Evaluation of a Bicycle-Mounted Ultrasonic Distance Sensor for Monitoring Obstacles and Holes on Road

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***Abstract*—Monitoring bad road surface condition, such as break, potholes, obstacles, is helpful to prevent accidents in the case of cycling. In this paper, we consider to use low-cost ultrasonic distance sensor for monitoring road surface condition. We design and implement a monitoring system using an off-the-shelf node with a low-cost ultrasonic distance sensor. In the system, ultrasonic signal is periodically emitted to measure the distance from the system to the road so that the road surface condition can be estimated. To limit the sensing region, the ultrasonic distance sensor is covered by a plastic shield plate. Through experimental evaluations, we show that the monitoring system can detect the 360 cm away obstacle on road in the front area of bicycle. In addition, we show that the system also can detect a hole in the front area of bicycle.**

Keywords-bicycle; ultrasonic distance sensor; road surface condition monitoring; obstacle; hole; Arduino

I. INTRODUCTION

In the case of cycling at a blind road, at night or cycling by elderly people, it is helpful to prevent accidents if information on road surface condition is preliminary obtained. Figure 1 shows examples of bad road surface conditions: obstacles such as fallen objects, and potholes. Until now, there have been many proposals for monitoring road surface conditions.

In the area of research on partcipatory sensing, there are a lot of research work for monitoring road surface conditions using sensors such as smartphone attached at cars [1-3], motor bikes [4, 5], bicycles [6] or humans [7]. Most of these research works consider to use a GPS module and an acceleration sensor embedded in a smartphone. In these smartphone-based monitoring methods, the bad road surface condition is estimated after someone first passes the road and the acceleration sensor detects unusual vibration. The information on bad road surface condition and its position obtained using a GPS module is shared among users through the Internet. The drawbacks of these smartphone-based methods are as follows. First, they cannot be applied to new road, or road with insufficient monitoring information. In addition, these methods require up-to-date information since the condition of road surface is sometimes varied. For example, road is fixed by the government, or obstacles are scattered after typhoon. Furthermore, a human often moves bypassing the area of bad surface conditions. In such case, information on bad road surface condition cannot be obtained by using smartphone-based methods.

Figure 1. Example of bad road surface condition.

On the other hand, there have been proposals for monitoring the road surface conditions in the front area using special sensing devices [8-10]. In [8], the authors used laser range finders attached at a robot for monitoring damaged points on a road. In [9], the authors applied image processing methods to asphalt images obtained from a camera attached at a robot vehicle for pothole detection. In [10], the authors considered to use the Kinect sensor attached with a mobile vehicle for estimation of road condition. However, these sensors are relatively expensive compared to bicycle or they consume a lot of energy. In some researches [11, 12], they considered to use low-cost sensors for monitoring. In [11], they used an ultrasonic distance sensor for monitoring the road surface condition under the tire. However, to use the information on road surface condition for safe cycling, information in a bit far area from the bicycle is necessary

In this paper, we consider to use a low-cost ultrasonic distance sensor for monitoring the road surface condition in the front area of bicycle. The overview of our monitoring system intended in this paper is shown in Fig. 2. In the monitoring system, a device with ultrasonic distance sensor is mounted at the handle part of a bicycle. The ultrasonic distance sensor periodically measure the distance by emitting and receiving ultrasonic signals. According to the obtained information, the system estimates bad road surface conditions such as obstacles, holes, and so on. In this paper, we implement the system using off-the-shelf devices. In addition, we evaluate the monitoring system in terms of obstacle / hole detection capability through experiments.

