Preliminary Water Tank Test of a Multi-legged Underwater Robot for Seabed Explorations

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Abstract— **This paper describes the recent preliminary tests of multi-legged seabed walking robot, Crabster(CR200) to prepare sea trials. CR200 will be deployed to west sea of Korea where has strong tidal current and turbid water. The sea trial area has been excavated as marine archaeological site. In order to perform underwater missions in these environmental conditions, we analyze the requirements for the trials and test the required functions of CR200. In the preliminary tests, six test items are tested in ocean engineering basin in KRISO(Korea Research Institute of Ships and Ocean engineering). Through the tests, the required and usable functions for the trials are validated and the results are summarized.**

Keywords—Crabster200, Subsea robot, Swimming robot, Surface reverberation, Preliminary water tank test

I. INTRODUCTION

West sea of Korea is one of the oceans with strong tidal currents and maximum tidal current is 3 ~ 4 m/s according to location[1]. Another characteristic of the sea is murky water that incapacitates optic cameras of underwater robots. The conventional underwater robots with propeller type thrusters and optic cameras cannot be operated on these ocean environments. Hexapod seabed walking robot Crabster (CR200) is a new kind of underwater robot compare to conventional ones to be applied to the underwater environment with strong tidal current and murky water. CR200 has six legs as thrusters instead of propellers and hydrodynamic-friendly body frame to overcome tidal current effectively as in Fig.1. The legs have total 30 joints, with seven joints for front two legs and four joints for each of the other legs. Two front two legs are transformable to robotic arms. In order to explore underwater, CR200 is equipped with many sensors such as high resolution scanning sonar and acoustic camera for murky water, ultra-short baseline (USBL) for localization, acoustic Doppler current profiler (ADCP) to measure current speed, and several optic cameras to check status of the robot. So, CR200 has a size of compact car and the weight is about 700kg in the air. CR200 is allowed to operate in depths of 200 meters. The frame of CR200 is made of carbon fiber reinforced plastic (CFRP) and the specifications of the CR200 are described in Table 1[2, 3].

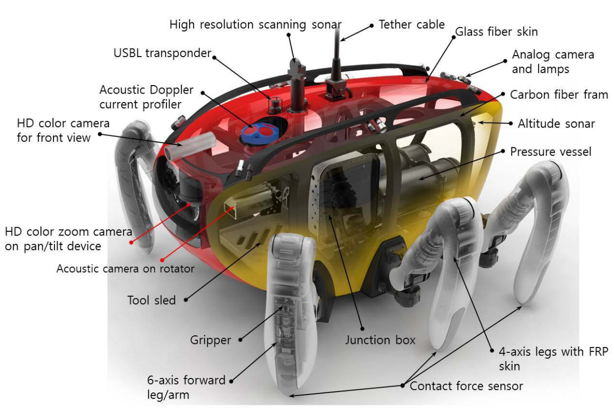

Fig. 1. Configuration of equipped devices on Crabster and its body shape

In May 2015, CR200 is applied to the sea to test applicability for the real sea environment. The sea trial location is excavated place as an area of maritime heritages by National Research Institute of Maritime Cultural Heritage. Indeed, during the last 10 years, 5 ancient ships and about 30,000 pieces of cultural heritages such as potteries, iron pots are excavated. So, in the sea trials, functions for excavation of maritime heritages also has to be tested[4].

In this paper, we describe preliminary test of CR200 in water tank to prepare the sea trials. The site for the sea trials is located in front of Ma Island in the west sea of Korea. The

Table. I. Specifications of CR200

PARAMETER	VALUE
Size (m)	2.42(L)× 2.45(W)× 1.16(H)
Weight (Kg)	500 (including payload)
Frame weight (Kg)	60
Max. ground clearance (m)	Over 0.5
Number of legs	6
Max. walking speed (m/sec)	0.5
Max. depth of water (m)	200
Max. endurable current (knot)	2
Power supply (volt)	200 (external power, DC)

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around of exploration site is windy and strong tidal currents area. Also, seabed of the site is composed of muds. In preliminary test, several functions required for ocean exploration are tested.

