A Method for Calculating the Amount of Movements to Estimate the Self-position of Manta Robots

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Abstract. In recent years, the demand of underwater investigation is increasing in the circumference of a dam, the environmental research of the shallow where approach by ship is difficult, etc. It is known, however, that for man, all over the sea, danger exists mostly, and prolonged diving has a bad influence to a human body. Then, the development of underwater exploration robots that investigate underwater instead of humans is expected. Among underwater exploration robots, it is known that robots imitating aquatic organisms have little influence on underwater environment. Therefore, at this laboratory, a Manta robot using propulsive mechanisms with pectoral fins was developed, imitating the pectoral fin of Manta. Although underwater environmental research needs a function for estimating the self-position, it is not mounted in this Manta robot. This paper explains the amount estimation of movements using optical flows. Especially, a gimbal mechanism is introduced to reduce the influence on the optical flow calculation by pitch motion of the Manta robot. Several experiments are conducted to demonstrate the usefulness of the proposed method.

Keywords: Manta robot, Self-position estimation, Optical flow

1. Introduction
In recent years, the demand of underwater investigation is increasing in a dam, the environmental research of a shallow, etc. However, in the inside of the sea, there is much danger for man. Moreover, it is known that a bad influence will appear to a human body due to a prolonged diving. Therefore, an underwater exploration robot is expected to investigate underwater instead of man [1]. Among underwater exploration robots, robots that imitate aquatic organisms don’t have a rotor as a propulsive mechanism. Therefore, they are less likely to involve animals and seaweeds in the water, and they also have the feature that there are little underwater radiation noises. The load on the environment is small, so that it is thought that they are effective as underwater exploration robots [2].

Our laboratory has developed a Manta robot that has a propulsion mechanism with pectoral fins, which are constructed by mimicking the pectoral fin of the manta ray [3]. The Manta robot generates the propulsive force by undulating a propulsor composed of the right and left pectoral fins, and it is possible to make a forward and backward motion, a turning motion, and a diving motion. Since the Manta robot swims like actual aquatic lives without making a sound, it is possible to investigate aquatic lives without affecting seriously for them and its environment. In order for underwater robots to investigate an environment to be surveyed all over, it needs to have a function of estimating the self-position. However, such function is not mounted on this Manta robot. Since any radio wave
doesn’t reach underwater environments, it is impossible to acquire the positional information from GPS etc.

Therefore, in this research, we aim to implement a function of estimating the self-position using the optical flow, which expresses the motion of the object as flow vectors from the image taken by a camera. In this paper, a method for calculating the amount of movements is described by using the Lucas-Kanade method, which is one method of detecting optical flows. In addition, this manta robot causes a pitch motion during propulsion, so that it is a troublesome problem that the accuracy in the calculation of optical flows is deteriorated. Therefore, a technique of preventing the calculation accuracy of an optical flow from being degraded is proposed by introducing a gimbal mechanism, which controls a camera posture to follow a desired value, regardless of a pitch motion of the Manta robot. This validity is verified through some experimental results with the ground setup consisting of a camera experimental device mounted on a gimbal mechanism, which is attached to the finger-tip of a manipulator.

2. Manta robot
A Manta robot is an underwater exploration robot, which has a propulsion mechanism that imitates the pectoral fin of a Manta ray. Fig. 1 shows the appearance of the Manta robot developed in our laboratory, Okayama University.

The size of this manta robot is 420 mm in length, 620 mm in width, 90 mm in height and 5.3 kg in weight. The propulsive mechanism with a pectoral fin has six "fin-rays," one of which is equivalent to the skeleton in the fin of Manta ray, on each side of the fuselage, where the fins are attached between fin-rays. Each fin-ray is fitted with one servo motor housed in a waterproof box, and a sine wave is formed to obtain a thrust by operating the fin-ray up and down. In addition, it is possible to periodically transmit the photographed data and to instruct an action by human in emergency by communicating with the ground via the wireless communication function. Coral reef survey in shallow water is considered as an application of manta robot.

In this research, we are aimed at implementing the function of estimating the self-position, by incorporating a visual sensor into the Manta robot shown in Fig. 1. The amount of movements of the Manta robot is calculated using optical flows, which are constructed from the moving images acquired by the camera. The function of estimating the self-position is realized by accumulating this.

3. Method of estimating self-position
3.1. Optical flow
An optical flow is described by a vector, which represents the movement of an object between consecutive images. The optical flow can be calculated by analyzing images obtained from a visual
sensor to be typified by a camera. After acquiring stationary images such as landscape etc. from the moving Manta robot, it performs the detection and integration of optical flows. Thus, the relative amount of movements of Manta robot with respect to the background obtained from the image is realized.

