Development of Inspection Robot for Under Floor of House

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***Abstract*—We are developing robots for inspection of the under floor of houses. The developed robot system is reported in this paper. The mobile robot platform is based on a crawer type robot developed for rescue purposes. As sensors, a pan-tilt-zoom camera, top-view camera and SOKUIKI sensor are used. We constructed a test field and verified the performance of the robot.**

I. Introduction

THE inspection of under floor is an important after service for house construction companies. It must be done periodically to maintain the house condition but it is a very tough work for human as shown in Fig. 1 because there is no light, low height, dusty and very sultry in some seasons. We are developing robots for such inspection of the under floor of houses. The developed robot system is reported in this paper.

Fig. 1. Inspection of under floor of house by human.

There are similar researches for rescue purpose[1-3] and inspection/monitoring purpose[4-6]. In contrast with those studies, this work is a development of the concrete robot system for a particular application.

II. Inspection of Under Floor

Fig. 2 shows an under floor's environment of the Japanese house. The height is around 35 to 45 cm. There are many supporting poles. There are also some cables for electricity and communication, and tubes (typically 20 to 90mm in diameter) for hot/cold water. The under floor is divided by concrete walls almost same as the room division (living room, dining room, sleeping room, kitchen, bathroom etc.). Each area is connected via connecting hole as shown in Fig. 3. The height of the wall is around 5cm at the holes. It is necessary to have some special mechanism for the robot to get over the wall since it is not flat.

Fig. 2. Typical under floor of the Japanese house.

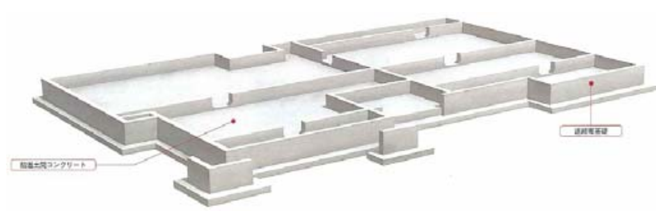

Fig. 3. An example of under floor plan.

The entrance to under floor is the inspection hole installed on a floor (typically existing in kitchen or washroom). Fig.4 shows the opened inspection hole by pulling the floor. The size of the entrance hole is normally 60 x 60 cm. Therefore the robot should be smaller than this size.

Fig. 4. Inspection hole installed on the floor.

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Usual inspection items done by human are mainly as follows:

- Cracks on concrete walls.
- Water leak from pipes.
- Termites.

We focus on the checking of concrete cracks in this development. It is important not only to find the cracks, but also to measure its width because widths over a pre-determined value must be reported. Fig. 5 shows a scene of crack width measurement by hand. A special scale is put on the crack and its width is compared with the lines which have various widths on the scale.

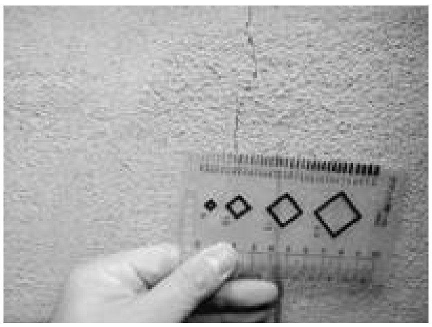

Fig. 5. Crack width measurement by hand.

III. DEVELOPMENT OF ROBOT SYSTEM

A. *Necessary Functions*

The followings are necessary functions for the robot system for under floor inspection of house.

1) *Maneuverability:* The robot must get over not only the cables and pipes, but also the walls at the connecting holes.
2) *Hazardousness:* The robot must work under dusty conditions, with obstacles and possible water leaks.
3) *Compactness:* The size of the robot must be smaller than the size of the inspection hole on the house floor at least when the robot passes through the hole. (If the robot has a folding mechanism, the robot can expand its body after setting on the under floor.)
4) *Image capturing and crack width measurement:* The system can provide clear image enough to check the width of the cracks. The image monitor is also useful to check the inspection process by the home owner.
5) *Map building and position estimation:* The system should construct a map of under floor and present the current position and posture of the robot. It is very difficult to understand where the robot is during inspection only from the image taken by the camera.
6) *Easy operability:* The user of this system may not be an engineer. It is necessary that a field inspector can operate the system easily.
7) *Easiness to carry:* The total system including human interface should be compact and light weight to carry easily. This is important for routine work as an after service.

B. *System Design*

To meet with the conditions mentioned above, we designed the system as follows. The design of the inspection robot is shown in Fig. 6.