II. Requirements Analysis for Seabed Explorations

The underwater environment of the sea trial site has strong tidal currents of 0 ~ 1.2 m/s, murky water and muddy seabed. Fig. 2 shows environmental conditions of the sea trial site. Fig. 2(a) shows tidal current speed and depth of the site. A Tidal current of about 0.5 m/s (1knot) would be flowed and which is calculated by mathematical model[1]. Fig. 2(b) shows condition of visibility of the site and we can notice that water condition is very murky. These environmental characteristics are very severe operating conditions for underwater robot. CR200 has to complete underwater works overcoming these harsh conditions. In order to perform underwater missions successively, preliminary tests have to include following test items and tests are performed in ocean engineering basin of KRISO.

- Survival test in the tidal current
- Improvement test of water surface reverberation for sonar
- Trajectory tracking test
- 7 D.O.F robotic arm function test
- Target lock crab gait algorithm test for 3D profiling
- Swimming function test

Through the preliminary tests in water tank, we should confirm the performance of each function that are required in the sea trials.

III. Preliminary Water Tank Tests

A. Survival test in the tidal currents

The most important characteristic of CR200 is capability of overcoming tidal current. The design specification for tidal current is that mission capable current is about 1 m/s (2knot) and survivable current is about 1.5 m/s (3knot). Although tidal current of maximum 4knot flows in excavation site, we test survival function with the current of 0.384 m/s (about 0.8 knot) due to the limitation of current generation of ocean engineering basin. The tidal currents are generated as four steps that are 0.144 m/s, 0.24 m/s, 0.336 m/s and 0.384 m/s. They are decided by rotational speed of big fans to generate the current in the basin. Fig. 3 shows experiments of capability for overcoming tidal current. On each current step, pitch angle of CR200 is changed from 0 degree to 10 degree. Closer to 10 degree, lower CR200's head so the robot would have more down force. Fig. 4 shows some results of overcoming tidal current test. From the tests, we measured axial force of each

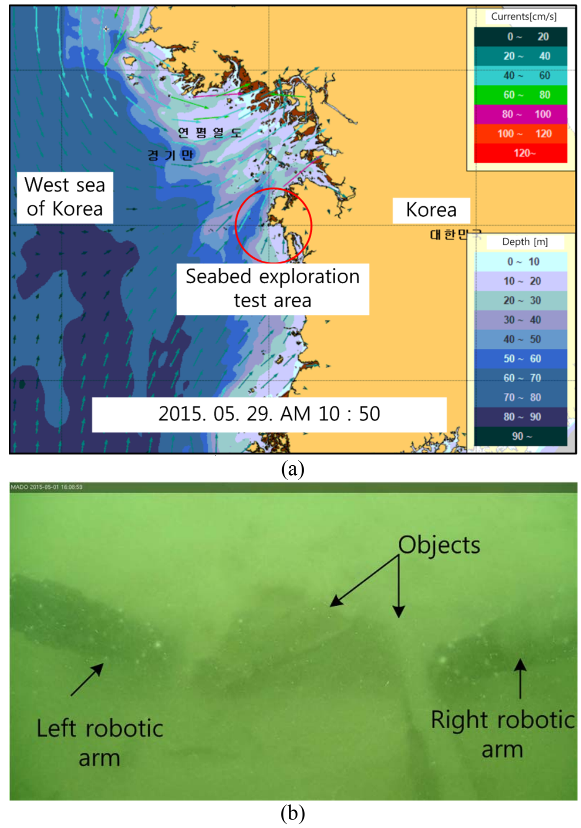


Fig. 2. Environmental conditions of sea trial site in west sea of Korea. (a) Tidal current and depth information of the site, (b) underwater visibility of the site [1]

foot and calculated tumble moment of the robot with respect to tumble axis which is the virtual line between two rearmost feet. Fig. 4(a) shows tumble moment of CR200 of front leg group with respect to the tumble axis according to various pitch angle. As can be seen in the figure, stronger tidal currents, weaker tumble moment of front leg group with respect to the tumble axis for each pitch angle. It is because stronger drag force according to increasing speed is generated and it is more applied to rearmost legs. However, the tumble moments of