In this research, the Lucas-Kanade method (i.e., LK method) is adopted as a method for detecting optical flows [4]. In the LK method, it is assumed that optical flows are uniform in a certain small region after detecting pixels, which have a feature suitable for tracking on the image as feature points. Thereafter, the least squares solution of flow vectors is obtained after imposing a constraint, i.e., the condition that the luminance is not changed for each pixel in the small region, on optical flows. As an advantage of LK method, the calculation is performed only on a feature point, so that the calculation load is light. The LK method is suitable for detecting optical flows in real-time due to such an advantage.

3.2. Gimbal mechanism
The gimbal mechanism is a mechanism that keeps the direction of a sensor constant by utilizing motors to control the posture, or a suspended weight is oriented in a vertical direction. In this research, a stable calculation of amount of movements is realized even if the posture of the manta robot changes, by acquiring optical flows, keeping the posture of the camera constant with a gimbal mechanism.

Fig. 2 is a graph showing the posture of the manta robot swimming in water. A periodic oscillation about 6 deg has occurred in the pitch angle, so that there may appear a certain influence on the acquisition of optical flows. Therefore, in this paper, one-axis gimbal is used to reduce the influence of this pitch motion.

Fig. 2. Attitude of swimming Manta robot [5]

Fig. 3 shows the gimbal mechanism used in this research. A brushless motor with an excellent response is adopted as an actuator for controlling the attitude. It is expected that the attitude of the camera can be controlled by following the change of posture of the Manta robot without any delay. In addition, as sensors for detecting the changes in the posture of the Manta robot, an inertial measurement unit (IMU: Inertial Measurement Unit) that detects the posture is mounted on the main body side and camera side of the Manta robot, respectively.
Fig. 3. Gimbal mechanism

Fig. 4 shows the block diagram of controlling a gimbal used in this study. The posture control of the gimbal consists of combining feedforward (FF) control, which is based on using the attitude angle of the main body side, and feedback (FB) control, which is based on using the attitude angle of the camera side. Properly speaking, in the block part of FF control, we should create the inverse dynamical model of the gimbal when the Manta robot performs the pitch motion. In this way, if the controlled variable of the gimbal is known, then the manipulated input can be determined for the minimum-time control of the gimbal by using the FF control. However, since the target value of the gimbal is known, but constant, the output of an inverse system is also reduced to a constant, and therefore we implemented FF control to calculate the manipulated input of the gimbal from the difference between the attitude angle of the Manta robot and the target angle of the gimbal. In addition, in order to improve the stability of the gimbal against mechanical errors and disturbances, PID control using the attitude angle of the camera was implemented in the FB block. Hereinafter, the combination of FF control and PID control is expressed as FF+PID control.

Fig. 4. Block diagram of controlling the gimbal

Fig. 5 shows each manipulated variable due to FF, PID and FF+PID control in gimbal control. The attitude control of the gimbal is realized by sending these signals as the manipulated variables to the brushless motor. The manipulated variable from the FF control was represented by a regular sine wave, whereas the manipulated variable from the PID control or the FF + PID control was represented by an irregular sine wave. As a reason why the manipulated variable from the PID control or the FF + PID control is represented by an irregular sine wave, it is considered that any noise is included in the measurement of the controlled variable because the manipulated variable is determined by calculating the deviation between the target value and the current controlled variable in the FB control.
Fig. 5. The manipulated variables due to FF, PID and FF+PID control:
(a) FF control (b) PID control (c) FF+PID control

Fig. 6 shows the graph of controlling the attitude of the gimbal, under a situation in which the manipulated variable by each control method shown in Fig. 5 is given to the brushless motor to generate a certain pitch motion. An input signal whose amplitude is 6.0 deg and period is 1.0 s was set to a servomotor so as to generate a pitch motion. This pitch motion was reproduced by adopting the periodical oscillation acquired when the Manta robot was swimming, referring to Fig. 2. In the case of only FF control, it doesn’t converge to the target value due to the mechanical error of the brushless motor, though the responsiveness is high. Originally, the FF control is a control method being capable of obtaining a controlled variable in a shortest time, under an environment where there exist no disturbances etc. However, as one of causes that the attitude of gimbal does not converge to the target value like this time, it is thought that the validity of a model for the FF control created is not high. When comparing the performance of PID control and FF + PID control, both converged to the target value, and there was no significant difference. Therefore, we conduct in this paper some experiments on the position detection for the Manta robot, using PID control and FF+PID control respectively to control the gimbal and select what is a suitable control method.