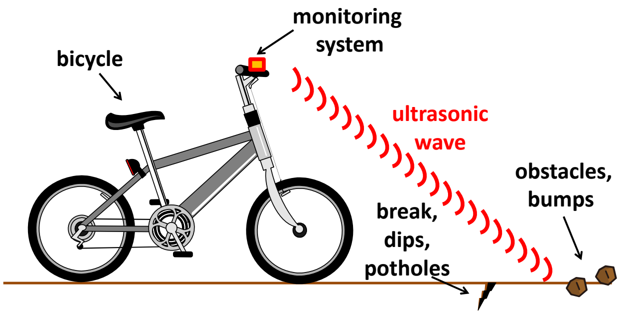


Figure 2. Overview of the road surface condition monitoring system.

The rest of this paper is organized as follows. We explain the road surface condition monitoring system intended in this paper in Section II. We implement the monitoring system using an off-the-shelf device in Section III and evaluate the prototype through experimental evaluation in Section IV. Finally, in Section V, we conclude this paper with an outlook on future work.

II. Road Surface Condition Monitoring System

In this section, we explain the overall architecture of the road surface condition monitoring system intended in this paper. Hereinafter, we denote the system the monitoring system.

Figure 2 shows the overview of the monitoring system. The monitoring system is composed of sensors such as ultrasonic distance sensor for estimating road surface condition and it is attached at the handle part of bicycle. When the monitoring system estimates bad road surface condition such as obstacles, bumps, breaks, dips, potholes, it notifies the information to the rider by alarm or blinking. As a result, the rider can react to the bad road surface by decreasing bicycle speed, bypassing the bad area, preparing for the impact, and so on. In this paper, for fundamental evaluation of the monitoring system, we evaluate the ultrasonic distance sensors in the viewpoint of obstacle / hole detection.

Although we do not introduce other sensors such as acceleration sensor in this paper, we plan to implement and evaluate the monitoring system with combination of various types of sensors in the future. For example, information on acceleration sensor might be used for removing the effect of sway of bicycle.

III. Implementation of the System

We implement a prototype of the monitoring system using Arduino [13], ultrasonic distance sensor [14], and a typical bicycle. A wireless communication module is also installed to the prototype to obtain sensor information for evaluation purpose. Figure 3 shows the snapshot of our prototype and Table I shows the details of parts used in the implementation.

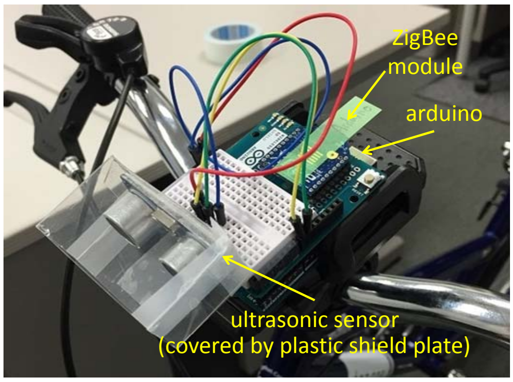


Figure 3. Prototype of the road surface condition monitoring system.

TABLE I. Details of Implementation

Name	Model
Bicycle	TOPONE CR276
Smartphone holder	BESTEK BTBM01
Main board	Arduino UNO Rev3
Ultrasonic distance sensor module	HC-SR04
Wireless communication module	XBee ZB

The prototype is installed to the handle part of the bicycle using a low-cost smartphone holder. According to the specification, the ultrasonic distance sensor HC-SR04 [14] (Fig. 4) can measure distance to an obstacle located between 2 cm to 450 cm from the sensor. To prevent for detecting the front wheel of bicycle by the ultrasonic distance sensor, the sensor is covered with a plastic shield plate as shown in Fig. 3. Here, we should note that the form of shield plate affects the sensing region of the ultrasonic distance sensor. Detailed investigation of the optimum form of shield plate is one of our future works.

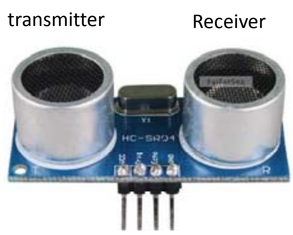


Figure 4. Ultrasonic distance sensor [14].