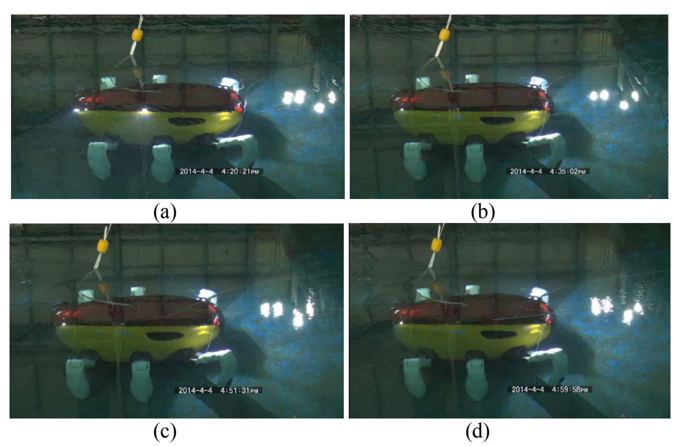
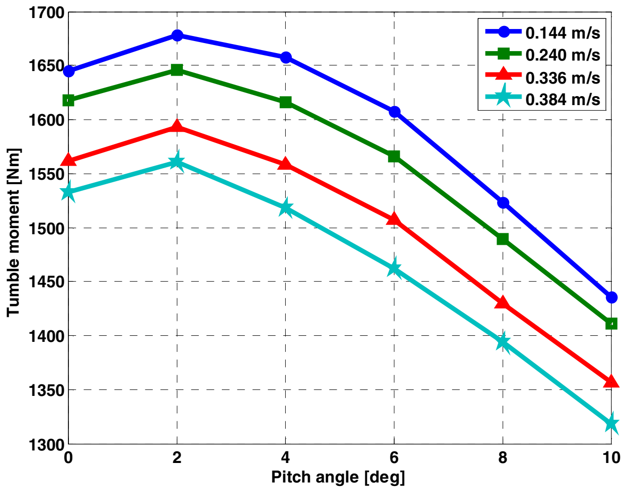
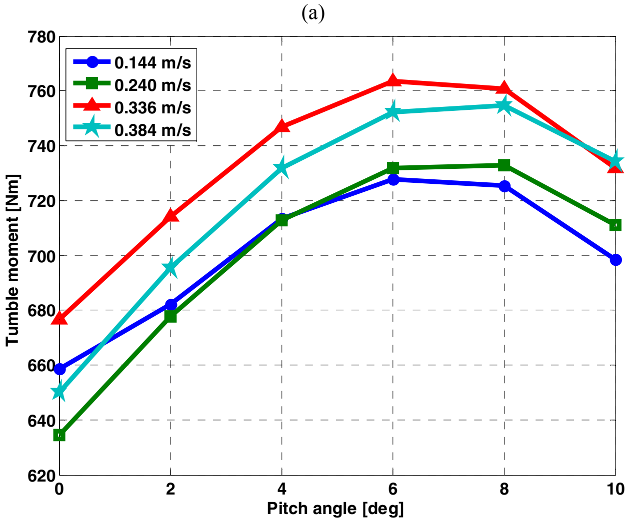


Fig. 3. Capability test of overcoming tidal current. (a) Current speed 0.144 m/s, (b) 0.24 m/s, (c) 0.336 m/s, (d) 0.384 m/s



(a)



(b)

Fig. 4. Measured tumble moments of each leg pair of CR200 with respect to tumble axis, (a) The front leg group, (b) second leg group

front leg group are decreased for the increasing pitch angles. Fig. 4(b) shows another tumble moment of the robot and they are measured from middle leg group. The tumble moments of middle leg group are not showed pronounced tendency compare to front leg group for the current speed. However, tendency of tumble moment for the pitch angle is clear. It is because center of gravity of the robot is on the virtual line between two middle legs. From the results, tumble stability of the robot is improved when bending robot's head down.

B. Improvement test of water surface reverberation

One of the important characteristic of CR200 is ability of overcoming low visibility by murky water. In CR200, two ultra-sonic devices are equipped and those are scanning sonar and ultra-sonic camera. Also, other underwater robots have ultra-sonic devices to obtain images of underwater such as side scan sonar and scanning sonar. However, CR200 can maximize and emphasize performance of ultra-sonic devices using kinematic redundancy of legs. Because CR200 walks on the seabed, the sonar devices can be stable when they are operated and it offers high quality of ultra-sonic images but other underwater robots such as ROV and AUV of propeller type cannot offers clear images. However, even CR200 cannot offer clear images in shallow sea because scanning sonar has beam band of 30° so if water surface is in the beam range, it makes surface reverberation in the images. So, we develop and implement a new method to reduce water surface noise on sonic images using conical motion named 'hula-hoop motion'[5, 6]. Conical motion to reduce surface reverberation make the robot body tilt toward sonar head facing direction. Because sonar head rotates revolvably when the sonar scans the sea floor, the body has to move continuously following sonar head direction. Fig. 5 shows extracted images of conical motion of CR200. When sonar scans front area, the robot tilts forward so that sonar head looks downward and if sonar head is toward left or right area, the body is also tilted following head direction so that the range of beam to see the water surface can be minimized. Fig. 6 shows sonar images obtained before and after hula-hoop motion. Fig. 6(a) shows scanned image of water basin before conical motion. We can notice that surface reverberation noise is on the image. Fig. 6(b) shows the

