Detection of Road Surface Damage Using Mobile Robot Equipped with 2D Laser Scanner

Taichi Yamada, Takeru Ito and Akihisa Ohya

***Abstract*— This paper introduces a road surface damage detection using mobile robot. Our research is aimed autonomous sidewalk investigation with mobile robot, for reduce the burden of human workers engaged in road maintenance. A mobile robot moves along the route for investigation and obtain shape information of road surface using 2D laser scanner. From this road surface information, road damage section will be automatically detected. By showing the detection result instead of site investigation by human workers, it expects to reduce the burden of human workers. Road surface have gradual curves and some road damage is small and less than 2 cm. Hence, our method uses random sampling to detect irregularity as road damage. This paper explains the measurement of road surface using mobile robot equipped with 2D laser scanner and the road damage detection method. In this paper, some experimental results also is shown.**

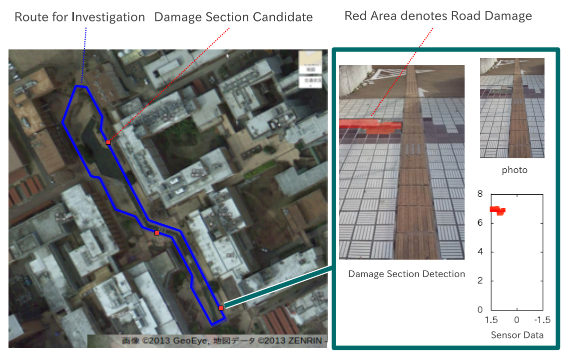

Fig. 1. System Concept :This system show the route for investigation(blue line) and the location of road damage section candidate around the route(red squares). In addition, this system show the detail data like right at this figure in each location. This detail data show the damage detection result as red area.

I. Introduction

Roads are often distorted and broken due to accidents, overload and disasters such as earthquake. We use road on a daily basis, hence it is desirable to quickly repair the road. Usually for road maintenance, human workers investigate the road damage. Road investigations are carried out on site, in response to reports from residents. Human workers need to go to the site, and wide area investigation becomes a burden on workers.

The purpose of our research is to reduce the burden on worker by automatic investigating with mobile robot. Reacently, some research collect data of sensor such as camera and laser scanner using mobile vehicle for investigating the road and extracting various kinds of feature[1], [3], [5]. Especially, laser scanner on mobile vehicle is popular used to obtain shape information of ground surface. We research a method to detect irregularities as road damage on sidewalk environment using mobile robot equipped with 2D laser scanner. Similarly, some researches are aimed to detect cracks as road damage from images [2], [9], [10]. Meawhile, we develop the irregularity detection, because irregularities interfere with pedestrians and bycycle riders. By presenting the detected irregularities as road damage, it is expect to eliminate the burden of going to the site. Fig.1 show the system concept that our research will supply. We develop a system which the robot moves along the route for investigation autonomously, and obtain the shap information of road surface. From this shape information, irregularities as road damage is detected, and the result is shown like red area described in Fig.1. This system needs the following 3 technologies: autonomous navigation, measurement of road

Intelligent Robot Laboratory, Graduate School of Systems and Information Engineering, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba City Ibaraki Pref., 305-8573, Japan, +81-29-853-5155. tyamada,takeru,ohya@roboken.esys.tsukuba.ac.jp

