Field Test of Aquatic Walking Robot for Underwater Inspection

Junichi Akizono, Senior Research Engineer
Mineo Iwasaki, Chief of Robotics Laboratory
Takashi Nemoto, Member of Robotics Laboratory
Osamu Asakura, Member of Robotics Laboratory
Machinery Division
Port and Harbour Research Institute, Ministry of Transport
1-1, Nagase 3-chome, Yokosuka, Japan 239

Summary

Aquatic walking robot named "AQUAROBOT" has been developed. Main purpose of the robot is to carry out underwater inspecting works accompanied with port construction instead of divers.

This robot has two main functions. One is the measurement of the flatness of rock foundation mound for breakwaters by the motion of the legs while walking. The other is the observation of underwater structure by TV camera.

AQUAROBOT is six-legged articulated "insect type" walking machine. Operation is fully automatic because this robot is so-called intelligent mobile robot. The working depth is up to 50m.

AQUAROBOT has an ultrasonic transponder system which is long base line type as a navigation device. It also has an underwater TV camera with ultrasonic ranging device at the end of the manipulator on the body.

Through the field tests, the performance of the robot was proved to be sufficient for the practical use.

Test results are as follows.

Walking speed is 6.5m/min. on the flat floor in the test pool and 1.4m/min. on the irregular rubble mound in the sea. In the case of navigation, the positioning accuracy is within ±21cm. The robot can measure the flatness of rubble mound by the motion of the legs with the same accuracy as divers.

key words: walking robot, underwater application, inspection work

1. Introduction

The underwater inspection works accompanying port construction are carried out by manual labor of divers. However, the efficiency and safety of underwater activity are not sufficient because underwater condition is austere. Increasing risks and lower working efficiency of port construction work at deeper sea area and shortage of divers make the situation worse. Therefore, it is necessary to develop the underwater inspection robot.

The robot which carries out the underwater inspection work taking the place of divers should have good stability, positioning ability and the ability to move on uneven seabed. Compared with free-swimming type, the bottom-reliant type is good for this purpose. We selected walking type, not wheel type or crawler type or archimedian screw type, as the underwater inspection robot.

Fig .1 is schematic view of AQUAROBOT measuring the flatness of rubble foundation mound.

We started this project from 1984 and have made 3 models up to now. The 1st one made in 1985 is an experimental model for overground test. The 2nd one made in 1987 is a prototype. The 3rd one made in 1989 is light-weight type.

In this paper, the walking test of prototype in the sea is mentioned.

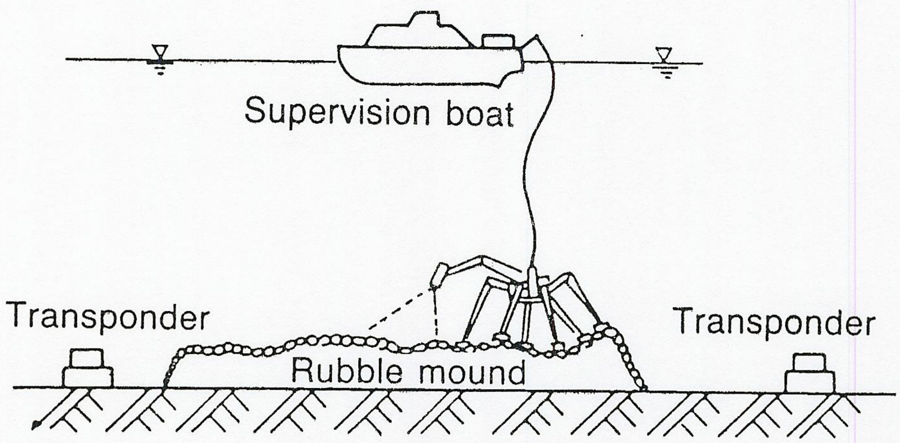

Fig.1 Schematic view of measurement of rubble mound by AQUAROBOT

2.Outline of AQUAROBOT

2.1 Hardware

AQUAROBOT is six-legged articulated "insect type" walking machine. Each leg has three articulations, and they are driven semi-directly by DC motors which are built inside the leg. The articulations are mechanically independent to each other.

All the motions are controled by a tiny lap-top micro computer (CPU 80286), which makes the robot be able to walk on irregular rough terrain. The measurement of the profiles of seabed is possible by recording the motion of the end of the legs while it walks.

AQUAROBOT can walk in any direction without changing its quarter and can turn within its own space. Each leg is equipped with a tactile sensor on its end and there are two inclinometers, a gyrocompass, and a pressure sensor in the body.

The prototype model has 150cm legs and weighs 857kgf. It can be operated 50m deep in the sea. A manipulator for underwater TV camera with ultrasonic ranging device is mounted on the body. The robot is connected by optical/electric cable of 100m long to the control unit on mother ship.