The flowchart of the prototype for distance measurement is shown in Fig. 5. The prototype periodically transmits ultrasonic signals using transmitter module of ultrasonic distance sensor. When the receiver module receives transmitted signals, the prototype calculates distance based on the sonic speed and elapsed time from transmission. For evaluation purpose, the distance data is transmitted to a monitoring PC by using XBee wireless communication module. At the monitoring PC, obtained sensor data is displayed.

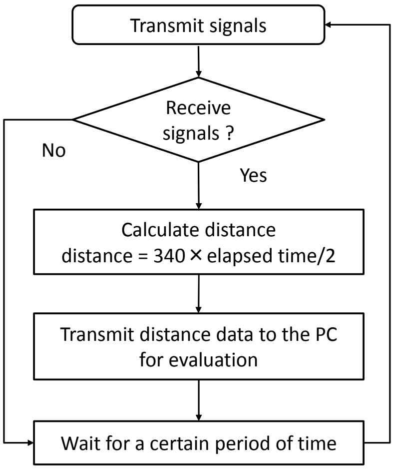


Figure 5. Flowchart of the behavior of the prototype for distance measurement.

IV. Experimental Evaluation

In this section, we evaluate our prototype in terms of obstacle detection capability and hole detection capability through experiments using actual bicycle.

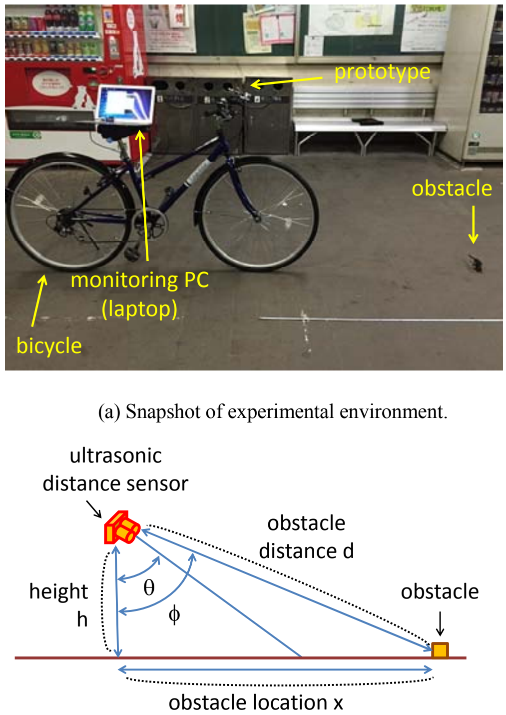
A. *Evaluation on Obstacle Detection Capability*

1) *Experimental environment*

We first evaluate our prototype in terms of obstacle detection. Figure 6 shows the experimental environment for evaluating obstacle detection capability of the prototype in this paper. The experiments are conducted in Kindai University, Japan. A 5.5 cm × 6.5 cm × 2.0 cm obstacle is placed at location of x on a road. Here, we define the location of the prototype is 0. The sensor angle θ between the direction of the ultrasonic distance sensor and the perpendicular line is set to 75°. The height of installed point of prototype h is around 100 cm. We denote the distance between the prototype and the obstacle as obstacle distance d. We define the angle between the line from the prototype to the obstacle and the perpendicular line as obstacle angle ϕ. Table II summarizes the parameters and their values in the experiment.

2) *Evaluation on detection of obstacle*

We first evaluate whether the prototype can detect the obstacle or not. In the experiment, we try to obtain the sensor information when obstacle is on the road or not. As the result of experiment, it is shown that the prototype can obtain the distance when there is the obstacle on the road. On the other hand, the prototype cannot obtain the distance when there is no obstacle on the road because transmitted ultrasonic signals do not return to the receiver module.



(a) Snapshot of experimental environment.

(b) Relation of locations between sensor and obstacle.

Figure 6. Experimental environment for obstacle detection.