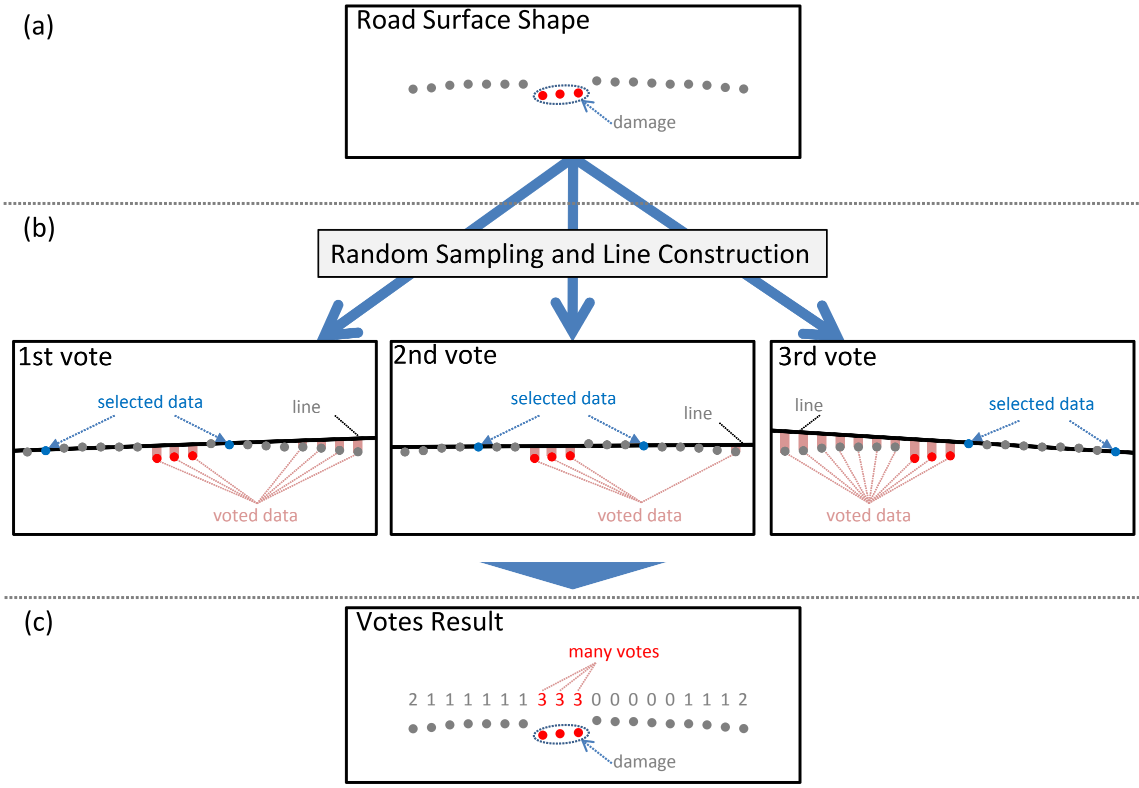

Fig. 2. Repeat of Plane Construction Using Random Sampling and Vote: Essentially, in our method, plane is constructed as a road surface representation, for simplicity this figure explains by line.

surface shape and road damage section detection. One of these technologies, autonomous navigation is popularly researched and developped. Hence, this paper presents the measurement of the road surface using mobile robot, the road damage section detection method, and evaluation experiment in some sidewalk environment.

II. Approach

Our method obtains the shape information of road surface, using a mobile robot equipped with 2D laser scanner facing downward. From the shape information obtained when robot moves along the route for investigation, irregularities that seems like road damage is detected based on elevation. Some researches are similar to our research in that laser scanner is used to detect irregularities.These researches are aimed to detect irregularities as obstacle and find free obstacle area for navigation. Actually the elevation of targeted irregularity is different from our research. For example, Stanley: the robot run the DARPA Grand Challenge [7], [8] detect the irregularities that differ in elevation greater than 0.15m as obstacle. In sidewalk environment, the irregularities that have a difference elevation of greater than 0.05m from nearby data is detected as obstacle [11]. Meanwhile, in our research the elevation of targeted irregularity is small. The elevation of some irregularities as road damage is less than 0.02m, and there are smooth irregularities. In addition, road surface is not flat but a gradual curve(such as cross slope for well drainage). This gradual curve makes it more difficult to detect small damage sections.