Fig. 6. The attitude control of the gimbal for a certain pitch motion

4. Experiments for estimating the self-position
4.1. Estimating the self-position without oscillations
It is confirmed that the LK method, which is one method of detecting optical flows, is useful in estimating the self-position of the Manta robot. The camera (BSW13K08H) was attached to the robot
arm (RV-M2) and was moved 300 mm in the horizontal direction. It was confirmed whether the self-position was able to be accurately estimated by using optical flows detected from the images obtained during movements. The distance from the camera to the landscape on a seafloor was set to 300 mm. Considering an actual environment to be measured, the paper which printed a submarine landscape was installed in the photography side. Since the maximum speed of the Manta robot is about 300 mm/s, the experiment was conducted with the moving speed changed in the range from 50 mm/s to 300 mm/s. When estimating the self-position, it causes errors, if any shadows appear in the photography side. In laboratory experiments, the shadow of the robot arm and the gimbal mechanism may be reflected on the photograph side due to the ceiling illumination. Therefore, the ceiling lighting was turned off during the experiment, and the photography surface was illuminated with a desk light from the side-direction. In addition, a stabilized power supply was used as the power source for the brushless motor in the gimbal mechanism, where the voltage applied to the brushless motor was 5.0 V. Using a notebook PC with Core i5 2.4~Hz and RAM 4~GB for the measurement, a 320 × 240 pixel image acquired from the camera at 30 fps was calculated using Open CV 2.4.11. The measurement was conducted five times under all conditions.

4.2. Estimating the self-position with oscillations

It is confirmed that the attitude control of a camera using a gimbal mechanism is useful for reducing periodic oscillations generated when the Manta robot is propelled. In addition to the conditions given in the previous section, some experiments were conducted with a pitch motion generated by adding an input of amplitude 6.0 deg and period 1.0 s to a servomotor. On the case with gimbal control, and the case of being nothing, the experiments were conducted, respectively. Especially, on the case with gimbal control, experiments and comparisons were carried out for the case of only PID control and for the case of FF+PID control, respectively.

5. Experimental results and considerations

5.1. Estimating the self-position without oscillations

Fig. 8 shows the experimental result on estimating the self-position without pitch motion. The self-position is estimated stably at the moving speed less than 300 mm/s, so that it is concluded that calculating the amount of movements by optical flows is effective as a method for estimating the self-position. In addition, a reason why the amount of movements calculated by optical flows is smaller than the actual one may be attributed to the fact that there is a processing dropout in program. It is thought that an improvement in accuracy can be expected by taking an image at a frame rate lower than 30 fps, and reducing the resultant amount of data.
5.2. Estimating the self-position with oscillations

Fig. 9 shows the experimental result on estimating the self-position accompanied by pitch motion, but without gimbal control. Any pitch motion has affected on the calculation accuracy in the amount of movements, so that it was impossible to estimate the self-position accurately. Also, there was a remarkable deterioration in the calculation accuracy on the amount of movements, at the moving speed more than 150 mm/s. As this cause, it is attributed to the fact that the acquisition of a flow vector becomes inaccurate by the existence of oscillations of a camera, and that if especially a certain fixed forward speed is exceeded, then the estimated speed with a very large variation is calculated through an optical flow method. From the above, it was shown that the influence of a pitch motion is so large that it can’t be ignored, and any countermeasures are indispensable.
Fig. 10 shows the experimental result on estimating the self-position accompanied by pitch motion, when the gimbal is controlled only by the PID control. The influence of a pitch motion was suppressed, and the result close to a target value of 300 mm was obtained in all speed ranges. In addition, it was confirmed that the accuracy in estimating the self-position during movement was improved, compared to the previous gimbal control. The variation in position information adversely affects the performance in position control of the Manta robot. Therefore, the attitude control of a camera by a gimbal mechanism is considered to be effective for improving the performance in position control of the Manta robot. However, it was observed that the accuracy in estimating the self-position was deteriorated immediately after the start of movement, due to the influence of the rising time in PID control.

![Fig. 10. Experimental result of estimating the self-position accompanied by pitch motion (with PID control)](image_url)

Fig. 11 shows the experimental result on estimating the self-position accompanied by pitch motion, when the gimbal is controlled by the FF+PID control. An improvement was found in the accuracy of estimating the self-position immediately after the start of movement, compared to the case where the gimbal was controlled only by the PID control. In particular, the influence was remarkable in the speed range less than 100 mm/s. It is attributed to the fact that since the rising time in the gimbal control was improved by the FF control, the accuracy in estimating the self-position was improved immediately after the start of the movement. From this result, the FF+PID control is used for gimbal control in future research.
6. Conclusion

In this paper, we have been aimed at implementing a function of estimating the self-position by optical flows into a Manta robot, and demonstrated the usefulness of Lucas-Kanade method which is one of detection methods of optical flows. As a result, it was found that a method of calculating the amount of movements by optical flows is effective as the method for estimating the self-position. In addition, we conducted some experiments to confirm an improvement in stability for estimating the self-position by a gimbal mechanism, taking account of the influence of a pitch motion occurring in the Manta robot when acquiring optical flows. It was proved that the attitude control of a camera by a gimbal mechanism was effective for improving the performance in position control of the Manta robot.

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