Waypoint Tracking Control of a Multi-legged Underwater Robot Crabster

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***Abstract*— Korea Research Institute of Ships & Ocean Engineering(KRISO) developed a new type of underwater robot, "Crabster(CR200)" for a precise survey and underwater tasks at a range down to 200m underwater by. This paper introduce a waypoint tracking control algorithm for efficient underwater exploration of CR200. The algorithm consist of Heading controller, Position controller and Path segment selector with four diverse modes which are Forward heading mode, Fixed heading mode, Fixed target mode and Target locked crab gait mode. Effectiveness and applicability of the proposed algorithm are confirmed by simulation and experiment results. The experiment is performed on March and May 2015, that are CR200's function test in ocean engineering water tank facility and real sea test in Korea yellow sea for Korea cultural properties survey.**

Keywords—Crabster; underwater robot; legged robot; path tracking; waypoint

I. Introduction

CR200 which be developed by KRISO has various functions for its efficient underwater performance[1~4]. One of the functions is a waypoint tracking control algorithm. The algorithm allows to generate a straight path between each waypoint in regular sequence and track the path. Waypoints are defined gradational goal positions.

J. A. Cobano, J. Estremera, P. Gonzalez de Santos suggested a trajectory-tracking algorithm with a robot localization algorithm in natural ground terrain for a hexapod robot[6]. The algorithm are composed by Heading controller, Horizontal body position controller, Horizontal body velocity controller and Trajectory transition controller with gait selector as below.

- Heading controller : to keep the body orientation.
- Horizontal body position controller : to determine moving direction.
- Horizontal body velocity controller : to determine moving velocity.
- Trajectory transition controller and gait selector : to determine tracking segment.

Their algorithm is accurate and specific on real time trajectory tracking. Our approach is to design applicable algorithm widely and we modified their algorithm more simple and appropriate for our system. As result, the waypoint tracking algorithm consist of Heading controller, Position controller and Path segment selector, in addition, it realize four kinds of Waypoint tracking mode such as Forward heading mode, Fixed heading mode, Fixed target mode and Target locked crab gait mode.

We confirm availability of the proposed algorithm through simulation and experiment results. Experiment of CR200 progressed as a function test in engineering water tank and a real sea test in Korea yellow sea. The tracking algorithm should be supported localization algorithm for accurate position control. CR200's localization accomplish using USBL(Ultra-Short-Base-line). But, in the experiments, USBL localization could not be applied for the system, because the exam depth environment is shallow less than USBL usage depth circumstance. Therefore, CR200 estimates its position by kinematical method which calculates its translation and rotation position using kinematic equation of the robot. But it is not real time position feedback. Thus, CR200 needs a localization which is adaptable on underwater environment.

After the experiment, we consider to apply localization method with an acoustic camera which CR200 has. We tracked its position through a mosaicking image of the camera. The process implemented acoustic camera images and SIFT(Scale-Invariant Feature Transform) mosaicking method[8~10]. The acoustic camera Supplies regular images because CR200 can hold its body steadily and stably.

II. Waypoint Tracking Algorithm

The waypoint tracking algorithm is divided as Heading controller, Position controller and Path segment selector. Heading and Position controller manage locomotion parameters for tracking given trajectory. Path segment selector checks tracking condition while CR200 performs the waypoint tracking mission.

Fig. 1. Crabster(CR200)

Specification of CR200

Contents	Specifications
Length	2.42m
Width	2.48m
Height	1.16m
Weight	700kg/200kg (land/water)
Leg	6 leg of 4 freedom (front legs have two manipulators)

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A. Heading controller

Heading controller determines a heading angular position. θ_d and θ_c describe a desired heading angle and a current heading angle respectively. An heading angular position error of , θ_e, is defined as below.

$$\theta_e = \theta_d - \theta_c$$

A heading angular velocity, ω_h, is controlled using a simple proportional control law.

$$\omega_h = K_{pr}\ \theta_e$$

where, K_{pr} is the control gain.

ω_h depend on a step size of the robot, thus, be applied as below.

$$\omega_h = \begin{cases} K_{pr}\theta_e & if\ \omega_h < W_{r\max} / \mathrm{W}_{period} \\ W_{r\max} / \mathrm{W}_{period} & if\ \omega_h > W_{r\max} / \mathrm{W}_{period} \end{cases}$$

where, W_{rmax} is a maximum rotation step angle and W_{period} is a walking period.

