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The Development of Flying Type Moving Robot Using Image Processing

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***Abstract*—**Wheel-running type moving robot has the restriction on the moving range caused by obstacles or stairs. Solving this weakness, we studied the development of moving robot using airship. Our airship robot moves by recognizing arrow marks on the path. To have the airship robot recognize arrow marks, we used edge-based template matching. To control propeller units, we used PID and PD controller. The results of experiments demonstrated that the airship robot can move along the marks and can go up and down the stairs. It is shown the possibility that airship robot can become a robot which can move at wide range facilities.

***Keywords*—**Template matching, moving robot, airship robot, PID control.

I. Introduction

IN recent years, as well as a factory, development of autonomous robot supporting a user in a more general space e.g. an office or the hospital is prosperous.

Inside of that, some autonomous mobile robot which can perform a tour guide or a guard patrols in facilities have been developed. For example, guide robot “KEITA” or, “enon” is included. However, they have an unsuitable point that moving range is limited by stairs, a step, the obstacle on the floor because these most are wheel-running type moving robot.

As one of the solution to this unsuitability, we decided to develop the flying type moving robot from a point of view that it can move in three-dimensional space. For a reason that is cheap, low power drive and safety for indoor movement, we decided to use an airship-type robot.

So far, there are some researches about the mobile robot using the airship. Tsukamoto performed a research to let an airship robot perform an autonomous object tracking using the vision sensor [1].

In the research of Tsunoda and others built diameter 50[cm] circles as a landmark all over the floor and took picture of them with vision sensor, then controlled the movement by the self-position judgment to an airship robot [2][3].

However, in both researches, movement in a limited range or one space is assumed. It is not mentioned about a wide range of movement paths in facilities separated by stairs or a corridor.

To overcome a limit of the moving range, in this research, we aimed at develop the airship robot system which can move at wide range of paths and can go up and down the stairs.

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II. Outline of the System

A. Overview of the system

This system is going to let an airship robot perform the autonomous run along a specific mark arranged as a moving path. The general view of the system is shown in Fig.1.

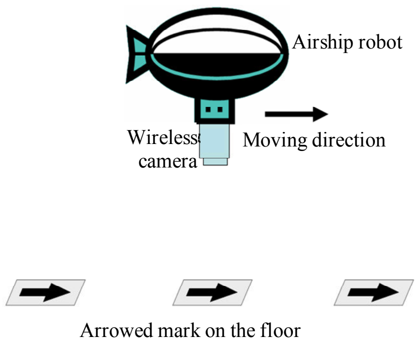

Fig. 1 Overview of the system

We capture the mark on the floor by wireless camera attached to an airship robot downwardly. We compute the size and the direction angle of the mark by image processing then decide a height, a direction angle and a velocity of the airship robot using this information. We decided to use 10[cm] x 10[cm] arrow mark this time.

B. System Configuration

System configuration is shown in Fig.2. The video signal from a wireless camera is taken and input to a PC for image processing. Then recognition of the mark and the control signal are calculated on the PC.