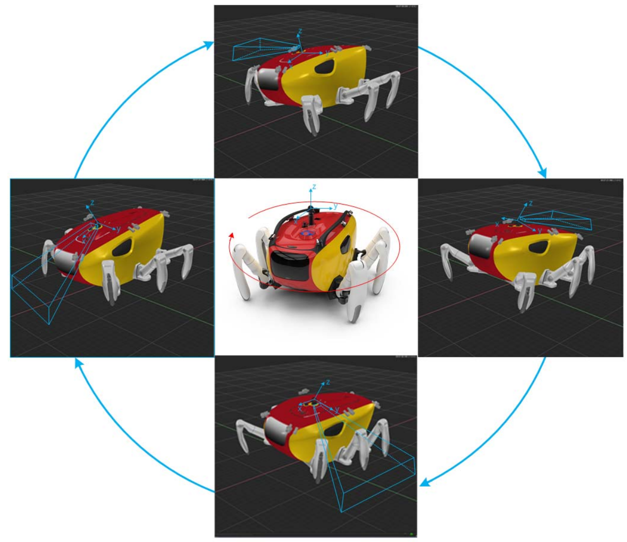
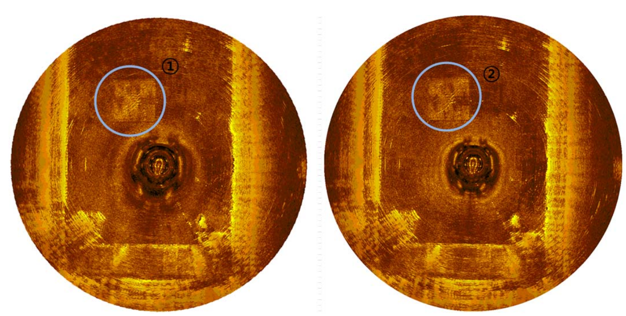


Fig. 5. Conical motion of CR200 to reduce water surface reverberation



(a) (b)

Fig. 6. Sonar images with and without conical movement

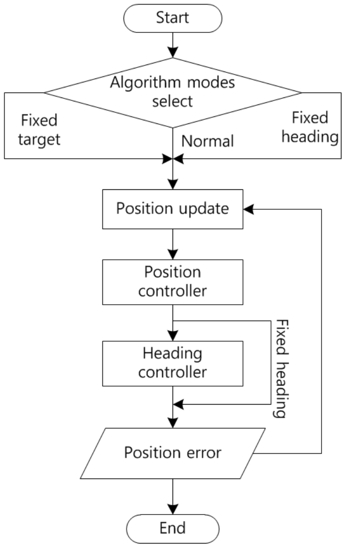
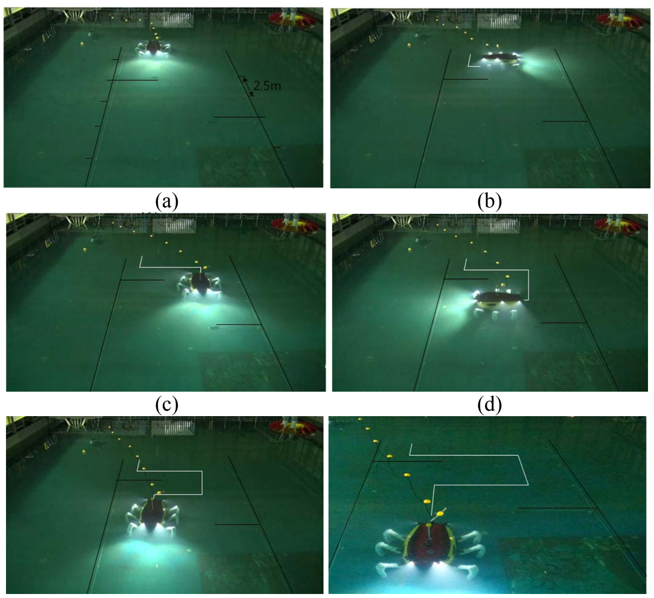