Fig.2 show the summary of our method. Essentially, our method deal in 3D data. However, for simplicity, Fig.2 explains using 2D data instead of 3D data. (a): First, a mobile robot obtains road surface shape information. (b): From this shape information, planes (lines in Fig.2) are constructed using random sampling, and the data that has difference in elevation from these planes are voted. Usually, the width of road damage section is much smaller than normal section. Therefore, in many cases, it is expected that the selected points at random is the data at normal section, and the plane which is constructed from these points represent a part of normal section road surface. Road damage sections are expected to be clearly different in elevation from normal section. Hence, comparing all of shap information with the plane in elevation, the data that differ more than a certain threshold is voted. Whereas, because of gradual curves on road surface, some data at normal section is voted too. For this reason, plane construction by random sampling and vote is repeated. Because of elevation difference of damage section and normal section, data at damage section is voted in most case. Consequently, by repeated vote, the number of vote for damage sections become particular large. (c): Finally, the data that have vote greater than certain is detected as road damage irregulality.

III. Detection of Damage Section

In this section, this paper explains the measurement of road surface shape and the specific procedure of damage section detection from this information. Fig.3 shows how to obtain the shape information. This robot is equipped with 2D laser scanner facing downward, and is able to estimate self position. The robot obtains self position and 2D laser scanner data, while the robot moves along the investigation route. By associating robot position and 2D laser scanner data, the shape information of road surface is obtained.

When the robot moves along the road, huge quantities of points of raw laser scanner data is obtained. It brings on increase of computational cost in the process of damage section detection. Furthermore, the margin of laser scanner error have an adverse effect on road damage detection. Hence, to reduce and smoothen the lase scanner data, digital elevation map (DEM [4]) is built from the data (shown in Fig.4). In DEM, horizontal plane space on the ground is subdivided into equal interval grid. Each cells have the elevation average of all laser scanner data in the cell.

In damage section detection, following procedure is repeated a certain number of times for the DEM. Here, the nth data of DEM is described as $p_n = (x_n, y_n, z_n)^T$.

(i) select 3 data p_i, p_j, p_k at random from DEM under some conditions for efficiency

(ii) compute the normal vector $\vec{n} = (a, b, c)^T$ of the plane that includes p_i, p_j, p_k, by solving following equation

$$\vec{n} = \vec{p_i p_j} \times \vec{p_i p_k} \tag{1}$$

(iii) vote the data that differ greater than threshold δ in elevation

$$vote_n = \begin{cases} vote_n + 1 & (diff \geq \delta) \\ vote_n & (otherwise) \end{cases} \tag{2}$$

$$diff = \left| \frac{a(x_i - x_n) + b(x_i - x_n)}{c} + z_i - z_n \right| \tag{3}$$

Here, $vote_n$ denotes the number of vote for nth data of DEM.

Finally the data that have more than certain threshold is detected as road damage. Specifically, $Damage_n$ that denotes nth data of DEM is damage or not is determined followings.

$$Damage_n = \begin{cases} true & (vote_n \geq N) \\ false & (otherwise) \end{cases} \tag{4}$$

The elevation threshold δ at (iii) is determined based on the depth or height of usual road damage section. The number of repeat and the threshold of vote quantity N for damage section detection is determined empirically.

The conditions at (i) for efficiency follows 2 conditions. One is that the distance between new

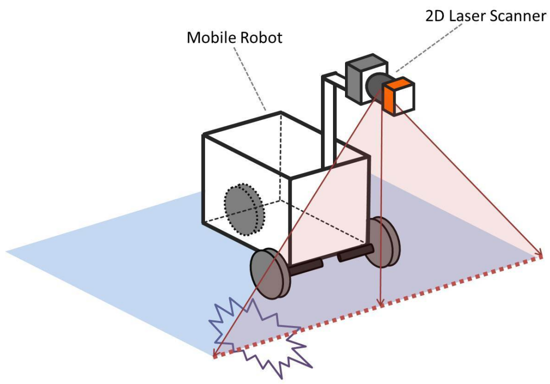

Fig. 3. Measurement of Road Surface Shape Information Using Mobile Robot: The mobile robot moves while obtaining 2D laser scanner facing downward data and computing self position. By associating these 2D laser scanner data and robot position, the road surface shape information is obtained.

