A Road Surface Condition Monitoring System Using Bicycle-Mounted Laser Light

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Abstract — In the case of cycling at night, it is helpful for cyclist if information on bad road surface condition is obtained automatically. In this paper, we propose a system for automatically monitoring road surface condition by using laser light and camera modules. In our system, the laser light module emits laser light, and the camera module captures the image of front road area periodically. When the camera module detects bad road surface condition by processing obtained images, it alerts to the cyclist. In this paper, we apply template matching for detecting obstacles in the front of bicycle. We implement the system using off-the-shelf node, Raspberry Pi, a laser module and a typical bicycle. Through experimental evaluations using various kinds of laser light, we confirm that the monitoring system can detect obstacles in the front of bicycle.

Keywords - Bicycle; Laser light; Road surface condition monitoring; Raspberry Pi;

I. INTRODUCTION

In the case of cycling at night, a light module is usually used so that the cyclist can see the front area and road surface condition. However, it is not easy for the cyclist, especially elderly people, to see the road surface condition carefully during cycling at night. If information on bad road surface condition is obtained automatically, it is helpful for the cyclist to prevent accidents.

Until now, there have been many research works or products for monitoring road surface conditions. In the area of research on participatory sensing, there are a lot of research work for monitoring road surface conditions using sensors such as smart phones attached at bicycles [1]—[3]. In these researches, after someone first passes the road, the road surface condition is estimated and the information is shared among users. However, these approaches cannot be applied to new road, or road with insufficient monitoring information.

On the other hand, there have been proposals for monitoring road surface conditions in the front area using special sensing devices [4]—[6]. In [5], [6], we used a low-cost ultrasonic distance sensor for monitoring road surface condition of front area. We implemented a prototype of our proposed system by using an off-the-shelf node and an ultrasonic distance sensor, and evaluated the system in terms of detection capability of holes and obstacles. However, the ultrasonic distance sensor-based approach can only detect whether the hole or obstacle is in the front area or not. In the approach, the position or size of obstacle/hole cannot be estimated.

In this paper, we propose a system for automatically monitoring road surface condition based on image processing technologies. The overview of our monitoring system is shown in Fig. 1. Our system consists of a laser light module and a camera module. The laser light module emits laser light, and the camera module captures the image of front road area. When the camera module detects bad road surface condition, it alerts to the cyclist. In this paper, we implement the system using off-the-shelf node, Raspberry Pi, a laser module and a typical bicycle. We evaluate our proposed system through experimental evaluations.

II. RELATED WORK

There are some research work or products for monitoring road surface conditions [4]—[11]. In some research work, road surface condition monitoring using robots [7], [8] or
low speed vehicles [9] are considered. They considered to use laser range finders or Kinect sensors for monitoring. However, the costs or the energy consumption of these sensors are comparatively high.

On the other hand, in [4], the authors considered to use an ultrasonic distance sensor for monitoring road surface condition under the front tire. In [5], [6], we also applied an ultrasonic distance sensor for monitoring holes or obstacles in the front area of bicycle. However, the ultrasonic distance sensor-based approach can only detect whether the hole or obstacle is in the front area or not. In the approach, the position or size of obstacle/hole cannot be estimated.

Byxee [10] is a concept of a device for monitoring road surface condition in the front area of bicycle. It is currently not commercially available. It uses camera for detection, and the range of detection is from 15 m to 25 m. Our proposed system also uses camera for detection. However, we especially consider to monitor road surface condition at night using light module in this paper.

There are some products or concepts of laser light module for bicycles [12], [13]. Lumigrids [12] is a concept of grid laser light module for bicycles and we inspired from the concept. Currently Lumigrids is not commercially available. Therefore, we implement a prototype of laser light using off-the-shelf modules in this paper. Blaze [13] is also a laser light module for bicycle. In this product, a pattern of bicycle is displayed on the front road surface of bicycle so that a driver can notice the existence of bicycle. Our proposed monitoring system can be applied in a variety of pattern of laser light. We evaluate our system using various kinds of laser light in this paper.

III. ROAD SURFACE CONDITION MONITORING SYSTEM

In this section, we propose a road surface condition monitoring system using laser light.