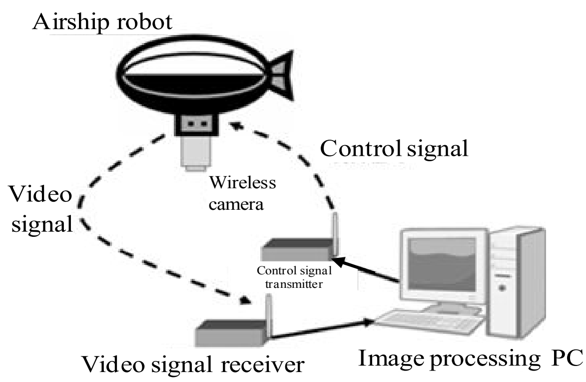

Fig. 2 System configuration

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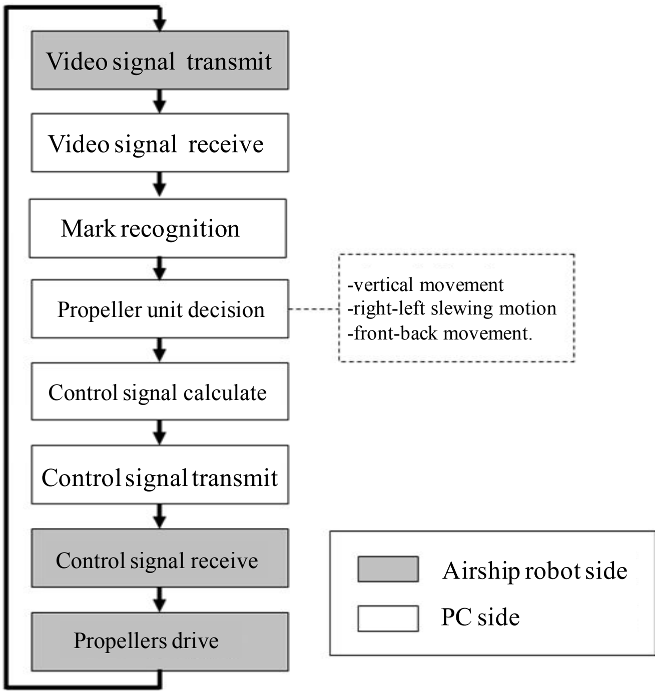

Fig. 3 Flowchart of the process

Afterwards, the control signal is transmitted to an airship robot. The airship robot outputs a control signal to each propeller unit to fly. The airship robot is controlled by repeating these series of processes in a real time. The flowchart of the process is shown in Fig.3.

The specifications of wireless camera and the PC for image processing used this time are shown in Table 1 and 2.

TABLE I
SPECIFICATION OF THE WIRELESS CAMERA

modulation method	NTSC
Effective pixel number	300,000[pixel]
Wave sending possibility distance	200[m]

TABLE II
SPECIFICATION OF THE IMAGE PROCESSING PC

CPU	Core2 Quad Q6600 2.4[GHz]
Main memory	2[GB]
OS	Windows XP

We used HALCON9.0 of MVtec Software and Visual Studio 2008 of Microsoft Corporation for system development. The resolution of the camera image used for a process is 320 x 240 [pixel].

C. Airship robot

We make our own airship robot in this research. The perspective of the airship robot is shown in Fig. 4. This airship robot consists of an electronic driven part and a balloon part.

In the balloon part, to get aerodynamic lift, two spheroid balloons of 650 [mm] diameter and 400[mm] heights are connected together. Each balloon can be filled with up to approximately 120 [l] helium.The electronic driven part is included the wooden base that connect motor propeller and power supply system together. We remodel Haluna-5H and use it in this part. The dimension is 770 [mm] length, 120 [mm] width, and 55 [mm] height. Three propeller units are installed to a driven part as shown in Fig. 5. Each propeller produces driving force of vertical movement, the right-left slewing motion and the front-back movement.