Prototype has an ultrasonic transponder system which is long base line type as a navigation device. It also has an underwater TV camera with ultrasonic ranging device at the end of the manipulator on the body.

Main dimensions and the positions of the sensors are shown in Fig.2 and the specifications in Table 1.

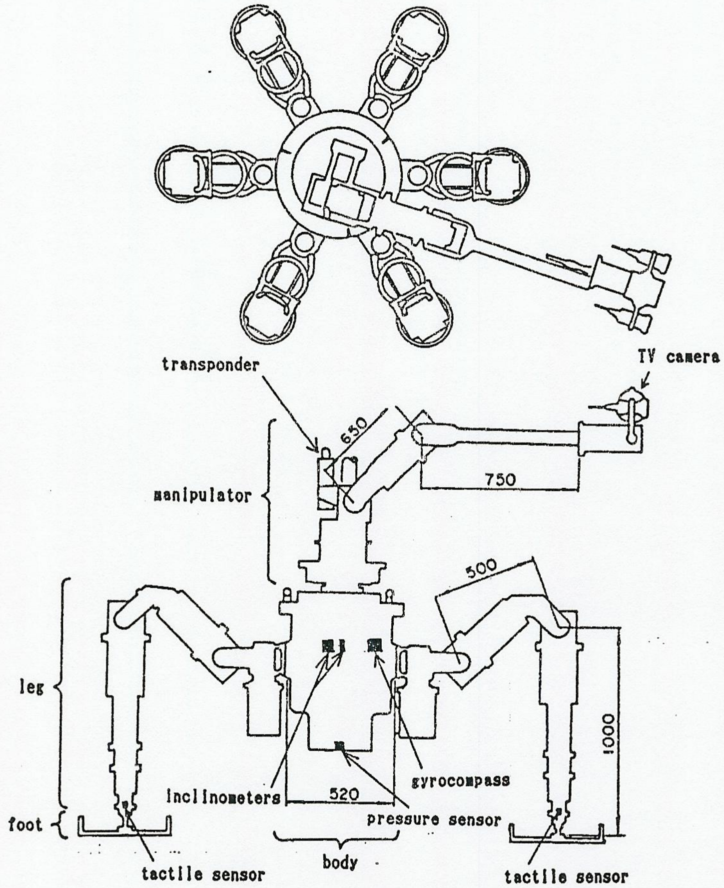

Fig.2 Dimensions and sensors of AQUAROBOT

type	axis-symmetric 6-legged insect type walking robot
articuration drive method	semi-direct drive by DC servo motor
control method	software control by micro computer
main material	anti-corrosive alminum
weight	857kgf(in the air) 440kgf (in the water)
sensors	6 tactile sensors, 2 inclinometers 1 gyrocompass, 1 pressure sensor
terrain roughness	±35cm max.
watertightness	50m deep
purpose of practical robot	measurement of flatness of rubble mound observation of underwater structure supervision of underwater construction work

Table.1 Specifications of prototype

2.2 Software

The control program consists of operating program and walking algorithm program which are independent of each other. They are interfaced by a robot language. The calculation for linear interpolation and synchronization of motor rotation is processed in the real time by this robot language.

Operation is quite easy. Operator just input walking direction and walking distance when not navigated, or X and Y coordinate values of the destination when navigated. In both case, AQUAROBOT walks on irregular terrain autonomously utilizing informations from sensors with the body kept horizontal.

The state and the motion of AQUAROBOT is shown on the computer display all the time.

3. Field test

3.1 Test place

Field test was carried out at Izumi working area in Kamaishi Port of Iwate Prefecture on February 14-23, 1990.

Test area, which is 42×77m wide, is next to the caisson yard for Kamaishi Bay Breakwaters. It is the place for temporary storage of completed caisson until final submersion at the projected place. Average water depth is about 24m and the sea bottom is rubble mound which was leveled by the rubble leveling machine developed by 2nd District Bureau of Port Construction in Yokohama.

AQUAROBOT was submerged on the sea bottom being hung by crane barge. Photo.1 shows AQUAROBOT walking on the test area.

