Automatic Inspection of Embankment by Crawler-type Mobile Robot

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Abstract –

In this paper, we report a method that a mobile robot operates automatic inspection of embankment. The mobile robot KENAGE, which has been developed by Japan Aerospace Exploration Agency, tows a truck with an inspection instrument and is basically controlled by Robot Operating System. From the result of way point navigation experiment, it is confirmed that the mobile robot is able to go through several way points and to inspect the embankment automatically.

Keywords –

Mobile Robot; Self-localization; Inspection of Embankment; Automatic Inspection

1 Introduction

Construction demand is keeping high not only in modern times but also expected to grow in the future because of reconstruction of buildings and maintenance management of the infrastructures such as bridges and tunnels. However, decrease of the working population in the construction industry is becoming a severe problem especially in America and Japan. For example, in Japan, the population in construction was 3.4 million in 2014 which is estimated to become 2.2 million in 2025. Despite of the population problem, the construction demand is predicted to rise. Therefore, shortages of workers are exceedingly concerned, so young workers on construction are desired.

For the problem about shortages of workers, it is necessary to take measures not only to employ young workers but also to create more efficient construction methods. It is considered that one of the methods is bu introduction of construction robots. The robots which work autonomously or support human workers lead to more efficient constructing. Many researches and developments on the construction robot are in progress. Menendez et al. developed tunnel structural inspection and assessment robot which detects defects of tunnel by using computer vision system and ultrasonic sensor[1]. Cebollada et al. are on research of a robot which sprays foam insulation in underfloor[2]. SAM (Semi-Automated Mason) produced by Construction Robotics company in America which lays bricks faster than human[3]. BIM (Building Information Modeling) will also become one of support technology for automatic constructing robots.

In this paper, we propose the automatic embankment inspection robot system for manpower saving in construction site.

2 Inspection Procedure of Constructed Embankment by using Radio Isotope

Quality of constructed embankment is checked by an instrument using radio isotope in Japan. For developed embankment, density and moisture content is measured at several points by the placing the instrument. A selection method of the measuring points is ruled by MLIT (Ministry of Land, Infrastructure, Transport and Tourism) Japan. The rules are as follows. [4]

1. Embankment is divided into several units. It is necessary that quality is checked and recorded at each unit.
2. It is ruled that unit size is one layer of embankment area constructed for one day. Standard unit size is 1500m2. If embankment area size is over 2000m2 a day, the area is necessary to be divided into 2 units.
3. Each unit is inspected at 15 points in principle and an average of them is calculated and recorded. If embankment area size is smaller than 500m2, At

least 5 points inspection is required.

4. The inspection is executed on the constructed day in principle.
5. If several layers of embankments are constructed in a day, an unit area doesn't cover the layers.
6. When the nature of soil used for filling changes, the area in where the corresponding soil is used becomes another inspection unit.

Fig. 1 Embankment inspection instrument ANDES[5]

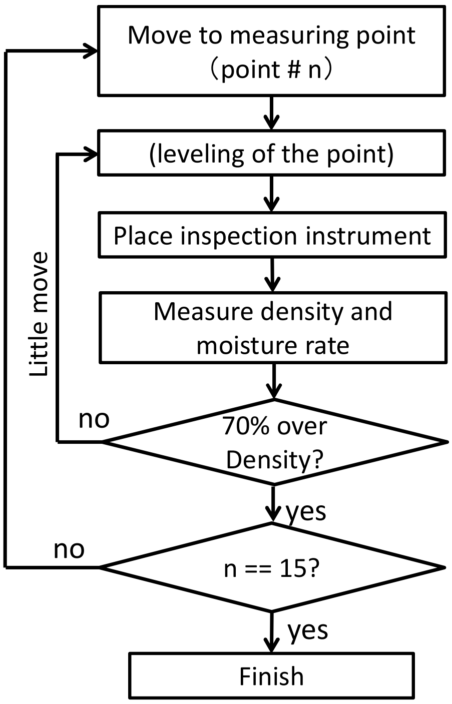

Fig. 2 Embankment inspection procedure

Fig. 1 and Fig. 2 show the instrument of inspection and inspection procedure respectively. The weight of the instrument is 10.5kgw. Additionally, 2kgw steel stick with radiation source is attached. Although the inspection procedure includes calibration before measurement strictly, explanation of the calibration is omitted because of low importance in this paper. Detail of inspection procedure is as follows: density and moisture content are measured 1 time per second at each point and averages of them are recorded. For avoiding defective measurement, the recorded data that shows smaller than 70% density is removed. With changes of measurement points, this procedure is operated 15 times in principle.