Fig. 4 Airship robot appearance

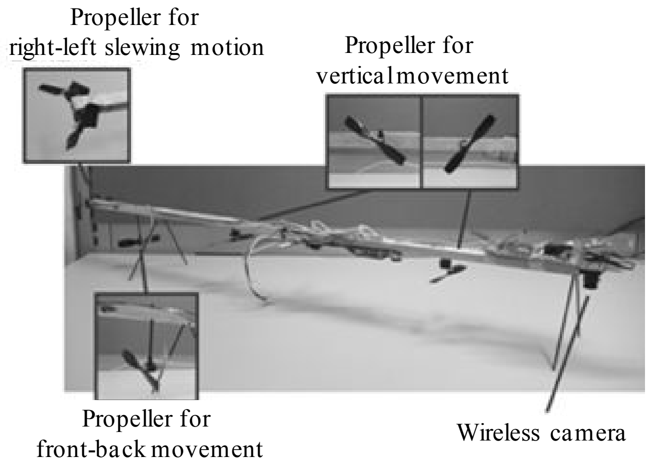

Fig. 5 Three propeller units of airship robot

III. AERONAUTICAL NAVIGATION USING THE IMAGE PROCESSING

A. Recognition of the arrow mark

We decided to use a pattern matching technology for the recognition of an arrow mark built as a path.The technique of the pattern matching is introduced to many divergences; the simplest method is to have template matching by using a luminance value of each pixel as feature vector[4]. In other words, we make a decision whether it is match or not by using the correlation of the luminance value between reference image and input image.However, the method that use a luminance value directly, the luminance value of each pixel will easily changes by a variation of the lighting. As a result, there are problems to cause a decline of the matching accuracy.Even as for this research, we also cannot avoid the lighting variation in the movement path. Therefore, it is not appropriate selection that uses template matching by using a luminance value for

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directly. By this reason, we decided to have template matching made from a contour of the reference image which is relatively strong to a lighting variation. Overview of the template matching is shown in Fig.6.

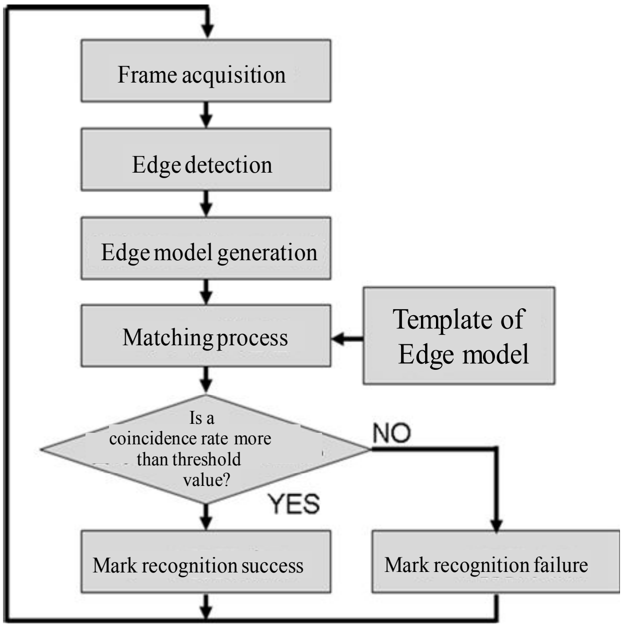

Fig. 6 Overview of the template matching

To make an arrow mark be able to detect at every size and from every direction angle, it is necessary to make extension to compute a template matching for every size and every rotation angle of the input image.

A direction angle of the mark in input image is used for controlling the propeller unit for left-right slewing motion. Relation between the mark and direction angle is shown in Fig. 7. The direction angle of the airship robot is range from 0 to 359[deg].

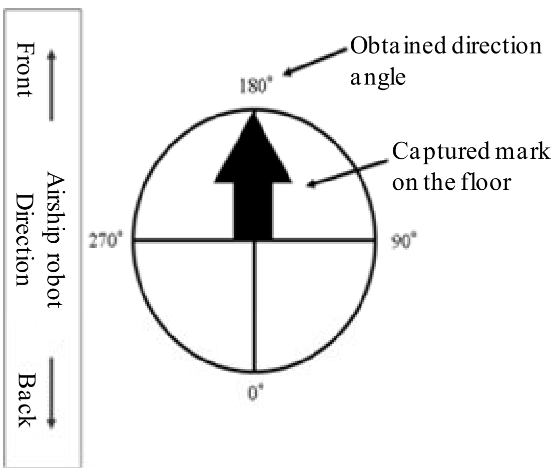

Fig. 7 Relation between the mark in input image and direction angle.

On the other hand, we calculate a scaling factor of the mark in the input image compared to reference image. Then we transform this value to "the distance between the mark and camera", and we use this value to control the propeller unit for vertical movement.The range of scaling factor is decided after having determined a range of distance between the mark and camera. The distance is assumed that it ranges from 0.5[m] to 3[m] in consideration of the height of the ceiling of the general corridor.Because relation between scaling factor of the mark and distance were not linear, we measured this correspondence in a preliminary experiment and showed the result in Fig. 8.