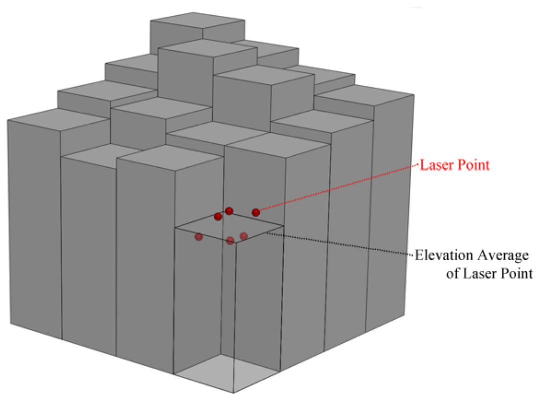

Fig. 4. Digital Elevation Map Building

data and the data already selected is greater than 1m and less than 2m. To reduce sensor error influence in plane construction, each data that have distance greater than 1m is selected. Because road surface have gradual curves, the plane may not represent in wide range. For this reason, our method selects new data with distance from other data less than 2m. Another condition is that the difference from neighbor datas in elevation is less than 0.01m. Because such data that has difference from neighbor data in elevation is likely to be road damage section.

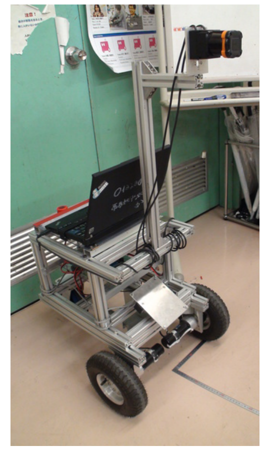

Fig. 5. Robot

TABLE I
THE SPECIFICATION OF HOKUYO UTM-30LX

Detection Range	0.1 - 30 m
Scan Angle	270 degree
Angular Resolution	0.25 degree
Scan Speed	25 ms
Accurracy	White kent Sheet: $\pm$ 30 mm

IV. EXPERIMENT

In experiment, we evaluated our method by detecting road damage section at some real sidewalk environment at University of Tsukuba. In this experiment, we used the outdoor wheeled mobile robot shown in Fig.5. This robot is equipped with Hokuyo UTM-30LX 1m above the ground as laser scanner facing downward. The specification of Hokuyo UTM-30LX is shown in Tab.I. We experimented in 3 sidewalk environments shown in Fig.6,7,8. In environment (A) (shown in Fig.6), the damage sections are 2 holes of about 0.05m depth and there are saggings around these holes. In environment (B) (shown in Fig.7), the damage section is tile damage of about 0.015m depth. Environment (C) (shown in Fig.8) is a bumpy sidewalk. There are some smooth irregularities.

In each environment, we instructed the robot to run as shown by arrows in each figures at 0.4m/s, to obtain shape information of road surface,

and odometry is used to estimate robot position.

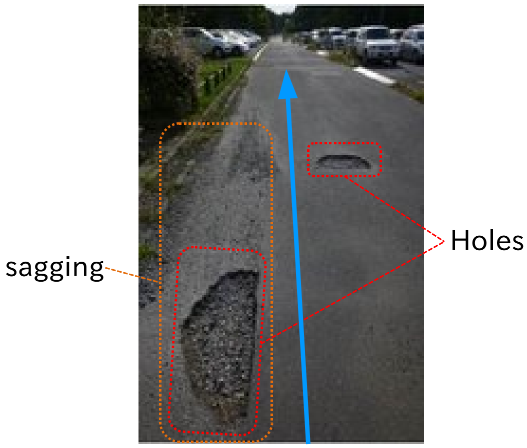

Fig. 6. Experiment Environment (A): There are 2 holes and sagging as road damage.