Fig. 7. Block diagram of trajectory tracking algorithms



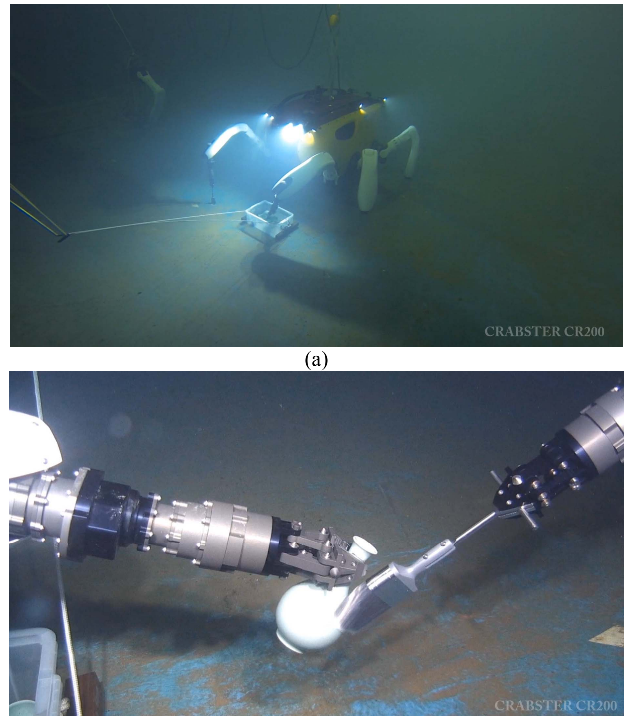
(a) (b) (c) (d) (e) (f)

Fig. 8. Experimental test of normal mode trajectory tracking algorithm

sonar image after conical motion. Although water depth is too shallow (water depth is 3 m) for dramatic improvement, we can see the reduction of surface reverberation noise at circled area.

C. Trajectory tracking test

Automatic function is helpful for operation because the exploration area can be large. So, trajectory tracking algorithms are implemented for CR200. Tracking algorithms are composed of normal tracking mode, fixed heading tracking mode and fixed target-view tracking mode. Normal tracking mode is that direction between walking and heading is united. Fixed heading tracking mode is that heading angle is fixed as specific angle when it tracked. Fixed target-view tracking mode is that target point of heading is fixed as specific coordinates and heading angle is changed to see the target point when it walks[7]. Fig. 7 is a control block diagram of trajectory tracking algorithms. As we can see in Fig.7, trajectory tracking control algorithms includes position and heading angle control algorithms and heading control algorithm is skipped when fixed heading control mode is selected. Fig. 8 shows experimental tests of normal mode trajectory tracking algorithm. The test have been performed in track of 5m width and the robot followed the track successively. In the water tank test, position feedback was not included because using ultra sonic base line(USBL) cannot be used in shallow water.



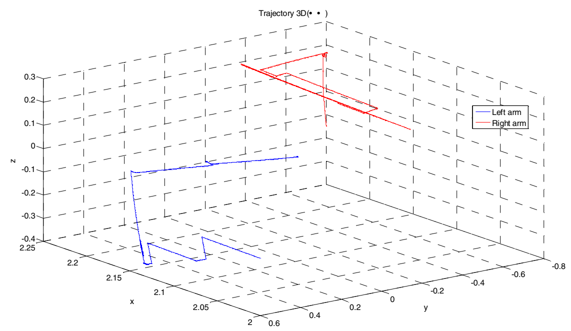
(a)

(b)