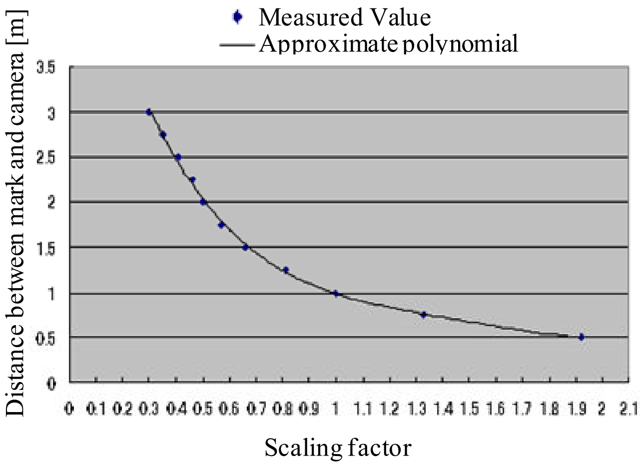

Fig. 8 Relation between scaling factor of the mark and distance

We calculated by a least squares method to these plotting points and obtain approximate polynomial that shown in equation 1. We use this equation to control the propeller for vertical movement.

$$d = 0.8202x^4 - 4.9143x^3 + 11.1x^2 - 11.698x + 5.6765 \quad (1)$$

d is the distance between the mark and camera, x is the scaling factor. We take scaling factor from 0.3 to 2.0 by the reason that the system can recognize the mark by this range.

We registered all template of every 1[deg] from 0 to 359[deg] by direction angle and every 0.1 from 0.3 to 2.0 by scaling factor to cope with a variation of input mark as shown in Fig. 9.

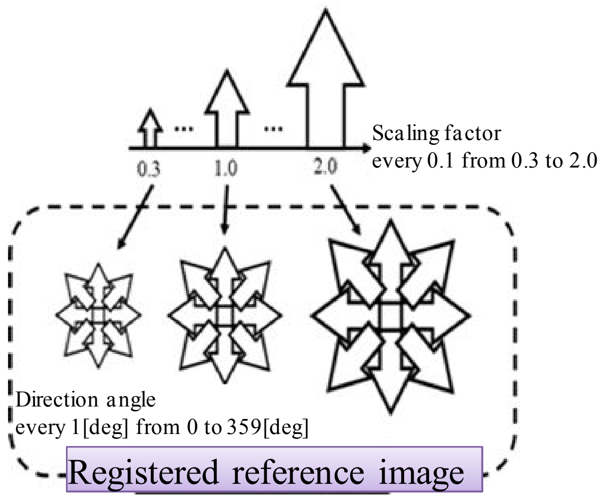

Fig. 9 A variation of scaling factor and direction angle

Finally we describe the mark recognition rate by the template matching process that we implemented. Recognition rate of the mark in the specific size by scaling factors from 0.3 to 2.0, 200 [Frame] is shown in Fig. 10.

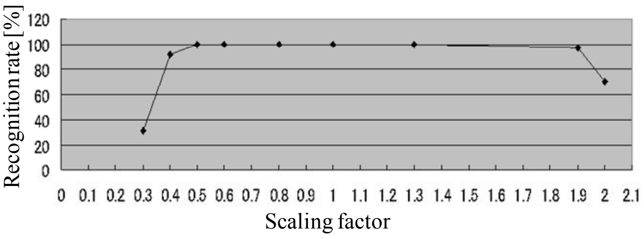

Fig. 10 Recognition rate of the mark by scaling factor from 0.3 to 2.0

The processing time for 1 cycle of this template matching process from frame acquisition to mark recognition was about 70[msec].