3 Hardware of inspection system

3.1 Multi-crawler type Mobile Robot

In this research, we used a multi-crawler type mobile robot which was developed at JAXA (Japan Aerospace Exploration Agency) and called KENAGE[6][7]. Fig. 3 shows overall view of the robot and electric equipment. Specification is shown in Table 1. The robot has four crawlers and eight passive links structure. By utilizing this structure, the robot is able to climb over an about 450mm wall and a slope of 45 degrees. Because of the ability, we considered that the mobile robot is useful in construction site.

Additionally, the mobile robot equips with 2 dimensional LIDAR, GNSS module and IMU (inertial measurement unit) as sensors for self-localization.

3.2 Towing truck with inspection instrument

For accomplishing unmanned inspection, the mobile robot equipped with embankment inspection instrument goes around the measuring points and inspects at each point automatically. To carry the instrument, a towing truck is developed.

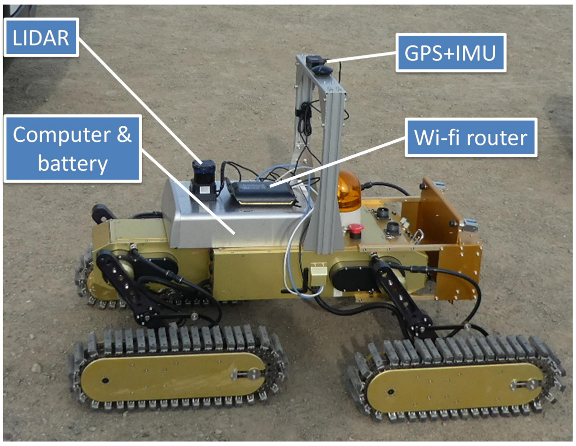

Fig. 3 Multi-crawler type mobile robot KENAGE

Table 1 specification of the mobile robot

External dimensions	1115L x 780W x 250H
weight	45kg
equipment	4 crawlers
Power source	Li-ion battery(54V/6Ah)
sensors	GNSS, IMU and LIDAR

Fig. 5 Mobile robot and developed towing truck

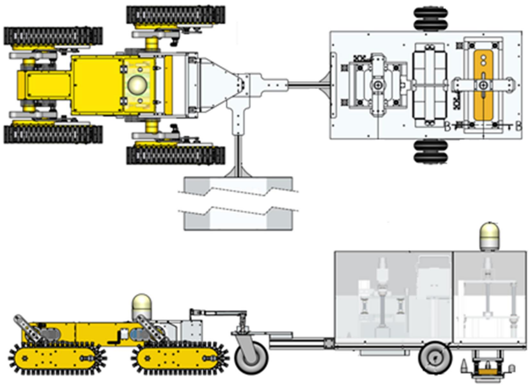

Fig. 4 Top and Side view of towing truck

Fig. 4 shows top and side view of robot and towing truck CAD images. Fig. 5 shows overall system picture which captured on construction site. The inspection instruction is equipped in the truck. A micro-controller is also placed. By sending signal from the micro-controller, the instrument goes up and down. When measuring density and moisture content of embankment, the instrument goes down and is placed on the ground. After finishing the measurement, the instrument goes up and the robot moves to next point. Furthermore the battery for the truck and the mobile robot is equipped inside the truck. The towing truck is connected by link joint, so the truck follows the robot same as a trailer.

4 Autonomous mobile system

The mobile robot is necessary to move automatically for the unmanned inspection. To achieve it, the autonomous mobile system is required, which consists of self-localization, path planning and obstacle avoidance. For applying the developed system on the construction site in a short period, we used ROS (Robot Operating System) for robot control in this research[8].

4.1 Control program structure

Program packages for robot control are provided by ROS. Combination of several packages leads rapid prototyping of robot control system. In this research, we used mainly two packages called robot localization package and navigation stack. Connections and data flow of each function are shown in Fig. 6.