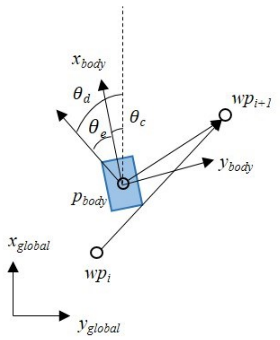

Fig. 2. Heading control strategy

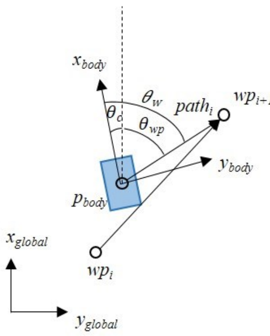

Fig. 3. Position control strategy

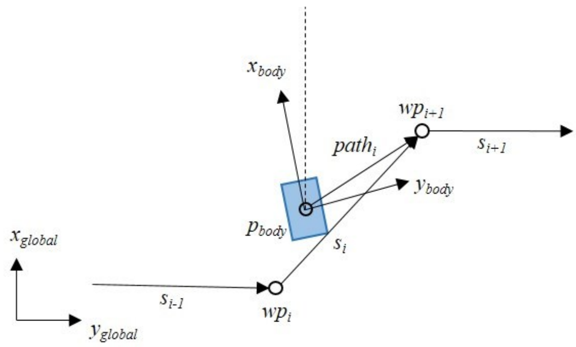

Fig. 4. Waypoint tracking strategy

B. Position controller

Position controller decides a walking direction and a walking step size of CR200. where, the walking direction and the heading angular position are always not equal, but be applied to locomotion control together. Firstly, the controller generates a straight line path between its body and *i+1* th waypoint, $path_i$, and then, calculates walking direction, θ_w, as below.

$$\theta_w = \theta_p + \theta_c$$

where, θ_p is *i+1* th waypoint direction. An omni-directional walking ability of legged robots enable CR200 to move the desired walking direction, even though it's the heading angular position and the walking direction are not equal.

A body position error, p_e, and a walking velocity, v_w, are defined as follow.

$$p_e = wp_{i+1} - p_{body}$$

$$v_w = K_{pt} p_e$$

$$v_w = \begin{cases} K_{pt}\, p_e & if\ \ v_w < W_{t\max} / W_{period} \\ W_{t\max} / W_{period} & if\ \ v_w > W_{t\max} / W_{period} \end{cases}$$

where, wp_{i+1} is *i+1* th waypoint position, p_{body} is CR200's body position, K_{pt} is the control gain, W_{tmax} is a maximum translation walking step size.

C. Path segment selector

Path segment selector chooses a segment for proceeding as planned waypoints by user. Where, the segment mean a path which has a start point and an end point. In Path segment selector, we define parameters as follow. *i* th waypoint vector is $\overrightarrow{wp_i}$ as the start position of selected segment, *i+1* th waypoint vector is $\overrightarrow{wp_{i+1}}$ as the goal position of the segment and the body position vector is $\overrightarrow{p_{body}}$. Then, *i* th segment vector, $\vec{s_i}$ and *i* th path vector are defined as

$$\vec{s_i} - \overrightarrow{wp_{i+1}} + \overrightarrow{wp_i}$$

$$\overrightarrow{path_i} - \overrightarrow{wp_{i+1}} - \overrightarrow{p_{body}}$$

Also, a segment finish identification factor, *S_finish*, is

$$S\_finish = \begin{cases} 1 & if\ \left|\vec{s_i} \bullet \right. \qquad {}_{arrive} \\ 0 & \qquad otherwise \end{cases}$$