B. Control of the airship robot

We decided to use PID control to control the airship robot in this research. The expression of the general PID control in the digital control system becomes like equation 2.

$$u(t) = K_P e(t) + K_I \Delta T \sum e(t) + K_D \frac{e(t) - e(t-\Delta T)}{\Delta T} \quad (1)$$

Here, *u(t)* is manipulated variable, *e(t)* the deviation between targeted value and the controlled variable in time *t*. *KP, KI, KD* is proportional gain, an integral gain and derivative gain, respectively. *ΔT* is a sampling time, in this research we give *ΔT*= 0.2[sec].

We implement PID control for each propeller unit individually. We decided to implement PD control to propeller unit of right-left slewing motion and front-back movement and we decided to implement PID control to the propeller unit of vertical movement.

The manipulated variable of vertical movement, right-left slewing motion and front-back movement are shown in equation 3, 4 and 5, respectively.

$$u_z(t) = K_{Pz} e_z(t) + K_{Iz} \Delta T \sum e_z(t) + K_{Dz} \frac{e_z(t) - e_z(t-\Delta T)}{\Delta T} \quad (2)$$

$$u_\theta(t) = K_{P\theta} e_\theta(t) + K_{D\theta} \frac{e_\theta(t) - e_\theta(t-\Delta T)}{\Delta T} \quad (3)$$

$$u_y(t) = K_{Py} e_y(t) + K_{Dy} \frac{e_y(t) - e_y(t-\Delta T)}{\Delta T} \quad (4)$$

$e_z(t)$ is the deviation of the height that means differences between goal height and present height. $e_\theta(t)$ is deviation of the direction angle that means differences between goal angle and present angle. $e_y(t)$ is deviation of the velocity that means differences between goal velocity and present velocity. Here, the velocity means amount of pixel that the center of the mark have moved in the time of one frame.

Next, we describe a determination of each parameter in each control type.About the PID control type for vertical movement, we calculated the value that was suitable by using the most famous resolution sensitivity method as the adjustment method of the control parameter [5,6,7,8].

About the PD control type of right-left, front-back propeller, we calculated a parameter by the following procedure.

At first we set K_D to zero and gradually increase only K_P. If a system response is vibrational, and that vibration becomes sustained, control gradually increases K_D to stable suitable value.We gather up each control-type parameter that we mentioned above in Table III.

TABLE III
PARAMETERS OF EACH CONTROLLER

Gain / Propeller	K_P	K_I	K_D
vertical movement	0.54	0.027	2.7
right-left	0.08	—	0.4
front-back	15	—	10

IV. EXPERIMENT

We had four experiments to confirm whether we could control an airship robot by the template matching process mentioned above.

A. Experiment 1(the height holding experiment)

We drove only a propeller unit for vertical movement in this experiment. We will confirm whether the airship robot can reach and hold the targeted of the height.

The height targeted is set at 160[cm]. The result of the experiment is shown in Fig.11. We can confirm that deviation of the height is less than ± 20[cm].

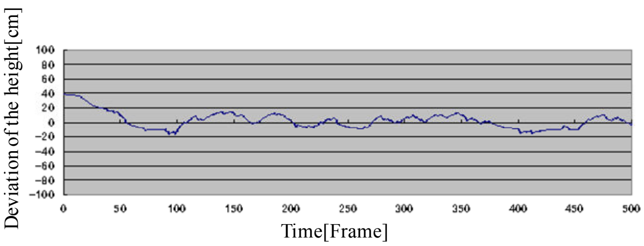

Fig. 11 Deviation of the height at experiment 1

B. Experiment 2(Height and direction holding experiment)

This experiment aims to confirm if the airship can keep holding the targeted of the height and turn a body in the direction of the mark. We drove a propeller unit of vertical movement and right-left slewing motion. The control targeted is 160[cm] high and 180[deg] of direction angle.The result of the experiment is shown in Fig.12-13. Figure 12 shows deviation of the height, Fig.13 shows deviation of the direction angle, respectively.We can finally control deviation of the height in the range of ± 20[cm] as well as the case of the height holding in experiment 1. And we can confirm that deviation of the direction angle is under the range of ± 30[deg].