TABLE II. PARAMETERS IN THE EXPERIMENT FOR OBSTACLE DETECTION

Parameter	**Value**
Obstacle	5.5 cm ×6.5 cm ×2.0 cm
Hight of install point h	100 cm
The sensor angle θ	75°
The interval of measurement	0.5 second

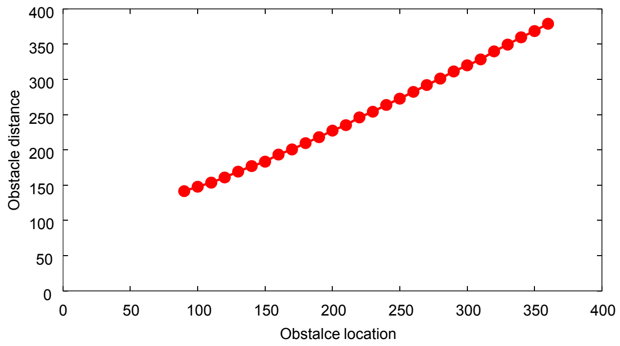
3) *Evaluation on sensing region*

We next evaluate the sensing region of the prototype. In this experiment, the bicycle is fixed for investigating fundamental characteristics of sensing region, and we change the location of the obstacle linearly. For each location, the obstacle distance is measured by the prototype. In the following all results are averaged over 20 measurements.

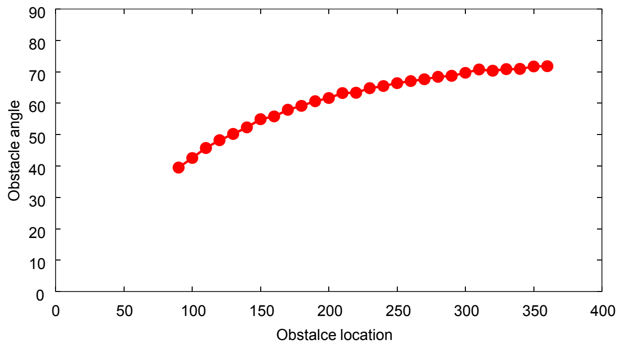
Figure 7 shows the obtained obstacle distance, obstacle angle ϕ and detection rate for each obstacle location. The detection rate is the rate of the number of successful measurements divided by the total number of measurements. As shown in Fig. 7, the prototype can measure the obstacle distance when the obstacle location is between 90 cm and

360 cm whose corresponding obstacle angle ϕ is between 39° and 71°.

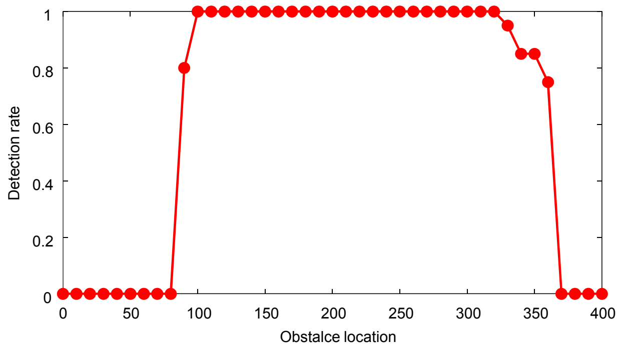
In this paper, we only used one obstacle and evaluate the sensing region by changing the location of obstacle linearly. In addition, we did not change the form of shield plate, which affects the sensing region as described in Section III. We plan to investigate detailed sensing region by changing various parameters such as the size of obstacle, two-dimensional location of obstacle, the form of the shield plate, the angle of ultrasonic distance sensor, model of ultrasonic distance sensor, and so on.



(a) Obstacle distance d.



(b) Obstacle angle ϕ.



(c) Detection rate.

Figure 7. Experimental results for obstacle detection.

4) Evaluation with moving bicycle

Finally, we conduct experiments by moving bicycle. In this experiment, a person rides the bicycle from 500 cm away from the obstacle. Then the person moves the bicycle toward the obstacle linearly.