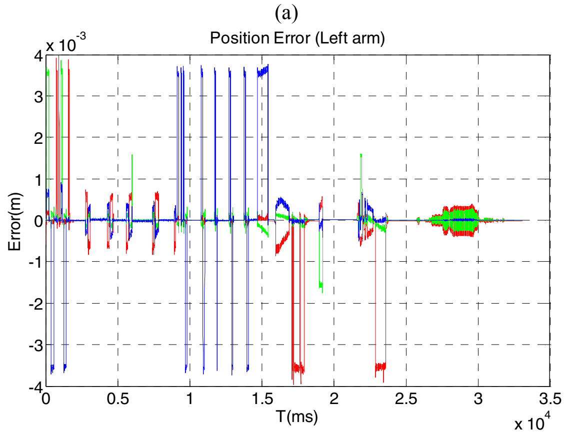
Fig. 9. Manipulator tests of CR200

D. Performance test of 7 D.O.F robotic arms

In the excavation, manipulation must be required to pick the objects interested. The robotic arms of CR200 have 7 degree of freedom and they are fully operated using electric motors. Each manipulator has six rotational joints and one gripper. The last rotational joint is limitless rotational joint using slip ring. Work space control algorithm is applied to operate manipulators conveniently. Fig. 9 shows robotic arms test in the water tank with ceramic bottle. In the experiments, CR200 grabs ceramic bottle in the basket and brushes it using other robotic arm. Fig. 10(a) shows trajectory of both arms from the base coordinates when performing underwater working in Fig. 9 and Fig. 10(b) shows position errors of both arms with respect to the command references. The maximum position error are under 4 mm and it is pretty positive result because length of the arm is very long.

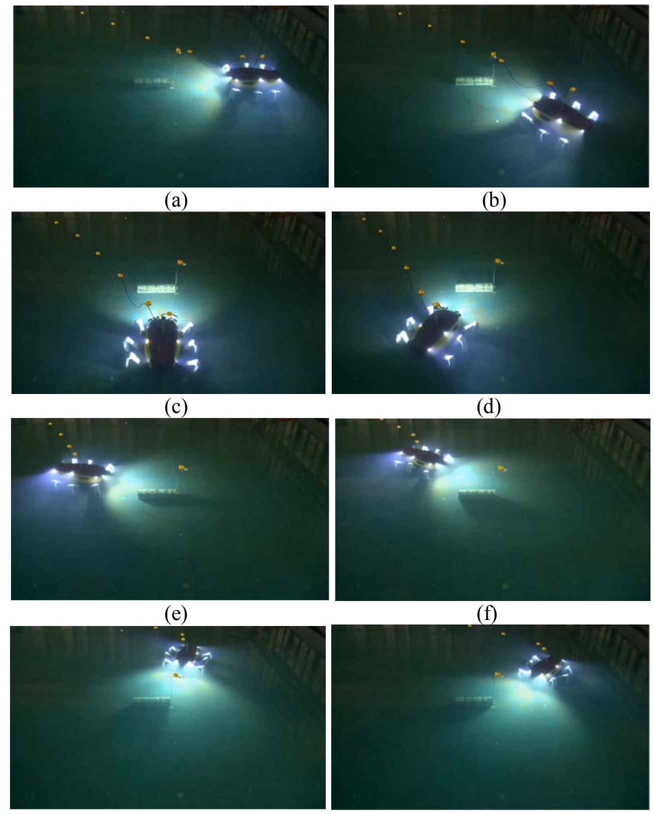


(a)



(b)

Fig. 10. Manipulator tests of CR200



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 11. Experimental test of target lock crab gait

E. Target lock crab gait

When interesting object is discovered in seabed exploration, meticulous observation can be required. We implemented special walking algorithm for detailed observation, named target lock crab gait. Target lock crab gait is that CR200 moves circularly with the interesting object as the moving center and heading is always toward the object. So, we can obtain the detailed sonar images of surrounding object from scanning sonar and acoustic camera. Fig. 11 shows test scenery of target lock crab gait with an empty oil drum. CR200 moves circularly looking forward an oil drum and the robot obtains acoustic images of the drum

F. Swimming function test

One of the most impressive function of CR200 is swimming function using hydrofoil type of six legs. Because of fin shape of the leg, CR200 can make movements such as forward, backward, upward, downward and rotation. Fig. 12(a) shows shape of the legs of CR200. As can be seen in the figure, a part from body to Joint 4(J4) has round shape to reduce water register when it moves but the other has shape of paddle to make propulsion effectively. Fig. 12 (c) shows schematic view of swimming pattern for advanced movement. In order to make propulsion for advance direction, the leg moves up and down direction using joint 2. Also, to enhance thrust force, angle of the paddle part is changed by pattern schedule. Fig. 12(b) shows variation of angle of each joint to make advance motion. The swimming patterns of CR200 are designed mimicking swimming pattern of sea turtles. Sea turtles have swimming pattern of lemniscate however, we simplified the swimming pattern of sea turtles as ellipse shape to apply to the robot easily as in Fig. 12(c). CR200 has basically three types of swimming styles such as vertical, horizontal, lemniscate and wave swimming style. Vertical swimming style is to swing the legs as up and down. The vertical swimming mode is described as in Fig. 13(a). Horizontal swimming style is to swing the legs as back and forth. Trajectory of leg movement is also ellipse type. The lemniscate swimming style is turtle swimming style. Lastly, wave swimming style makes the legs move back to front following a wave of stepping actions on each side of the body and which is described in Fig.13(b). Fig. 13 shows experiments of swimming test of CR200. Because weight of CR200 underwater is about 200kg, we equipped buoyancy materials inside body to make buoyancy of CR200 positive.

