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Simulation and implement of Memory-based PID control for indoor blimp robot

Yoshifumi Yamagata[1], Hidenori Kawamura[1], Azuma Ohuchi[1]
Toshihiko Takaya[2], and Hiroyuki Iizuka[3]

[1] Graduate School of Information Science and Technology, Hokkaido University
North 14, West 8, Kita-ku, Sapporo, Hokkaido, 060-8628, Japan
E-mail : yamagata, kawamura, ohuchi @complex.eng.hokudai.ac.jp
[2] Ricoh Software Inc.
North 7, West 4, Kita-ku, Sapporo, Hokkaido 060-0807, Japan
E-mail : toshihiko.takaya@rsi.ricoh.co.jp
[3] Department of Media Architecture,Future University-Hakodate
116-2 Kamedanakano-cho, Hakodate, Hokkaido, 041-8655, Japan
E-mail : ezca@fun.ac.jp
URL : http://harmo.complex.eng.hokudai.ac.jp/

Abstract

We report on simulation and implement of Memory-based PID control for indoor blimp robot. In the control of indoor blimp robot, it is known that the PID control is effective. However, it is necessary to adjust PID parameters dynamically, since the environment changes dynamically. We use Memory-based PID controller for PID parameter tuning. The method is that a set of the PID parameters and input/output data of the controlled object are stored in the data-base, and are used to calculate the PID parameters to control object. The results of experiments demonstrated the effectiveness of Memory-based PID control for indoor blimp robot.

key words - indoor blimp robot, Memory-based PID, disturbance, controller

1 Introduction

Indoor blimp robot can float in the air by buoyancy. Therefore, they have the advantages of free three dimensional movement less influenced by geographical features than two dimensional mobile robots that move on the ground. Their buoyancy also enable them to move for long periods using low energy. Additionally, even if they crash, they suffer less damage than small air-crafts or helicopters because the balloon is used for them. For these features, indoor blimp robots have enormous potential for applications such as an entertainment fright, security check, safety checks at high attitudes, and overhead advertising. Researchers have investigated the PID[2], fuzzy[3], and learning[1] controllers for blimp robots. It has been shown that the PID control is effective for the complex movement control[4]. However, it is necessary to set parameters manually in the PID control. To adjust the PID parameters autonomously, there are some researches to adjust the PID parameters by neural network, fuzzy theory, and genetic algorithm in the nonlinear control. However, these methods are difficult to adjust the PID parameters in an on-line manner because it takes long time to learn the parameters. In order to overcome this problem, the Memory-based PID controller[5] that is PID controller based on a memory based modeling are used for the rotation control of blimp robot[6]. Memory-based PID controller is that a set of the PID parameters and input/output data of the controlled object are stored in the data-base, and used to calculate the PID parameters to control object. The controller has an ability to adapt to the physical characteristics of the blimp by using reference model. However, it is difficult to construct the reference model of the blimp robot. Therefore, in the blimp robot control, instead of the data modification, two or more parameters are prepared for initial data-base[6].

Our aim is to develop a method that can tune the PID parameters in response to the environment that changes dynamically. It is difficult to prepare two or more appropriate PID parameters for initial database in three dimensional. In this paper, we describe a method to modify the PID parameters by using the target value. Experiments in a real environment showed the effectiveness of the parameter tuning using the Memory-based PID controller that modifies PID parameters ongoingly by the target value.

2 Indoor blimp robot

We use cylinder-shaped blimp robot. Compared to ellipsoidal typed balloon, cylinder type balloon has the advantages of uniform air resistance for directions, moving precisely in the desired direction directly without rotation. These features might be necessary to achieve the applications for indoor blimp robots.

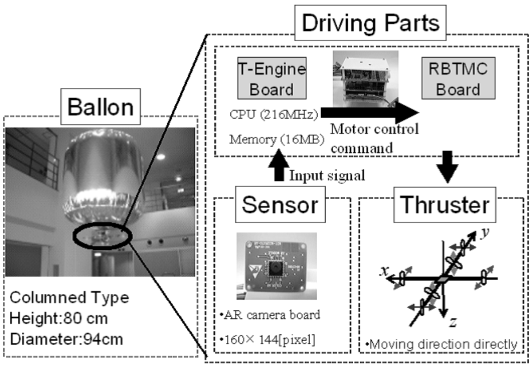

Figure 1: Overview of indoor blimp robot: balloon and control system.