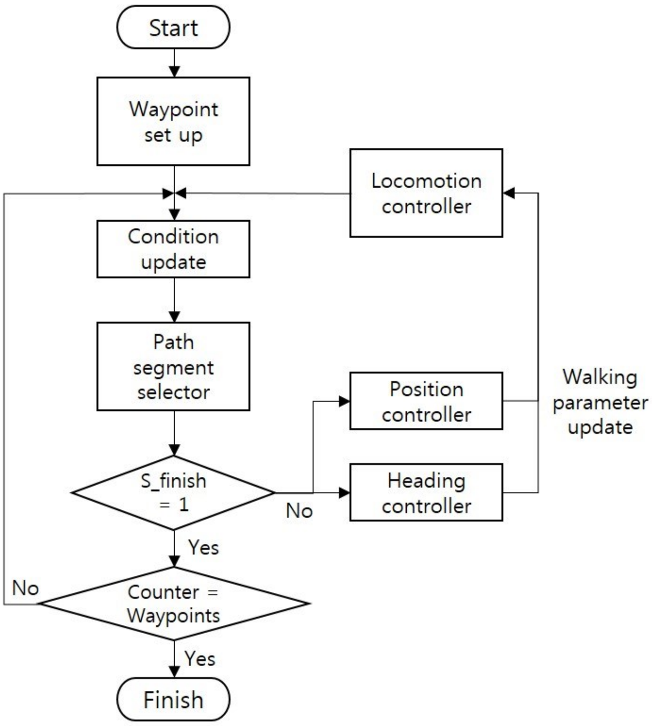

Fig. 5. Block of waypoint tracking algorithm

where, r_{arrive} is a criteria range which identify to reach to the goal position. If the robot arrives at the goal position of i th segment, the factor is set, or else the factor is zero. In addition, the controller count finished segments for finish check of the algorithm. If the counter is equal with the number of waypoints, waypoint tracking algorithm is completed. Fig. 5 shows a block diagram of the waypoint tracking algorithm.

III. Exlporation Functions of Waypoint Tracking Algorithm

The waypoint tracking algorithm focuses on developing CR200 exploration ability and it is possible that to realize a variety of survey modes as to control both heading and moving direction respectively. This section introduces each survey mode with simulation results.

A. *Forward heading mode*

Forward heading mode as common survey mode, we called "normal mode", is to keep its heading angular position to its walking direction, i.e. the heading angular position and the walking direction is equal. CR200 follows the path with constant heading angular position and it rotates on each waypoint for next segment. The mode can be applied when move survey location in wide area.

B. *Fixed heading mode*

Fixed heading mode is to move omni-direction with constant heading position. CR200 heading angular position is not changed during tracking waypoints. The mode is useful for precise survey in narrow area.

C. *Fixed traget mode*

Fixed target mode is to track waypoints with keeping its heading angular position to a special position or object. CR200 follows the path and continuously changes its heading angular position to the target at the same time. The mode is used for investigation of irregular shape object or special terrain such as a wrecked ship.

D. *Target locked crab gait mode*

Target locked crab gait mode(TLC mode) is to move around a special target with side walking motion. CR200 follows the path which surround an object and keeps its heading angular position to the object. The mode is for precise survey of one object.