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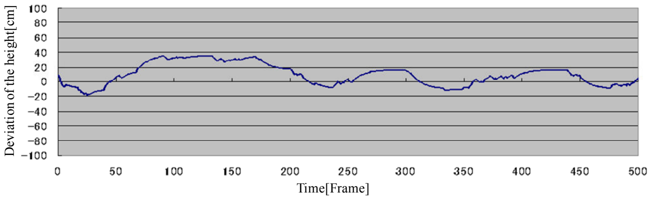

Fig. 12 Deviation of the height at experiment 2

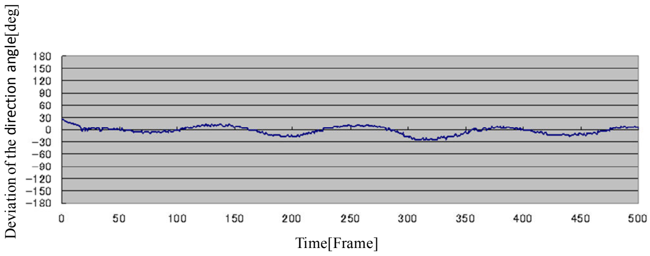

Fig. 13 Deviation of the direction angle at experiment 2

C. Experiment 3(height, direction angle and velocity holding experiment)

This experiment aims to confirm whether an airship robot can hold the height, direction angle and velocity while moving along the arrow mark which placed as a straight line. Ten pieces of arrow mark are placed on a straight line every 50[cm] by this experiment.

We drove all propeller units. The control targeted value of each propeller unit is 160[cm] of height, 180[deg] of direction angle, 3[pix/frame] of velocity. The results are shown in Fig.14-16, respectively.

We were able to confirm that deviation of the height and deviation of the direction angle range like as the result in experiment 2. Furthermore, we were able to confirm that deviation of the velocity was carried out in a range of ± 2[pix/frame].

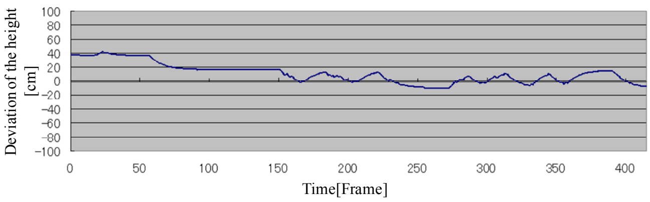

Fig. 14 Deviation of the height at experiment 3

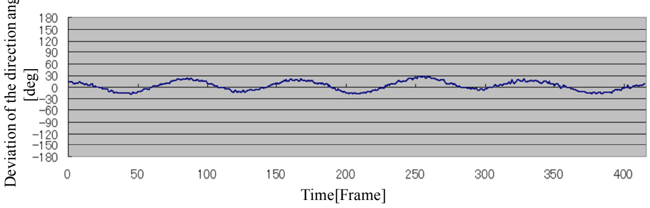

Fig. 15 Deviation of the direction angle at experiment 3

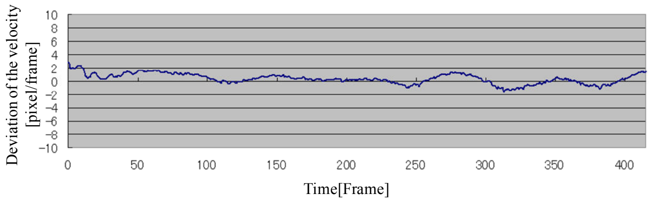

Fig. 16 Deviation of the velocity at experiment 3

D. Experiment 4(experiment of going up and down the stairs)

In this experiment, we build a mark on stairs and confirm whether an airship robot is possible to go up stairs and go down stairs along the marks. Stairs are all 12 steps, one step 28[cm] widths and 17[cm] heights. We place the mark every two steps of stair.

The result of the go up experiment is shown in Fig. 17-19; the result of the go down experiment is shown in Fig.20-22, respectively.