Fig. 6. Design of the inspection robot. It has two main crawlers and four sub-crawlers. Two cameras, a SOKUIKI sensor and a lighting device are mounted on the robot.

The robot is remotely controlled by a human on the floor near the inspection hole (entrance to under floor). The operator controls the robot by watching the camera images sent from the robot.

The mobile platform's design is based on a robot developed for the rescue purposes[7]. It has two main crawlers and four sub-crawlers (left and right, back and forth). The sub-crawlers are used to get over the walls on the connecting holes, pipes and cables lying on the floor.

The two cameras, one is for inspection and the other is for robot control, are mounted on the robot. A SOKUIKI sensor (Scanning Laser Range Sensor) is also mounted on the robot for the surrounding environment recognition. For the lighting device, 6 pieces of LED are mounted of the robot.

Fig. 7. Integrated inspection robot.

The size of the robot is 385mm(Length) x 300mm(Width) x 275mm(Height). The length of the body will be expanded to 600mm by stretching the sub-crawlers. The weight of the robot is 12.5kg. The maximum speed is 277cm/s and 17.9deg/s. The robot could get over the 160mm height wall. Two Ni-H Batteries (14.4V, 4200mAh) are mounted in the body of the robot. This is enough for 40min. working time. The integrated robot is shown in Fig. 7.

The robot has a small size on-board PC running with Linux and it is connected to the host notebook PC of the operator via IEEE802.11g wireless LAN. The control signal for robot operation and camera movement will be sent from host PC to the robot. Contrary, the images obtained by the camera, sensor measurements and the various status of the robot will be sent from the robot to the host PC.

C. Sensors

1) Pan-tilt-zoom Camera: To inspect the under floor, a camera (FCB-EX1000, SONY Corp.) is installed in the pan-tilt box mounted on the top of the robot as shown in Fig. 8. It has 36x optical zoom lens and the effective number of pixels is approx. 380,000. The camera is covered by a glass shield for dust free purpose.

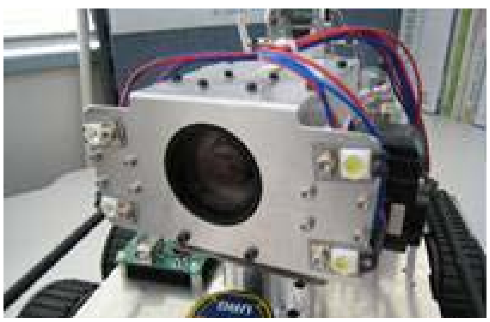

Fig. 8. Pan-tilt-zoom camera for inspection.

2) Bird's-eye Camera: As shown in Fig. 9, a small CMOS camera module (KBCR-M01NT, Shikino High-Tech Co., Ltd.) is installed in a bar which can be passively folded by a spring at lower ceiling place such as connecting holes. This camera can obtain a bird's-eye view from the back side of the robot, so it is used for robot operation by human. The maximum resolution of the image obtained by this camera is 510 x 492 pixels.

Fig. 9. Bird's-eye camera for robot control.

3) SOKUIKI Sensor: A SOKUIKI sensor[8] (URG-04LX, Hokuyo Automatic Co., Ltd.) is mounted on the robot as shown in Fig. 10 and installed also under the glass shield. It measures the surroundings and generates the map of under floor. The current position of the robot is calculated by comparing the measured data with the map. The distance to the target crack on the wall is also calculated using the information obtained by this sensor.

Fig. 10. SOKUIKI sensor for map building and robot positioning.

D. Human Interface

The human interface is designed so that a beginner operator can use it intuitively. The GUI has two operation modes, "movement mode" and "inspection mode". Fig. 11 shows an example display of the movement mode which is used to move the robot. The bird's eye image is displayed for control purpose. The signal strength of the wireless LAN, the posture of the sub-crawlers, the operation command given by the operator, surrounding obstacle information and the direction of the inspection camera are also presented in this mode.