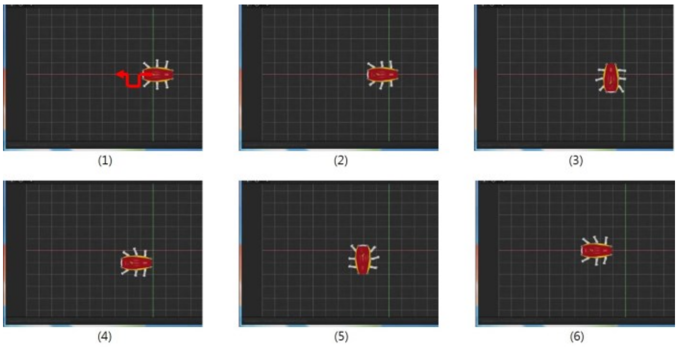

Fig. 6. Forward heading mode simulation

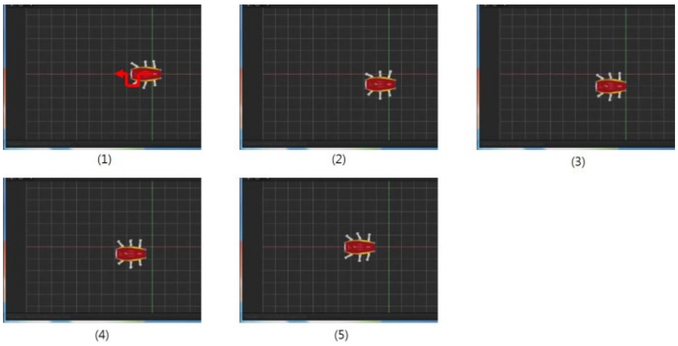

Fig. 7. Fixed heading mode simulation

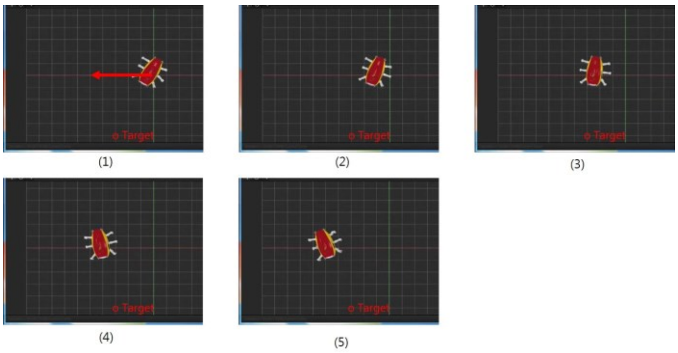

Fig. 8. Fixed target mode simulation

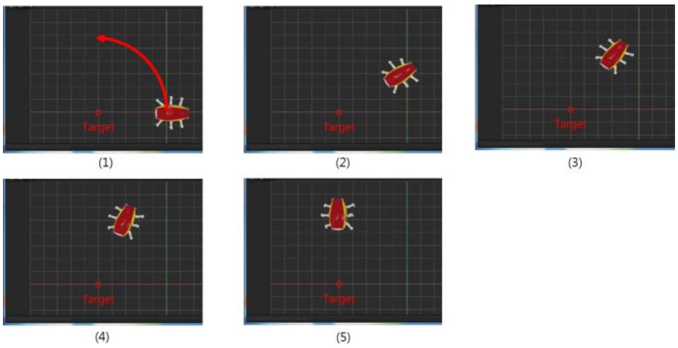

Fig. 8. Target locked crab gait mode simulation

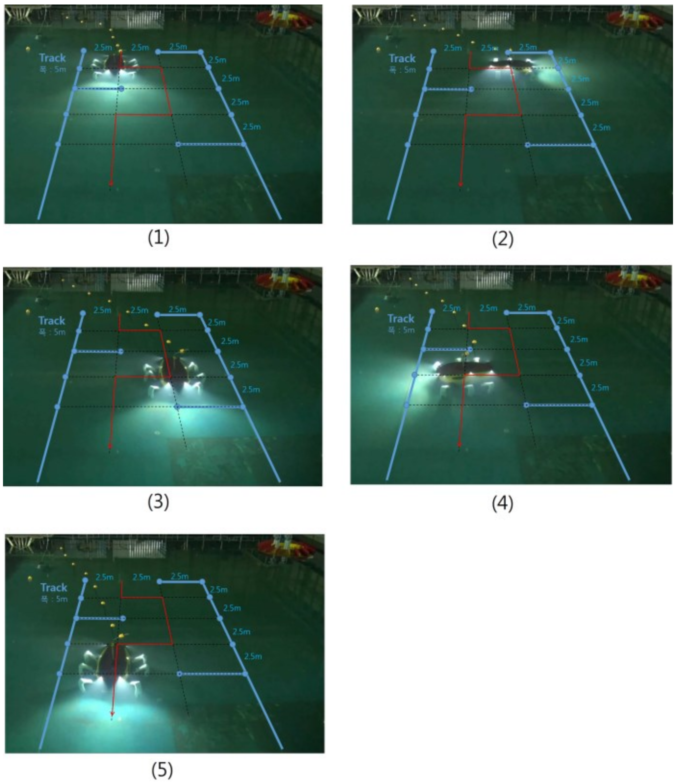

Fig. 9. Forward heading mode in the engineering water tank

IV. Experiment Result

We held two-time of experiments on 2015 such as engineering water tank test and Korea yellow sea real environment exploration. Also, we already mentioned on section.1, USBL dosen't be utilized for CR200 localization on both exams. Thus, we brief the experiment with figures.

A. CR200 function test in engineering water tank

For test of the waypoint tracking algorithm, a course is built on bottom of the water tank using marks which be drawn at regular intervals as 2.5m. The course size is 5m and CR200 size when it walk is 2.4m × 2.5m. Fig. 9 shows the course and a trajectory of CR200.

B. CR200 real sea environment exploration

The exploration is implemented with cooperation of National Research Institute of Maritime Cultural Heritage and CR200 shows its applicability for maritime cultural heritage survey. The waypoint tracking algorithm is applied in order to survey undersurface cultural heritage using a metal detector. Fig. 10 is a mosaicking image of the acoustic camera when the robot investigate a narrow area by the fixed heading mode of the algorithm. We track the robot trajectory using the mosaicking image. CR200 cannot follows a reference trajectory because it doesn't gain any position feedback, furthermore, mud type terrain cause walking slip.