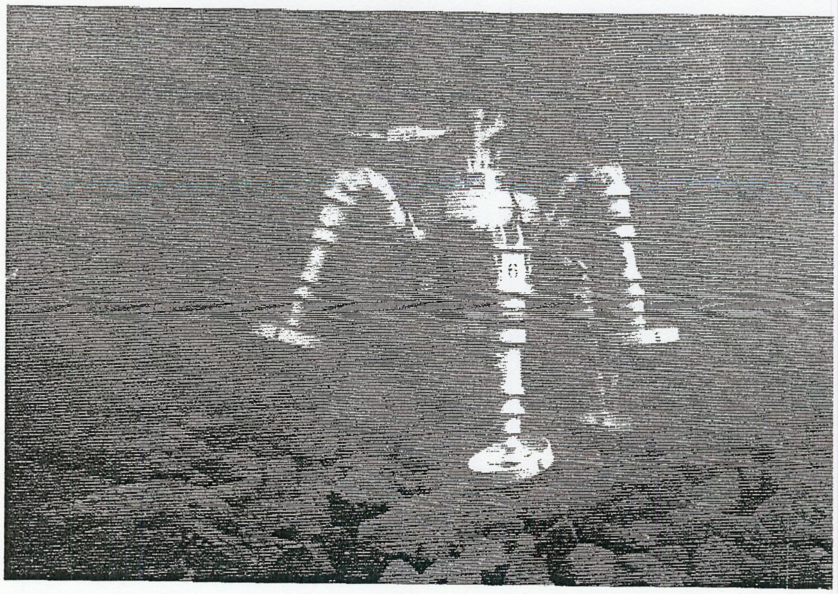

Photo.1 Walking 25m deep in the sea

3.2 Procedure of Test

In this field test, accuracy of navigation, walking speed, error of flatness measurement, maneuverability, are mainly investigated to examine the adaptability of AQUAROBOT for the practical use.

Navigation test is done by walking from one point to the other point where the location is measured previously. These points are landmarked by steel plates of 0.9×1.8m. AQUAROBOT is navigated by transponder system at every two step. Frequency of ultrasonic wave is 40-70kHz. The accuracy of transponder system alone is ±10cm at the measuring distance of 300m.

Relative height of walking terrain is measured by summing up the motions of the legs. Absolute water depth of terrain is achieved by calibrating the relative height by the values of pressure sensor recorded at the starting point and the finishing point of walking.

4. Test Results

4.1 Navigation

The test result is shown in Table 2. All the values are measured by transponder system. Error is within ±21cm. In addition to this, when AQUAROBOT reached the destination, it is observed that the robot is just on the steel plate from the view of underwater TV camera.

pulse output speed	step width (cm)	step height (cm)	commanded destination (cm)	measured destination (cm)	error (cm)	walking speed (m/min.)
1/3	15	35	X 34821	X 34816	-5	0.61
			Y -7251	Y -7264	-13	
1/3	20	35	X 35029	X 35044	+15	0.67
			Y -8232	Y -8218	+14	
1/2	15	35	X 34821	X 34822	+1	0.67
			Y -7251	Y -7249	+2	
1/2	20	35	X 35029	X 35037	+8	0.76
			Y -8232	Y -8231	+1	
1/2	20	25	X 32810	X 32811	+1	1.27
			Y -7371	Y -7350	+21	
1/2	20	25	X 33000	X 32981	-19	1.43
			Y -7500	Y -7504	-4	

Table 2 Accuracy of navigation and walking speed

4.2 Walking speed

Walking speed depends on the step height, step width, and pulse output speed from micro computer. Walking speed is also shown on the Table 2. Maximum walking speed is about 1.4m/min.

4.3 Flatness measurement

An example of measurement is shown in Fig.3. The maximum difference is 56cm. Considering the roughness of this area is ±30cm from the 30cm pitch measurement by divers, the measured value is proper.

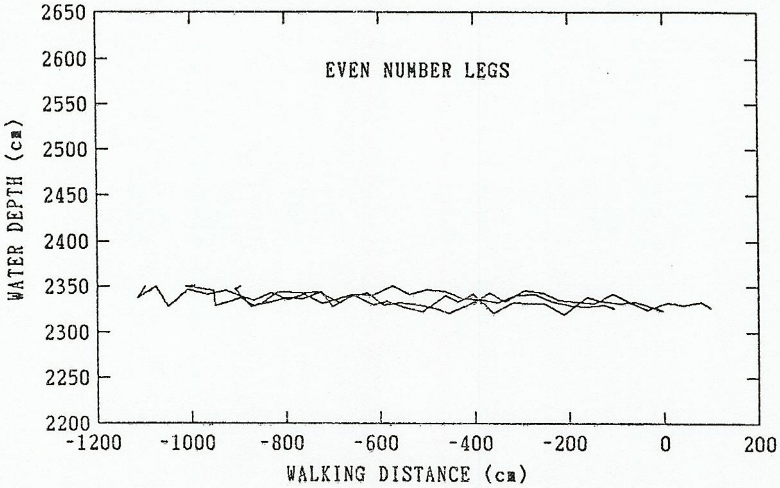

Fig.3 Result of flatness measurement

4-4 Automatic area scanning

For the practical use in the near future, the software for fully automatic operation is developed. When the operator just input the coordinate values of 4 vertex of projected area and measuring interval before operation, AQUAROBOT will generate walking lines shown in the left of Fig.4 and will walk along those lines automatically.