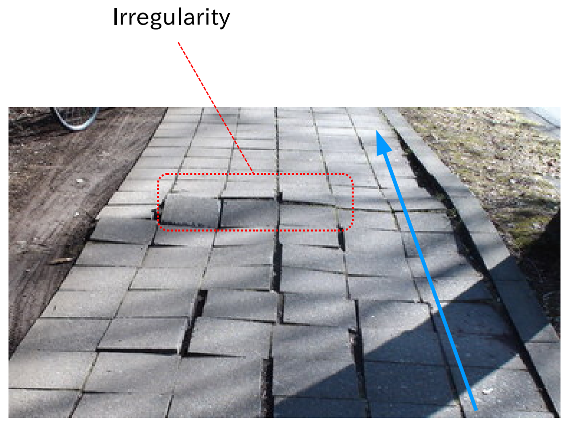

Fig. 8. Experiment Environment (C): This sidewalk is bummpy, and has smooth irregularity.

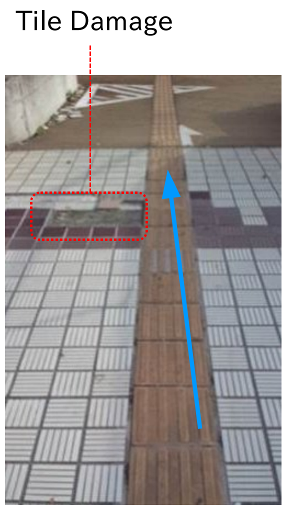

Fig. 7. Experiment Environment (B): There is a tile damage section as road damage.

From these shape information, each DEMs are created in the cell of 0.05m $\times$ 0.05m. In this experiment, damage section is detected from the DEM in the range of 3m $\times$ 8m. Because, the result of investigation at University of Tsukuba, there is no damage less than 0.01 m in elevation, the elevation threshold δ for vote is enough smaller than usual damage section and 0.005 m. Plane construction and damage section vote repeat 2000 times, and finally the data that is voted over 1900 times is detected as road damage.

Fig.9 shows the shape information, the result vote and damage detection in each environment. In enrivonment (A), 2 holes and the saggings around these holes have a lot of vote as the result of vote, and finally these area is detected as road damage. In enrivonment (B), the tile damage is clearly detected, and it is possible to confirm the presence of damage section. Our method allows the detection of small road damage depth of about 0.015m. In enrivonment (C), our method allows to detect smooth irregularities as road damage. In environment (B) and (C), the wall at the side of road and the outside of pavement is detected too. However, by presenting these detection result, human workers can confirmed the presence of road damage. In experimental result, it is expected that autonomously road investigation using mobile robot with our method.

V. Conclusion

This paper presents a road damage section detection method using mobile robot for road investigation. This method detect the irregularities as road damage, and aimed to decrease burdens of human worker by presenting the detected irregularities.

In our method, shape information of road surface is obtained with mobile robot equipped with 2D laser scanner facing downward. Plane construction as a represent of road surface by random sampling from this shape information, and road damage section is detected by comparing with this plane model in elevation. In the experiment, it is confirmed that our method can detect small irregularities depth of about 0.015m, and determine the presence of damage in some real sidewalk environments.

One of the future works on this research is to move along investigation route autonomously measuring the shape information of road surface. This research is aimed to reduce the burden of human workers by sidewalk investigation using mobile robot instead of human worker, and robot is required to go to the investigation site autonomously. Another future work is 3D pose estimation. In this experiment, the robot moves along the route that seems to be flat. However, because there are irregularities on roads, it is expected that robot is tilted when robot move on irregularities. For this reason, 3D pose estimation is required to correctly obtain the shape information of road surface. Specifically, by obtaining robot tile adding some sensor such as inclinometer [6] and estimating 3D pose, this problem is solved.

