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Experiments on a System of Multi-AUV Interlinked with a Smart Cable for Autonomous Inspection of Underwater Structures

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ABSTRACT

We proposed the HS (Hand-in-hand System) for the autonomous inspection of structures. The HS addresses cable-based modular robotics as an application. In this paper, 3 representative experiments are presented to demonstrate the efficiency of the HS. The first experiment is navigation by HS. AUV (Autonomous Underwater Vehicles) take images of all inspection targets and navigational accuracy is estimated. The second experiment deals with obstacle avoidance. In case the smart cable is entangled within obstacles, AUV disentangle the cable and modify the plan for avoidance. The last experiment is the high-speed scanning by HS. AUV make a formation to generate the panoramic image and scan the tank wall surface. Finally, we estimate the accuracy of the mosaicked image they have developed.

INTRODUCTION

Recently, underwater structures have rapidly increased in number, and their periodical safety inspections have become important. For the improvement of these inspections' efficiency and reliability, their automation is required. For autonomous visual safety inspection, we proposed multi-AUV(Autonomous Underwater Vehicles) based on the HS (Hand-in-hand System; Yu, 2004). It is a multi-AUV system interconnected with a smart cable (Shape tape website) which provides its shape. In the smart cable, many fiber-optics sensors provide not only the position of the endpoints but also information concerning its own shape in real-time.

The HS can accomplish the inspection task by these 3 processes:

• Navigation by HS: AUV move to target area

• Obstacle avoidance: When the smart cable is entangled with obstacles, they have to disentangle it.

• Scanning by HS: When AUV reach the target area, they have to take images of a target object or scan a target area.

This paper presents experiments and results of these 3 essential processes to demonstrate the efficiency of HS.

HS EXPERIMENTS

Navigation by HS

The navigation experiment was carried out to estimate the accuracy and performance of the HS. Fig. 1 illustrates the AUV coordinates. TD1 keeps its position by the vision system, and TB2 moves by dead reckoning of the smart cable. Points A, B and C correspond to the absolute position of the target, the starting point of the smart cable at TD1 (Tri-Dog1; Kondo, 200), and its endpoint at TB2 (Twin-Buger2; Balasuriya, 1997), respectively. Point A is the center of the target ball. TD1's rotations are defined as roll(ψ), pitch(ϕ) and yaw(θ). Xc and Zc are the center points in the image area. Xp and Zp are the target position in the image. f is the focus length of the camera; M_x and M_y, the physical distance of a pixel in the CCD at X and Y axes, respectively. *Dist* is the estimated distance from the object (wall) to the camera by the ranging device (Yu, 2004). Point A is known. Point B is obtained by the vision system and the TD1 device.

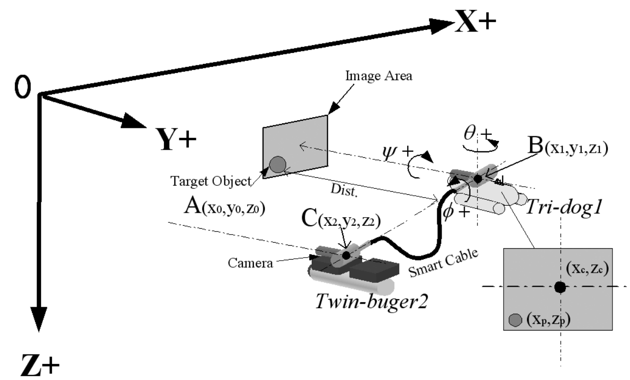

Fig. 1 AUV coordinates

In order to reduce the variables of the camera position, the camera angle was considered to be perpendicular to the wall.

Point B, the position of TD1, can be obtained as follows:

$$X_1 = \frac{M_x \times (X_c - X_p) \times Dist}{f} + X_0 \quad (1)$$

$$Z_1 = \frac{M_y \times (Z_c - Z_p) \times Dist}{f} + Z_0 \quad (2)$$

The smart cable provides the relative position of C, which regards B as the origin (0,0,0). This position is Cr (X_{2r}, Y_{2r}, Z_{2r}).

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KEY WORDS: AUV, cooperative, inspection, automation, multi-agent, fiber-optics.