Underwater localization is difficult because underwater robots cannot apply sensors for localization on ground environment such as GPS. USBL has high credibility but it has depth limitation. DR navigation(Dead Reckoning) apt to accrue its error. So, it is unsuitable to CR200 for detail survey. Fig. 10. Shows the mosaicking image using SIFT mosaicking method. Through the mosaicking image, we assure a possibility of localization using the acoustic camera. Optical cameras cannot observes consistently, because its visibility is unreliable underwater circumstance. In the acoustic camera case, it is visible underwater. Moreover, CR200 that designed for adapting irregular terrain and overcoming strong tide underwater can hold its body and the camera. Therefore, the camera can provides regular images and the images is applicability to visual localization such as visual SLAM(Simultaneous Localization and Mapping)

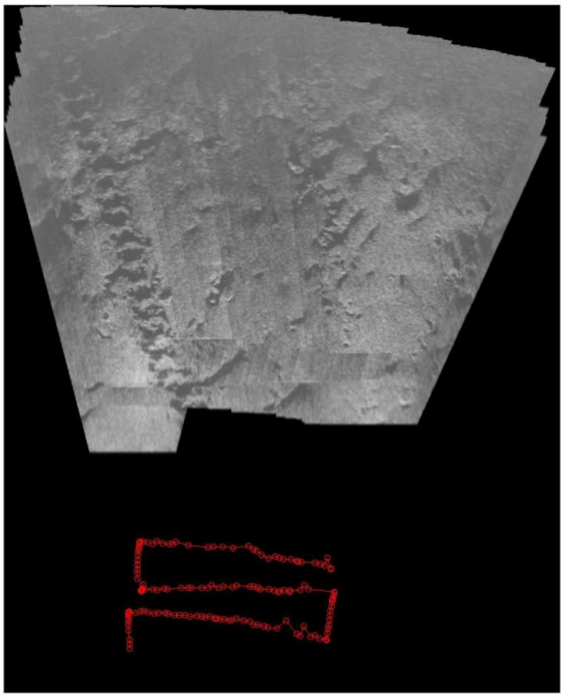

Fig. 10. The mosaicking image with CR200 trajectory

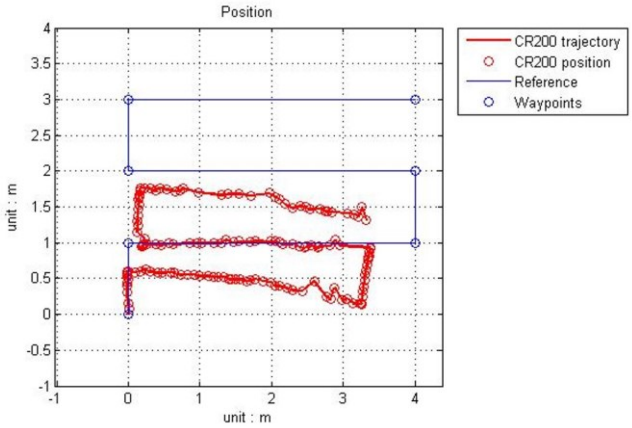

Fig. 11. CR200 trajectory and reference trajectory

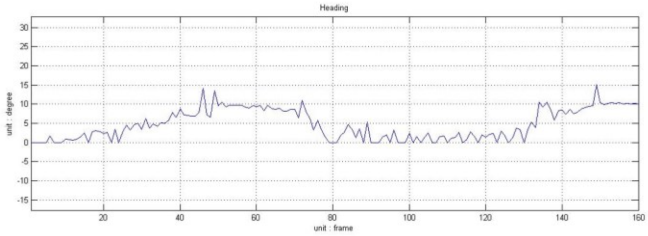

Fig. 12. CR200 heading position

V. Conclusion

This paper introduces the waypoint tracking algorithm with CR200 survey method. The algorithm is composed by Heading controller, Position controller and Path segment selector. Through to divide heading and position controller, CR200 makes the best use of omni-directional characteristic of legged robot, then, fulfills four kind of research modes. Simulation and experiment results show its applicability with localization problems. For the problems, we review acoustic camera images and find a possibility to improve its localization system.

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