IV. Conclusions

In this paper, we describe and summarize preliminary test results of multi-legged seabed walking robot to prepare sea trials. Because the area of sea trials has strong tidal current of maximum 1.2 m/s and murky water, we perform requirement analysis for seabed excavation in the coast. In the preliminary tests, survival ability test in the current, decreasing test of water

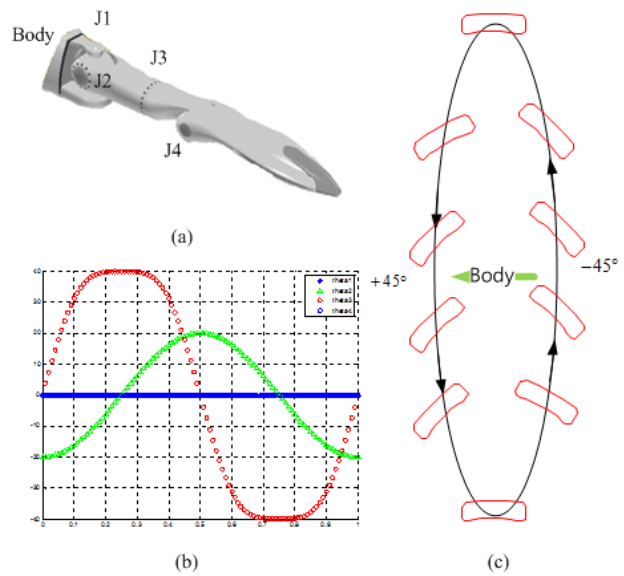
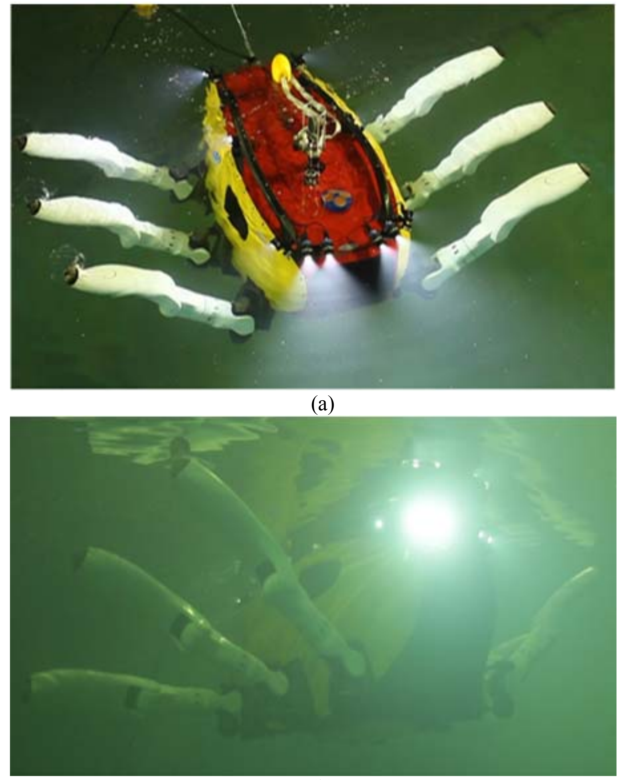


Fig. 12 (a) Hydrofoil type leg of CR200, (b) Joint angle of leg for swimming function, (c) schematic view of swimming pattern for advance movement



(b)
Fig. 13 Experiments of swimming function of CR200, (a) vertical swimming mode, (b) wave swimming mode

surface reverberation of sonar in shallow water, trajectory tracking test, robotic arm performance test, useful gait algorithm test, swimming function test are performed and successive results are obtained. Through the test, we have confirmed the tumble stability securing strategy in the tidal current and the effect of conical movement of CR200 to reduce water surface reverberation. Also, we have checked convenient functions for operation and performance of robotic manipulators. Also, swimming functions using hydrofoil type legs are tested. All of testing items in water tank are fully validated for sea trials and we expect to achieve successive results in the sea trials.

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