A. Overview

We first explain the overview of the road surface condition monitoring system intended in this paper. Hereinafter, we denote the system the monitoring system. Figure 1 shows the overview of the monitoring system. The monitoring system is mainly composed of two modules: the laser light module and the camera module. The laser light module just emits laser light to the ground. The camera module captures the image of front road surface. When the camera module detects bad road surface condition such as obstacles, bumps, breaks, dips, potholes, it alerts to the cyclist by blinking or sound. As a result, the cyclist can react to the bad road surface. In the next section, we explain how the monitoring system detects bad road surface condition.

B. A method for detecting bad road surface condition

In this paper, we propose a template matching-based method for detecting road surface condition from obtained image by camera module. The image $f_i$ is obtained from camera module periodically. The road surface condition is estimated based on each image $f_i$ as shown in Fig. 2. The detail is as follows:

1. From both obtained image $f_i$ and template image $f_T$, the color component of laser light (for example, red) is extracted.

2. By using template matching method, we compare the obtained image $f_i$ and template image $f_T$ as follows. First, the normalized correlation coefficient $R_{X,Y}$ is calculated for each pixel in obtained image $f_i$.

$$R_{X,Y} = \frac{\sum_{x,y} (T_{x,y} I_{X+x,Y+y})}{\sqrt{\sum_{x,y} (T_{x,y})^2 \sum_{x,y} (I_{X+x,Y+y})^2}}$$

where $I_{x,y}$ is pixel value of obtained image $f_i$ at $(x, y)$, $T_{x,y}$ is pixel value of template image $f_T$ at $(x, y)$. The normalized correlation coefficient $R_{X,Y}$ is changed between -1 and 1. The higher normalized correlation
coefficient indicates that the region in the obtained image is similar to the template image.

After calculating the normalized correlation coefficient for each pixel, the maximum normalized correlation coefficient (MNCC) $R_M$ is calculated as follows.

$$R_M = \max_{X,Y} R_{X,Y}$$

3. If $R_M$ is higher than a threshold $R_T$, the road condition is estimated as good. Otherwise, the road condition is estimated as bad.

IV. IMPLEMENTATION

In this section, we implement a prototype of the monitoring system. Figure 3 shows the snapshot of our prototype and Table I shows the details of parts used in the implementation.

For laser light module, we used a combination of a red laser module and lens for achieving various kinds of light pattern. For example, by using the lens DOE DE-R256, light pattern of square grid can be displayed on the ground. In this paper, we used four kinds of lens so that light pattern of grid, lines, dots, and rings can be accomplished. Although the strength of illumination becomes higher when higher powered laser module is used, we used the current laser module for safety reason. Figure 4 shows an example of obtained image from camera module when grid laser light is used.

We used Raspberry Pi (with RASPBIAN WHEEZY 2015-05-05 Release) for camera module of the monitoring system. A wireless module, a camera and a mobile battery are attached to the node. We used OpenCV and Python for implementation of our proposed method.

V. EVALUATION

In this section, we evaluate the implemented system through experiments.

A. Fundamental evaluation with grid laser light

We first confirm whether our proposed system can detect obstacles or not. We used grid laser light as pattern of laser light and we used following three obstacles for evaluation:

- Obstacle 1: Can (diameter 5 cm, height 15 cm)
- Obstacle 2: Circular box (diameter 18 cm, height 8 cm)
- Obstacle 3: Box (34 cm $\times$ 23 cm $\times$ 5 cm)

Figure 5 shows the snapshot of obstacles. For evaluation, we obtained images from camera module attached at bicycle as shown in Fig. 6. The size of image is 2592 $\times$ 1944. From one of obtained images without obstacle, we obtain template image $f_T$. The size of template image is 1300 $\times$ 1300. By using these images, we calculate the maximum normalized correlation coefficient $R_M$ of each image. For comparison purpose, we also calculate $R_M$ when
TABLE II. EVALUATION RESULTS USING GRID LASER LIGHT