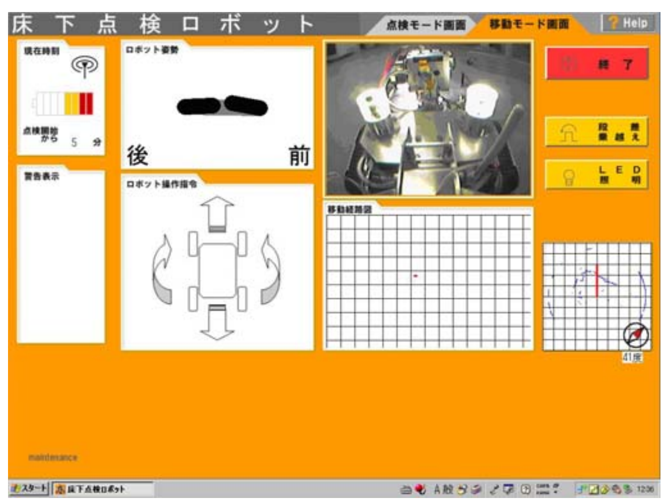

Fig. 11. Human interface of "movement mode" for robot operation.

Fig. 12 shows an example display of the inspection mode which is used to check the under floor condition and to measure the width of cracks. The image obtained by the inspection camera is arranged in the center of the display. The scale to measure the width of cracks will be displayed if necessary. The history of the captured images is placed in the bottom. The pan/tilt/zoom functions of the inspection camera can be controlled in this mode. The distance to the wall at the center of the camera image is automatically calculated and displayed using information measured by the SOKUIKI sensor.

A JoyPad is used as the controller. The sticks and buttons are used for the motion control of the robot (forward / backward / right turn / left turn), sub-crawlers (upward / downward), camera (pan / tilt / zoom), LED (on / off) and the mode change of the interface (movement / inspection).

Fig. 12. Human interface of "inspection mode" for clack width measurement.

IV. FIELD TEST

To test the performance of the developed robot system, we constructed a full-size mock-up of under floor as a test field in a building of Chiba Institute of Technology. It has 9m x 6.5m size and 6 areas divided by concrete walls as shown in the left of Fig. 13. It is almost the same as a commercial house. It has been covered by a floor as shown in the right of Fig. 13 to test in similar lighting condition.

Fig. 13. Test field. Before covered (left) and after covered by floor(right).

First, the lighting performance was checked. Fig. 14 shows an example scene of the under floor environment lightened by LED on the robot. It can be seen that the LED gives enough good light.

Next, we have tested the maneuverability of the robot. Fig. 15 (a) to (c) shows some consecutive scenes of the robot going through a connecting hole by getting over the concrete wall. The robot can move in the under floor environment without any difficulty.

Fig. 14. Under floor environment lightened by LED mounted on the robot.

(a)

(b)

(c)

Fig. 15. Scene of robot going through a connecting hole.

Finally, we have verified the map building and the current position's estimation capability. The odometry is not used in this work because the error is very large for the crawler type mobile robot. The current position of the robot is estimated only by the scan matching of the SOKUIKI sensor data[9]. The relative relationship between the current position and the position where a reference data was obtained is estimated by the scan matching. There are a lot of works relating with the scan matching[10-16]. We utilized ICP[10] for scan matching algorithm in this study. The map will be constructed by overlaying the scan data based on the estimated positions. The current position will be estimated between the current scan data and the constructed map data.

Here, the ICP algorithm is described briefly. Scan matching using ICP algorithm is a method to minimize the matching error using the total squared geometric distance between the points in an input scan and the corresponding points in a reference scan. ICP uses initial relative position between an input scan and a reference scan, which is zero in this case. Also, the previous scan data is used as a reference scan.

Fig. 16 shows the test field #1 for map building and current position estimation. The floor is made by concrete. There are several iron pillars. The start/end position of the robot is expressed by a star and the planned path of the robot is denoted by the dotted lines. In Fig. 17, the red crossings show the constructed map of the environment and blue triangles show the calculated position and posture of the robot in this figure. Fig. 18 shows the test field #2. The floor is soil. There are several wooden pillars and a pipe on the bottom. The result is shown in Fig. 19. The position of the robot was calculated at around 100mm interval in these experiment. The resultant maps have been successfully constructed and the position/posture of the robot has been reasonably calculated.

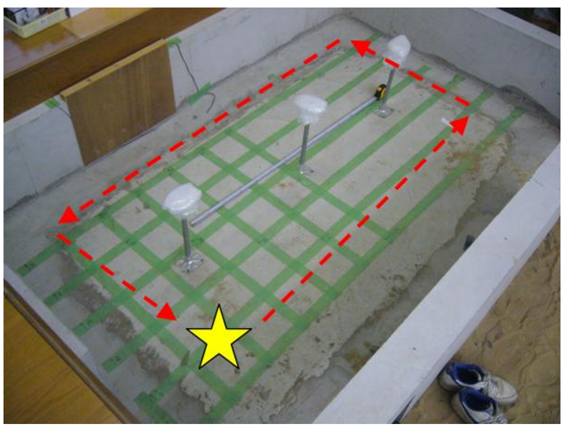

Fig. 16. Test field #1 and the path of the robot for map building and position estimation. The yellow star shows the robot start/end position and the red dotted lines show the planned robot paths.