Table III shows the obstacle distance and corresponding obstacle location. The order of experimental results in the table is in ascending order for easy understanding. The obstacle location is approximately estimated using the preliminary obtained relationships between obstacle distance and obstacle location depicted in Fig. 7. The time to the obstacle is calculated by assuming that the bicycle moves at 10 km/h. Here, the speed of bicycle by elderly people is less than 10 km/h.

TABLE III. EXPERIMENTAL RESULTS

	Obstacle distance [cm]	Obstacle location [cm]	Time to obstacle [sec]
1	153	110	0.397
2	192	160	0.577
3	265	240	0.866
4	269	245	0.884
5	286	265	0.956
6	297	275	0.992
average	244	223	0.805

As shown in Table III, the prototype attached at moving bicycle can detect the obstacle on the road in the front area of bicycle. The average distance to obstacle is 223 cm and the corresponding time to reach the obstacle is 0.805 second when the bicycle speed is assumed to be 10 km/h. In this condition, the time to reach the obstacle is quite short for bypassing the obstacle. However, it is sufficient for decreasing the bicycle speed or preparing for the impact. Alternatively, the signal of obstacle detection can be used as input of an automatic brake system. Collaborative control with other devices is also one of our future works.

B. Evaluation on Hole Detection Capability

1) Experimental environment

We next conduct experiments for evaluation of the prototype in terms of hole detection. Figure 8 shows the hole used for the evaluation in this paper. Since there is no pothole around our University, we use an opened manhole as hole. Hereinafter, we call the opened manhole hole, for simplicity. The size of hole is 40 cm × 40 cm × 7 cm as shown in Fig. 8(b). Unlike the previous experiments in Section IV-A, the location of hole is fixed and we change the location of bicycle. In this experiment sensor angle θ is set to 70°. Table IV summarizes the parameters and their values in the experiment.

2) Evaluation on detection of hole

We first evaluate whether the prototype can detect the hole or not. In the experiments, we first set the bicycle 500

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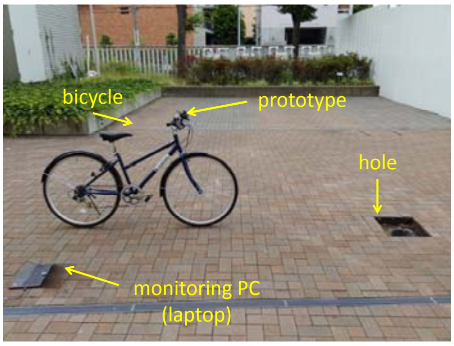
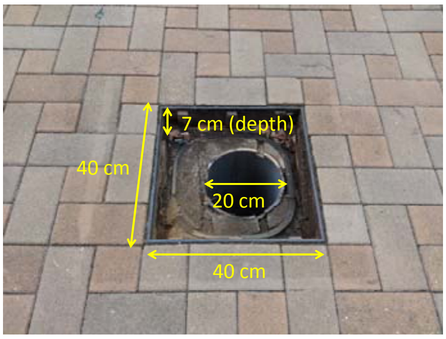
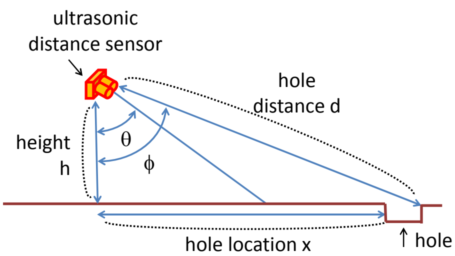
cm away from the hole. Then, we move the bicycle toward the hole.



(a) Snapshot of experimental environment



(b) Details of hole



(c) Relation of locations between sensor and hole.

Figure 8. Experimental environment for hole detection.