<table>
<thead>
<tr>
<th>Situation</th>
<th>Without preprocessing (All RGB information is used)</th>
<th>With preprocessing (Only red information is used)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MNCC $R_M$</td>
<td>Processing time [s]</td>
</tr>
<tr>
<td>No obstacle</td>
<td>0.987</td>
<td>16.38</td>
</tr>
<tr>
<td>Obstacle 1</td>
<td>0.901</td>
<td>16.49</td>
</tr>
<tr>
<td>Obstacle 2</td>
<td>0.827</td>
<td>15.83</td>
</tr>
<tr>
<td>Obstacle 3</td>
<td>0.727</td>
<td>18.55</td>
</tr>
</tbody>
</table>

Table II shows the maximum normalized correlation coefficient $R_M$ for each image. As shown in Table II, $R_M$ is varied depending on the size of obstacle. In this experiment, if the threshold $R_T$ is between 0.932 and 0.991, the proposed monitoring system can detect obstacle. However, in this evaluation, we just confirmed three kinds of obstacles. As future work, we should evaluate $R_M$ by using various kinds of images.

In addition, as shown in Table II, by using preprocessing, the maximum normalized correlation coefficient becomes higher and the processing time becomes lower. However, the processing time is quite large when we consider to apply the method for real-time detection of bad road surface condition from moving bicycle. Therefore, we should shorten the processing time by using non-script program such as C, by setting ROI (Region of Interest), and by shortening the size of image.

B. Evaluation with various laser light

We next evaluate our proposed system using various patterns of laser light. We used four laser light patterns: grid, lines, dots and rings. Figure 7 shows snapshots of images for each laser light pattern when there is the box (obstacle 3) in the front of bicycle.

Table III shows the maximum normalized correlation coefficient $R_M$ for each laser light pattern. As shown in Table III, for each laser light pattern, $R_M$ of non-obstacle image is the maximum. Therefore, by introducing appropriate threshold $R_T$, our proposed system can detect obstacle. The range and the center value of threshold for each laser light pattern in this experiment are shown in Table III.

In addition, as shown in Table III, the maximum normalized correlation coefficient $R_M$ is varied depending on laser light pattern. Therefore, it is shown that threshold $R_T$ should be determined depending on laser light pattern. From these results, we can conclude that our proposed system can be applied with a variety of patterns of laser light.

preprocessing (step 1 in section III-B) in our proposed method is not applied. In addition, we measure the processing time of the calculation of $R_M$ by using time command at Raspberry Pi node.
TABLE III. EVALUATION RESULTS OF $R_m$ USING VARIOUS LASER LIGHT PATTERNS

<table>
<thead>
<tr>
<th>Situation</th>
<th>Grid laser light</th>
<th>Lines laser light</th>
<th>Dots laser light</th>
<th>Rings laser light</th>
</tr>
</thead>
<tbody>
<tr>
<td>No obstacle</td>
<td>0.949</td>
<td>0.971</td>
<td>0.929</td>
<td>0.969</td>
</tr>
<tr>
<td>Obstacle 1</td>
<td>0.927</td>
<td>0.905</td>
<td>0.901</td>
<td>0.963</td>
</tr>
<tr>
<td>Obstacle 2</td>
<td>0.840</td>
<td>0.895</td>
<td>0.904</td>
<td>0.931</td>
</tr>
<tr>
<td>Obstacle 3</td>
<td>0.809</td>
<td>0.889</td>
<td>0.799</td>
<td>0.791</td>
</tr>
<tr>
<td>Threshold $R_t$</td>
<td>0.928—0.948 —</td>
<td>0.906—0.970</td>
<td>0.902—0.928</td>
<td>0.964—0.968</td>
</tr>
<tr>
<td>(Range and example)</td>
<td>(0.938)</td>
<td>(0.938)</td>
<td>(0.915)</td>
<td>(0.966)</td>
</tr>
</tbody>
</table>

Figure 7. Obtained images from camera module with obstacle using various laser light patterns.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a system for automatically monitoring road surface condition by using laser light and camera modules. We applied template matching for detection of obstacles in the front of bicycle. In addition, we implemented the system using off-the-shelf node, Raspberry Pi, a laser module and a typical bicycle. Through experimental evaluations, we showed that the monitoring system can detect obstacles in the front of bicycle under a variety of laser pattern conditions.

In the future, we plan to evaluate our method in realistic situations where a cyclist rides bicycle in an actual street. In addition, for safety reason, we plan to design and implement a method for automatically switching off the laser light when the light does not face to road or pedestrian is detected at the front.

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REFERENCES