For plainness, we insert an x cross mark to express the spot that detected the next arrow mark in Fig.17 and 20. The black x cross mark expresses the beginning and ending point of stairs.

In both experiments, we were able to confirm that the airship could go up and go down the stairs.

As from the figure, deviation of the velocity and the direction angle, a result like is obtained in experiment 3. On the other hand, deviation of the height is relatively large during moving over stairs, but gradually become small after end of the stairs.

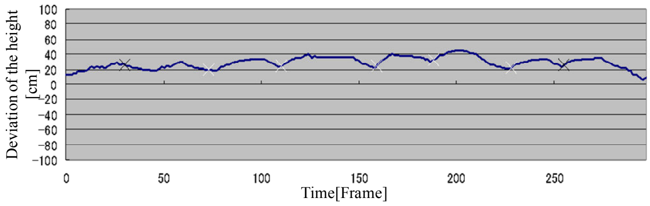

Fig. 17 Deviation of the height at experiment 4 (go up the stair)

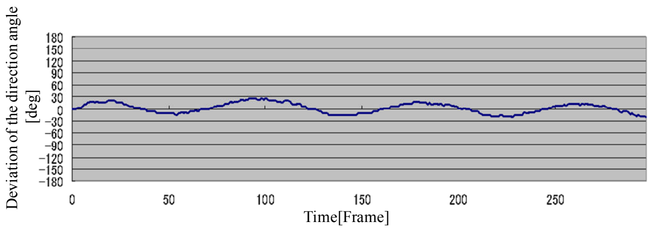

Fig. 18 Deviation of the direction angle at experiment 4 (go up the stair)

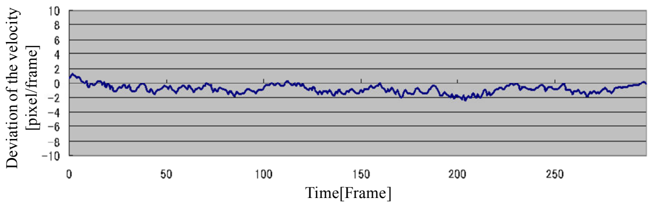

Fig. 19 Deviation of the velocity at experiment 4 (go up the stair)

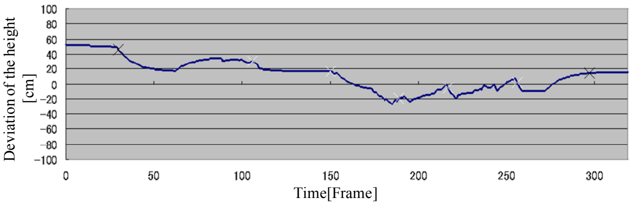

Fig.20 Deviation of the height at experiment 4 (go down the stair)

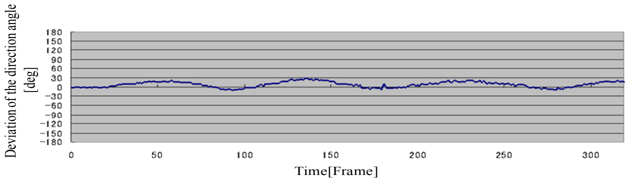

Fig. 21 Deviation of the direction angle at experiment 4 (go down the stair)

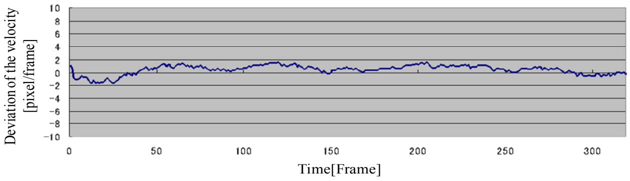

Fig. 22 Deviation of the velocity at experiment (go down the stair)

V. Conclusion

This paper described the development of flying type moving robot using image processing. We developed the airship robot which aims at autonomous running along the path. We were able to let an airship robot perform basic operation e.g. high holding, turn left-right, go up and down the stairs by using PID and PD control. This research shows the possibility that the airship robot could move in a wide area such as in a facilities separated by stairs or a corridor.

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