TABLE IV. PARAMETERS IN THE EXPERIMENT FOR HOLE DETECTION

Parameter	Value
Hole	40 cm ×40 cm ×7 cm
Hight of install point *h*	100 cm
The sensor angle θ	70°
The interval of measurement	0.5 second

As the result of experiment, it is shown that the prototype cannot obtain the distance when the hole location is larger than 230 cm. On the other hand, it can obtain the distance when the hole location is less than 230 cm. Therefore, the maximum sensing range is 230 cm in this experiment.

We note here that the maximum sensing range for obstacle detection is 360 cm in the previous experiments in Section IV-A. The reason is as follows. First, in the experiment in this section, the size of one side of hole is 40 cm long. The prototype detects far side of hole, although the hole distance is the distance between the prototype and near side of hole. Therefore, the maximum sensing range for hole detection becomes shorter than that for obstacle detection. In addition, the sensor angle θ in this experiment is smaller than that in the experiments for obstacle detection in Section IV-A.

3) *Evaluation on sensing region*

We then evaluate the sensing region of the prototype. We change the hole location by moving bicycle between 50 cm and 300 cm. In Fig. 9, obtained hole distance is plotted.

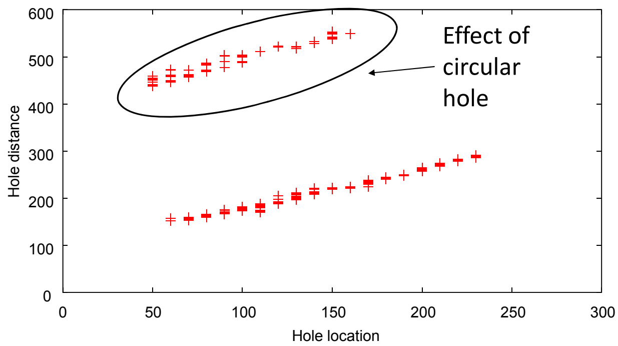


Figure 9. Obtained hole distance for each hole location.

As shown in Fig. 9, when the hole location is between 170 cm and 230 cm, the hole distance decreases against the decrease of hole location. On the other hand, when the hole location is less than 160 cm, roughly two groups of hole distance appear as shown in Fig. 9. For example, when the hole location is 150 cm, obtained hole distance is classified into two groups: group of around 220 cm and that of around 540 cm. The main reason is that the structure of hole in the experiments is double-layered structure as shown in Fig. 8(b). There is the circular hole inside of the square hole. When ultrasonic waves reach to the side of circular hole, the waves are multiply reflected inside the hole, and they return to the receiver module of the prototype with delay due to multiple reflection. It causes obtained hole distance larger. If ultrasonic waves reflected at the side of square hole first reach the prototype, the hole distance is correctly obtained. On the other hand, if the waves are missing and ultrasonic waves reflected at the side of circular hole reach the prototype, the hole distance becomes larger. However, it is not significant problem in the viewpoint of hole detection by moving bicycle, because the prototype can detect bad road surface condition and its location correctly when the bicycle-hole distance is between 170 cm and 230 cm.

V. Conclusion and Future Works

In this paper, we used an ultrasonic distance sensor attached at a bicycle for monitoring road surface condition. We implemented a prototype of the monitoring system using off-the-shelf node, a low-cost ultrasonic distance sensor, and a typical bicycle. In the prototype, to limit the sensing region, the ultrasonic distance sensor was covered by a plastic shield plate. Through experimental evaluations, we showed that our prototype can detect an obstacle on road in the front area of bicycle. In addition, we showed that the prototype also can detect a hole in the front area of bicycle.

In this paper, we confirmed the performance of prototype under limited conditions. In the future, we evaluate the detailed performance of implemented monitoring system, such as false positive rate and false negative rate, under wider conditions including other road surface conditions. In addition, we should improve the monitoring system by taking into account sway of bicycle. Furthermore, we plan to extend the monitoring system for sharing information on road surface condition among users.

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