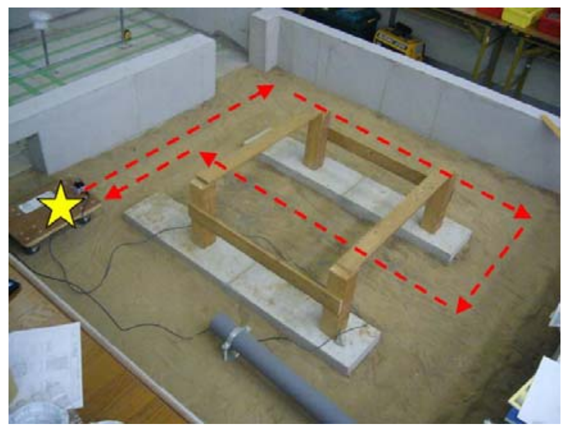

Fig. 18. Test field #2 and the path of the robot for map building and position estimation. The yellow star shows the robot start/end position and the red dotted lines show the planned robot paths.

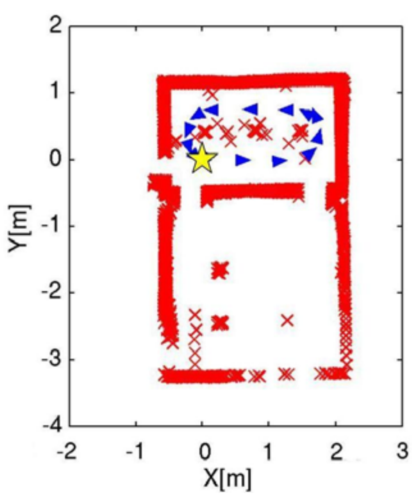

Fig. 17. Result of map building and position estimation in the test field #1. Generated map is denoted by red crosses and robot positions are denoted by blue triangles. The yellow star shows the robot start position.

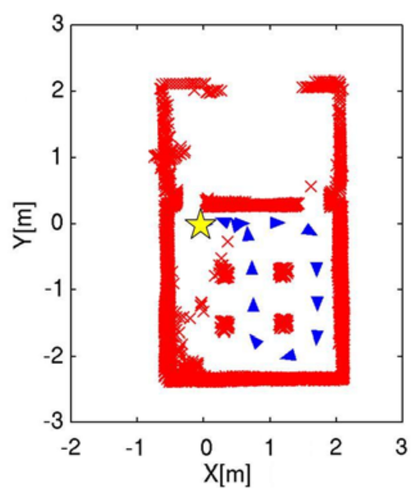

Fig. 19. Result of map building and position estimation in the test field #2. Generated map is denoted by red crosses and robot positions are denoted by blue triangles. The yellow star shows the robot start position.

V. Conclusion

We are developing robots for inspection of the under floor of houses. In this paper, the developed robot system is reported. The field test has been done at a full-size mock-up of under floor constructed exclusively for this research project. The performance of the developed system has been tested and good results ware obtained.

We are continuing to develop the system and a prototype for mass production version is constructed as shown in Fig. 20. Several parts are changed for improved performance, maintenance free purpose, easy operation and low cost. Also the robot and the operational PC are packed in carrying cases as shown in Fig. 21. We are trying to start a inspection business in near future.

Fig. 20. Prototype robot of mass production version. The robot has a large carrying handle and the shield cover for the inspection camera is made small.

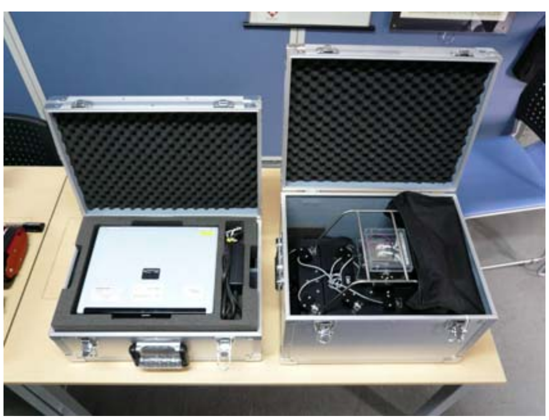

Fig. 21. Carrying cases for operational easiness (left: operational PC, right: robot).

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