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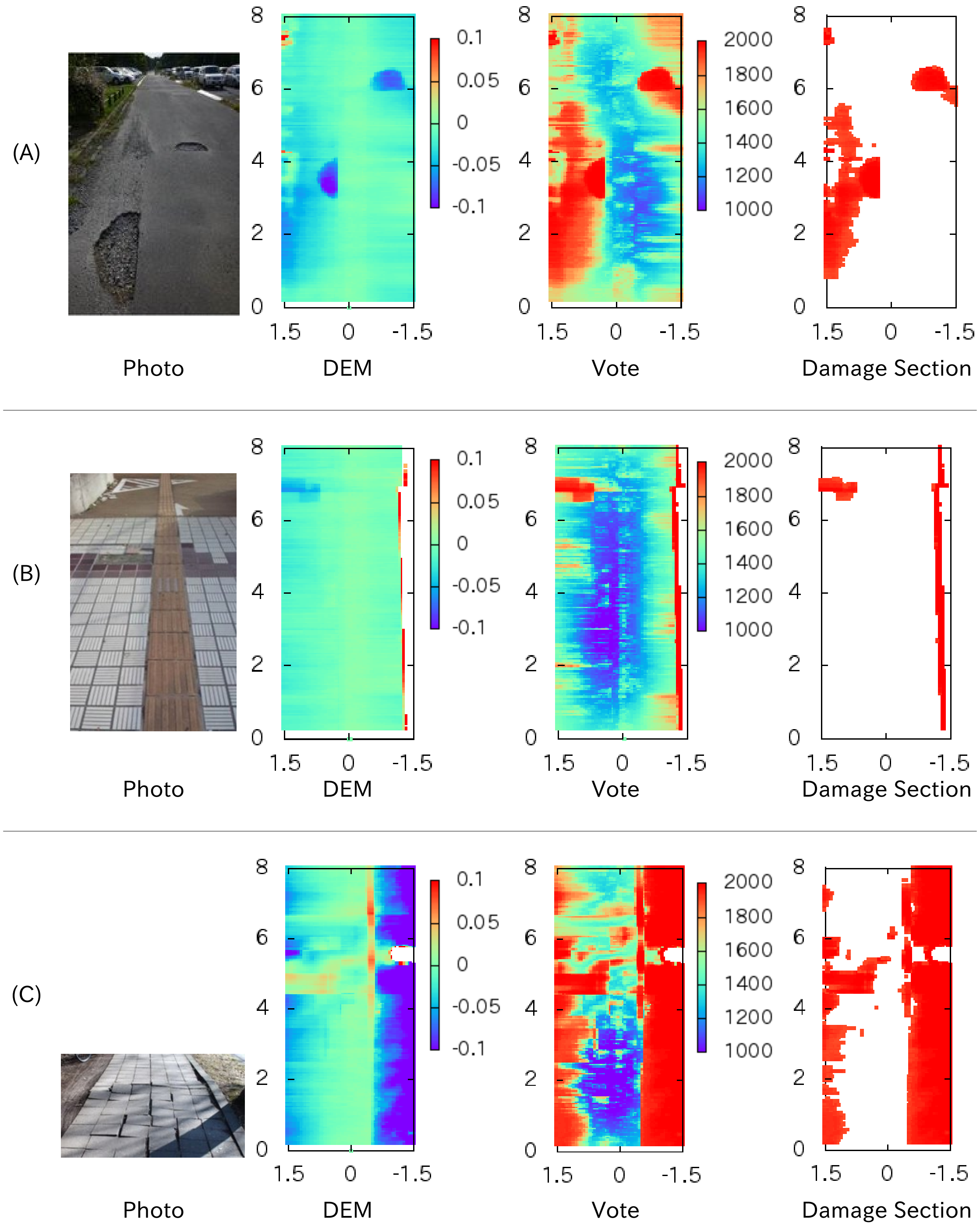

Fig. 9. Damage Detection in Each Environments: This figure is shown, from left, the photo of environment, the DEM of road surface, the result of vote, and the result of damage detection. In the DEM, the color denote elevation of the data. In result of vote, the color denote a number of vote for the data. The result of damage detection is shown the detected damage section as red area.