>
</tr>
<tr>
<td>Reference speed (km/h) = collected speed from reference detectors</td>
<td>Measured speed (km/h) = collected speed from speed detectors</td>
</tr>
</tbody>
</table>

| Error rate of license plate recognition | Error rate (%) = \(\frac{\text{the number of wrongly recognized vehicles}}{\text{the number of all recognized vehicles}} \times 100\) |

| Resolution | Resolution (%) = \(\frac{\text{the number of manually recognizable vehicles}}{\text{the number of all recognized vehicles}} \times 100\) |

**2.3 Existing Studies**

The performance evaluation methods for speed detection and license plate recognition have been studied in various environments. The most important evaluation metrics are license plate recognition accuracy and speed error rate. Ryu and Byun [3] proposed the methods of collecting reference data for developing evaluation methods of non-intrusive vehicle detectors. The authors provided flow, speed, and occupancy for evaluation metrics where possible error rate was ±5%. Lim and Ryu [4] introduced the evaluation methods for the devices on national highway. In study [5] and [6], the authors proposed over-weighted vehicle detection systems that consist of license plate recognition systems, speed detection systems, and weight measurement systems. New methods for improving existing ITS evaluation methods were proposed by Han and Ryu [7]. In study [8], a replacement interval was suggested because the life span is changed by installing environments and operating conditions. Various evaluation methods were performed for speed detectors. However, certain number of limitations was found. Jang and Choi [9] provided limitations and improvement for the evaluation of speed detection. The authors showed the methods of producing an uncertainty of reference data and confidence intervals of analyzing period.
3. PROPOSED EVALUATION METHODS

3.1 The Definitions of Evaluation Requirements

Standard evaluation criteria have not been defined for vision-radar sensor systems. Thus, in this study, we suggest specific requirements. First, we suggest evaluation metrics such as sampling rate, speed detection accuracy, the number of detected vehicles, and detected speed of vision-radar sensors. The sampling rate of a radar sensor and a vision camera is produced by operating software, and the interval should be less than 100msec.

For ITS devices, we use mean absolute percentage error (MAPE) for evaluating speed detection accuracy during the analysis interval. However, for speed enforcement systems, the analysis interval is not determined, and individual speed data is used. The number of detected vehicles is generated by counting vehicles in video data and in recognized vehicles. In case of vision-radar systems, the speed detection accuracy is calculated by counting the amount of data per second, and then it is compared with reference data. The evaluation period and data analysis interval should be determined.

Typically, the speed enforcement systems and intrusive speed detectors are used to produce reference speed data. However, these sensors have certain error rate as well. Thus, it is important to reduce the uncertainty of the reference data.

The accuracy of license plate recognition is calculated by comparing manual detection results with automatically recognized results where video data is used together for verifying the results. The number of wrongly detected vehicles is calculated by video analysis. Next, the evaluation of license plate recognition is performed.

Exceptional vehicles are manually removed to supplement sample data.

3.2 Evaluation Procedure

The sampling rate is individually produced for a vision camera and a radar sensor. The average speed of the same vehicles that have the same ID number is used in the operating software. On the other hand, it is produced by dividing the sum of sampling intervals by the number of samples.

![Figure 1: Evaluation regions](http://www.cisjournal.org)

In this study, we need to evaluate the accuracy of speed detection and license plate recognition for speed enforcement systems. We think that the AVI evaluation methods are appropriate for evaluating the accuracy of license plate recognition that can be calculated by comparing the number of recognized vehicles with the number of passed vehicles. As mentioned earlier, abnormal vehicles are removed as well.

The accuracy of license plate recognition is calculated as follows:

### Table 3: Proposed evaluation methods

<table>
<thead>
<tr>
<th>Evaluation criteria</th>
<th>ITS</th>
<th>National Police Agency</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy of speed detection (%)</strong></td>
<td>Mean Absolute Percentage Error (MAPE)</td>
<td>Speed error rate (MAPE)</td>
<td>Speed accuracy (MAPE)</td>
</tr>
<tr>
<td></td>
<td>$\sum_{i=1}^{n} \frac{</td>
<td>y_i-x_i</td>
<td>}{y_i} \times 100$</td>
</tr>
<tr>
<td></td>
<td>$y_i = \text{reference data}$</td>
<td>* Less than ±5%</td>
<td>* Uncertainty included</td>
</tr>
<tr>
<td></td>
<td>$x_i = \text{measured data}$</td>
<td>* Collected speed difference between target devices and reference devices (only for the vehicles that have run over speed limit).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$n = \text{the number of samples}$</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* vehicle speed: average speed during the analysis interval</td>
<td>* analysis interval: 1 minute</td>
<td></td>
</tr>
<tr>
<td><strong>Accuracy of license plate recognition (%)</strong></td>
<td>Accuracy = 100% − PE</td>
<td>Detecting entire number plate region</td>
<td>Accuracy = 100% − PE</td>
</tr>
<tr>
<td></td>
<td>$PE = \frac{E}{Y} \times 100$</td>
<td>* accuracy ≥ 80%</td>
<td>$PE = \frac{E}{Y} \times 100$</td>
</tr>
<tr>
<td></td>
<td>$E$: the number of wrongly detected vehicles</td>
<td>* error rate &lt; 2%</td>
<td>$E$: the number of wrongly detected vehicles</td>
</tr>
<tr>
<td></td>
<td>$Y$: passed vehicles during the analysis interval (60 minutes)</td>
<td></td>
<td>$Y$: passed vehicles during analysis interval (60 minutes)</td>
</tr>
</tbody>
</table>
| **Confidence intervals for data collection** | Data collection for 3 days on weekdays - sunrise (15 minutes before and after sunrise) - daytime (from 30 minutes after sunrise to 30 minutes before sunset) | None | Data collection for 3 days on weekdays - sunrise (15 minutes before and after sunrise) - daytime (from 30 minutes after sunrise to 30 minutes before sunset) - sunset (15 minutes before and after sunset) - nighttime (from 30 minutes after sunset to
license plate recognition accuracy = 100% – \frac{E}{Y} \times 100 \hspace{1cm} (6)

Where $E$ is the number of wrongly detected vehicles, and $Y$ is passed vehicles during the analysis interval. We use 60 minutes for the analysis interval.

3.3 The Methods of Producing Reference Data and Installation Requirements

First, we need to determine the installation requirements for vision cameras, radar sensors, and lighting devices. In case of the vision camera, installation height, camera angle, resolution should be determined, and detection range, horizontal angle, and vertical angle need to be determined. The measured distance should be matched to real distance correctly. Speed data can be calculated by counting pixels and mapping the radar coordinate information to vision information.

The evaluation area is from 25m to 30m as shown in Figure 1. The camera records 4 lanes at the same time. The camera angle is from 15 degree to 20 degree. Image distortion occurs at the image border. Thus, it should be revised.

We install reference devices on different location according to the evaluation metrics such as the accuracy of license plate recognition and speed detection. The target devices and reference devices are installed on the same location for generating the accuracy of license plate recognition, and more than 2 cameras are employed in order to record 4 lanes at the same time. First camera is positioned at the same location with the target devices, and the other camera is positioned near the reference devices. We use an inductive loop sensors and dual laser sensors for producing reference data.

Reference data is collected for 3 days on weekdays with 4 difference times such as sunrise, sunset, daytime, and nighttime. The analysis interval is 30 minutes. If enough sample data is not collected, the analysis interval is extended according to the previously defined.

3.4 Analysis Methods for Vehicle Speed Detection and License Plate Recognition

We compare measured speed data with reference data that collected from inductive loop sensors and laser sensors. After correcting the measured speed data based on the reference data, we produce accurate reference data. The reference sensor devices provide accurate speed data.

However, it is obvious that the two sensors still have uncertainty. When we evaluate detected vehicle speed, the uncertainty should be included. The uncertainty of measurement is the variance of measured data. Typically, error is the difference between measured data and reference data.

The speed data from vision-radar sensor is compared with reference speed data where reliability of data collection interval should be considered. Speed evaluation need to be performed for entire evaluation period. However, it is difficult in reality. Thus, we use the standard interval described in the evaluation guides of ITS and national police agency. Table 3 elaborates the proposed evaluation methods.

4. CONCLUSION

In this paper, we proposed new evaluation methods for the accuracy of speed detection and license plate recognition of vision-radar sensor systems. We referenced the evaluation metrics of ITS and national police agency. We found some differences between the two evaluation metrics. In case of speed detection accuracy, an average speed data was used in the ITS evaluation metrics. On the other hand, an individual speed data was used in the evaluation metrics of the national police agency. Moreover, there were different data collection intervals where data is collected for 3 days with 1 hour analysis interval in the ITS evaluation metrics but the national police agency does not provide the two metrics.

In the license plate recognition, both metrics have similar evaluation methods. Only data collection interval was different, for instance, ITS evaluation metrics require sunrise, daytime, sunset, and nighttime evaluation for 3 days on weekdays. However, the national police agency does not require them. On the basis of our analysis, we suggested our own evaluation methods for the accuracy of speed detection and license plate recognition by analyzing the methods of producing reference data and analyzing measured data.

ACKNOWLEDGEMENTS

This work was supported by KAIA grant funded by the Korea government(MOLIT) and development of hybrid traffic surveillance system using radar and ANPR camera in multi-lane, 2015(010401).

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