Datum from GPS and IMU modules are inputted to robot localization package and self-localization is calculated by using them. The obtained self-localization data is lead to local planner which is a part of navigation stack. The role of navigation stack is path planning and trajectory generation. Global planner and local planner generate rough trajectory to an inputted goal and short term trajectory to be on the rough one respectively.

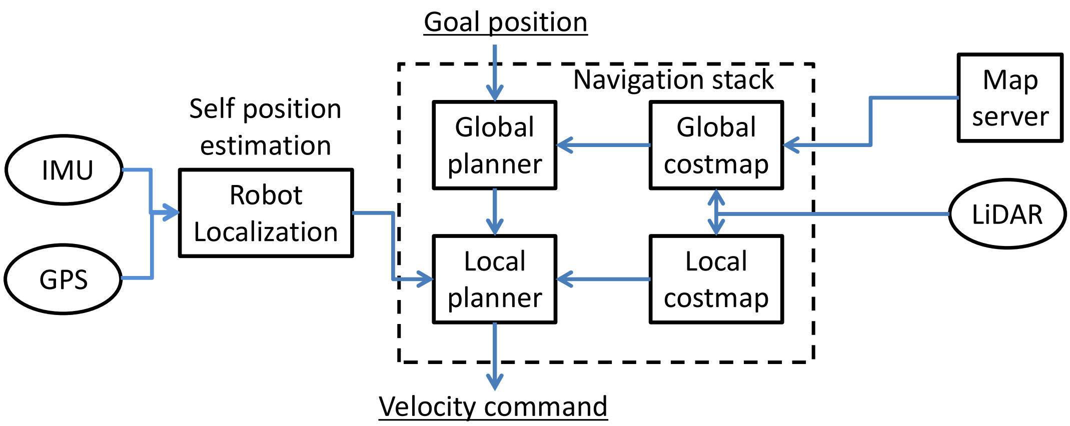

Fig. 6 Connections and data flow of each function

Inputs of global planner are the goal point data and costmap data. In local planner, difference between predict position in only navigation stack and estimated self-localization data from localization package is calculated and local trajectory is corrected.

On the other hand, LIDAR data and static map information which is set in advance make global costmap. Although the static map is usually used for showing floor plan of buildings, it is used for assigning entry permitted area in this research. It depicts in right side of Fig. 4. In contrast, local costmap only uses LIDAR data. When an obstacle appears on the planned trajectory, costmap is updated and obstacle avoiding trajectory is generated. Finally, navigation stack outputs velocity command of the robot and the command is sent to motor drivers hardware.

In this research, the goal information as input data to navigation stack corresponds measuring point, so after arriving the goal the mobile robot starts to measure density and moisture content of terrain. As mentioned before, there are 15 measuring points, so the robot begins to move next point after finishing the each measurement.

4.2 Evaluation of automatic driving of robot

For evaluating the developed system, we tested how accurate the robot moved on planned path to consist of several way points. The way points are supposed to be the measuring points in the construction site. The evaluation procedure is as follows.

7. Assign several points by mouse clicking on Google map.
8. Input the assigned points to the computer of the mobile robot
9. Start the robot to move to first way point
10. After arriving first way point, set the second way point as a next goal and the robot aims there
11. Repeat #4 several times

As supplemental information, the ROS program judges arrival at the goal when the robot completes travelling in a circle of goes into a 2 meter in diameter with the center as the way point. An Experimental field is selected to be outdoor environment for receiving GNSS signal. The size of the experimental field is about 50m by 50m square. The 7 way points are set in the field so as to form hexagonal shape based on the above procedure. For checking whether or not the robot goes out of entry permitted area, only one way point is set outside of the experimental area. Fig. 7 shows trimmed captured screen image when way points are setting.

4.3 Experimental result

Fig.8 shows the result of automatic moving experiment. Star marks represent assigned way points and continuous line shows connected GNSS signals.

As a rough analysis, the mobile robot went through assigned way points. However there is an error of several meters. It is considered that the reason of the error caused by the accuracy of the GNSS signal and judging requirement of arriving which is to go into the 2m diameter circle.

Concerning about the evaluation that the robot didn't go out of permitted area, the robot canceled corresponding point and aimed to next way point.