The actual walking line is shown in the right of Fig.4. In this case, walking distance is 95m and walking time is 72min. without down time of navigation system, so average walking speed is 1.32m per min.

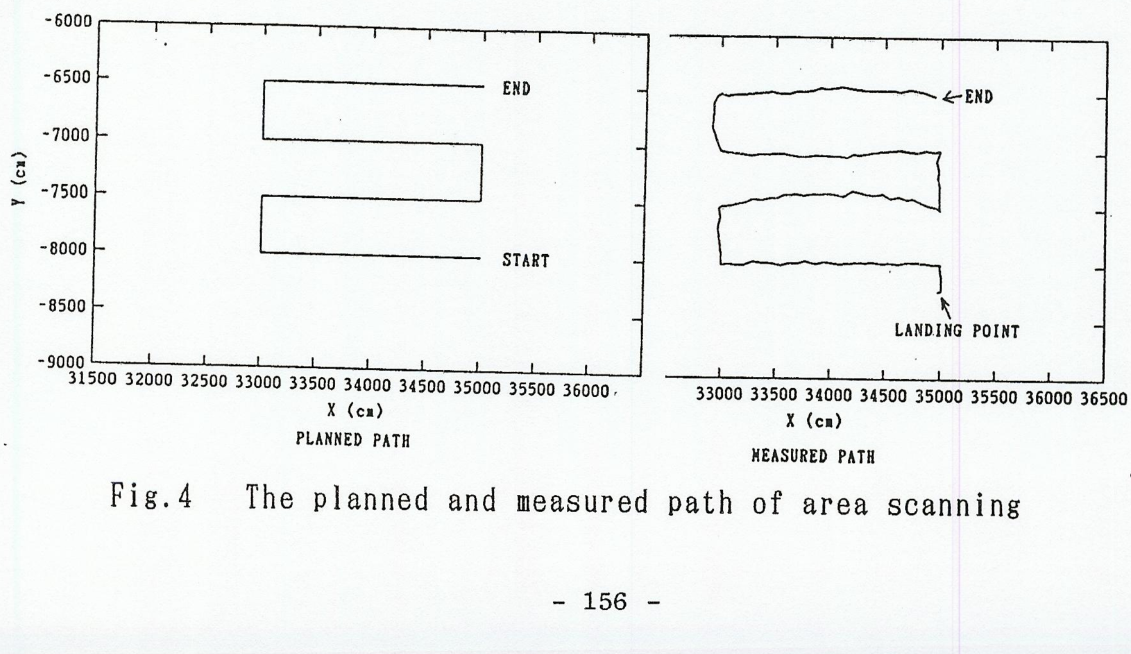

Fig.4 The planned and measured path of area scanning

4.5 Walking test on the sand

Walking test on the sand terrain is additionally carried out on the sandy sea bottom around the rubble mound. No problem can be observed compared with the walking on rubble mound except the water was made muddy when the foot touches the sea bottom.

5. Conclusion

Although the number of research on walking robot is increasing, the performances of walking robot for overground use seems to be insufficient for practical use. However, AQUAROBOT is proved to have sufficient ability for practical use through the field test. AQUAROBOT is expected to become the first practical walking robot. Our latest model of Light-weight type in Photo.2 is an example of easy-handling robot.

The technology of AQUAROBOT can be applied for the other severe conditions than underwater, such as space, radio active, and so on.

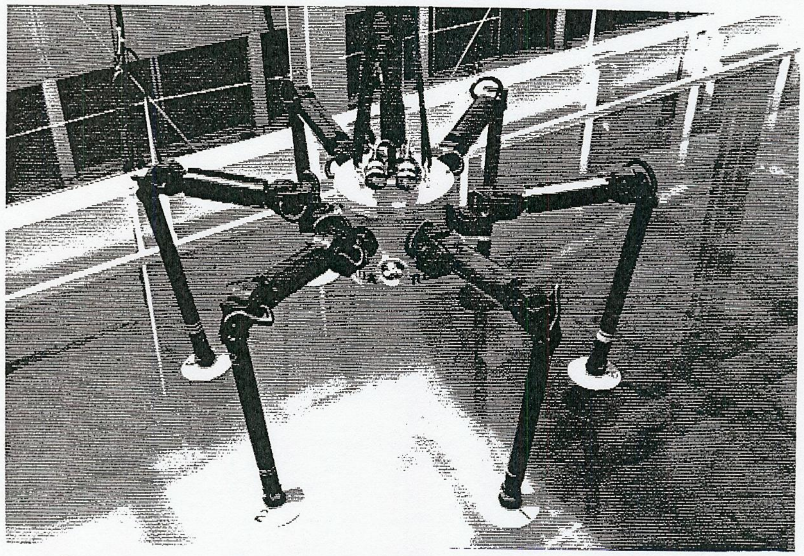

Photo.2 Light-weight type of AQUAROBOT

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