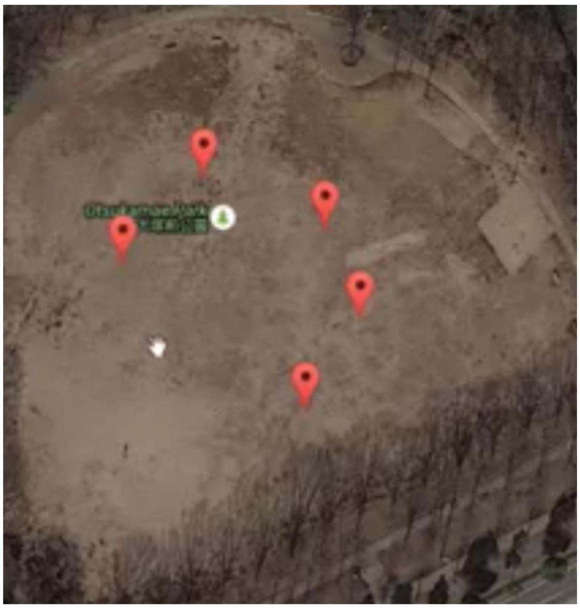

Fig. 7 Captured screen image when setting way points

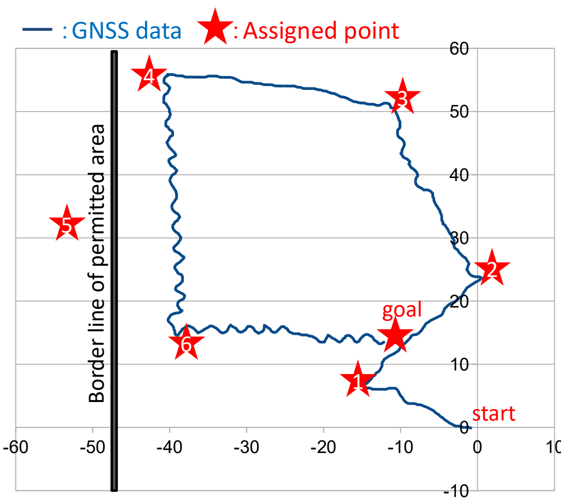

Fig. 8 Obtained self-localization data

Therefore the global planner functions performed correctly. A part of the continuous line is seen to have wave form. Posture measurement of IMU sensor seems to have an error on the way of moving, so it is required to prepare a more accurate posture sensor.

4.4 Evaluation of automatic inspection of embankment

Based on the inspection procedure mentioned in section 2, we evaluated automatic inspection of embankment. A procedure of inspection by using autonomous mobile robot is as follows.

1. GNSS coordinates data of 15 measuring points are acquired in advance
2. Input the coordinates data to the mobile robot
3. The mobile robot tows truck and aims to the measuring point
4. After arrival, the mobile robot takes down the instrument, places on the ground and starts to measure
5. After finishing measurement, the instrument is lifted up and the mobile robot start to move to the next point
6. Back to iv and repeat procedure

According to the above procedure, the automatic inspection was evaluated. The size of the experimental field was about 30 meter by 200 meter. The 15 measuring points were assigned at an interval of 10 meter. Same as experiment at section 4, the mobile robot judged arrival to the goal when the robot traveled into a 2 meter diameter circle of which center was the measuring point. Just after placing the instruments, the robot waited 1 minute for measurement.

Fig. 9 shows a picture of the experiment. X mark in Fig. 9 represents the measuring point. Furthermore the inspection instrument is seen to be taken down from bottom of the towing truck and placed on the ground. Table 2 shows the density and moisture content derived from the experiment. The data represents the average of 15 times measurement and includes standard existing method and automatic inspection method which is proposed in this paper. The results are much the same and 2% difference of measured value which is less than measurement error. This result proves that the proposed automatic inspection is feasible.

5 Conclusion

In this paper, we propose the automatic inspection of embankment system which consists of the crawler-type mobile robot and towing truck. The mobile robot goes through several way point as measuring point. The evaluation experiment indicates that the robot accurately goes on the planned trajectory. Furthermore through the other experiment, we show automatic placing of the instrument and measurement work fine for the reason that the measured value is within the measurement error. As a future work, we will make the system practicable.

Fig. 9 Field test of inspection

Table 2 comparison of density and moisture content

Inspection method	Automatic	Existing standard	Difference
Density(g/cm^3)	2.192	2.242	0.05
Moisture content (%)	7.0	6.9	-0.1

Acknowledgement

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