Figure 1 shows the blimp robot that we have studied and an overview of the control system. Blimp robot consists of a balloon to float and driving parts for moving. The driving parts consist of the controller, thrusters, and a sensor. In the design of the balloon, we decided on diameter as $94[cm]$ and height as $80[cm]$ to enable the blimp to float by buoyancy. The controller consists of a T-Engine board and $RBTMC$ board. Image processing calculations and decisions on outputs to control the blimp are run on the T-Engine board and sent to the $RBTMC$ board as control commands for propellers on thrusters. Based on control commands, the $RBTMC$ board controls motors that drive propellers at a sampling time $\Delta T = 0.3[s]$, which is based on consumption time for image process and control decision. The blimp recognizes positional information and environmental conditions through the camera sensor, AR camera, which sends image data to the controller via an internal bus and is fitted on thder T-Engine board. The image resolution is 160 144 pixels, and color information is composed of 16bit data in RGB color space. The blimp robot has six propellers, $ch0$ and $ch2$ for x-axial movement, $ch1$ and $ch3$ for y-axial movement, and $ch4$ and $ch5$ for z-axial movement. We adjust thrust by switching On/Off signals controlling motor rotation.

3 Control method

3.1 Memory-based PID controller

Memory-based PID controller designed by Takao[5] and modifications in our proposing method are described as follows.

An element accumulated in the data-base is defined as follows.

$$\phi(t) \equiv [r(t+1), r(t), y(t), \quad , y(t \quad n_y + 1),$$
$$u(t \quad 1), \quad , u(t \quad n_u + 1)]$$
$$\mathbf{K}(t) \equiv [K_P(t), K_I(t), K_D(t)]$$

where t denotes the time when the input/output data was acquired. r is the target value, y is controlled variable, u is output, n_y denotes degree of y, and n_u is degree of u. Memory-based PID controller generates a suitable PID parameters by STEP1-5.

[STEP1] Making of initial data-base

Initial data-base consists of input/output data and the PID parameters are decided by a conventional method, i.e., the Zieglar&Nichols method, Chein,Hrones&Reswick method, etc.

$$\Phi^j \equiv [\phi^j, \mathbf{K}^j], j = 1, 2, \quad , N(0)$$

where $N(0)$ denotes the number of initial data.

[STEP2] Calculation of distance, selection of neighborhood

A distance d between $\phi(t)$ and ϕ^j that has been stored in the data-base is calculated as follows.

$$d(\phi(t), \phi^j) = \sum_{l=1}^{n_y+n_u+1} \left| \frac{\phi_l(t) \quad \phi_l^j}{max_m \phi_l^m \quad min_m \phi_l^m} \right|$$
$$(j = 1, 2, \quad N(t))$$

where $N(t)$ is the number of data at time t. ϕ_l denote the $l \quad th$ element of data, and $max_m \phi_l^m$ denotes the maximum element of $l \quad th$ elements of all the data that exists in the data-base. Similarly, $min_m \phi_l^m$ denotes the minimum element of $l \quad th$ elements of all the data that exists in the data-base.

The closest k elements on the data-base are selected and defined as neighborhood.

[STEP3] Calculation of local model

A local model is calculated by linearly weighted average method using neighborhood in STEP2 as follows.

$$\mathbf{K}^{old}(t) = \sum_{i=1}^{k} w_i \mathbf{K}_i$$

where

$$w_i = \sum_{l=1}^{n_y+n_u+1} \left(1 \quad \frac{[\phi_l(t) \quad \phi_l^i]^2}{[max_m \phi_l(m) \quad min_m \phi_l(m)]^2} \right)$$

After the weights are calculated, the weights are normalized to satisfy the following equation.

$$\sum_{i=1}^{k} w_i = 1$$

This $\mathbf{K}^{old}(t)$ is used as PID parameters to control(see Sect. 3.2).

[STEP4] Modification of data

PID parameters $\mathbf{K}^{old}$ calculated in STEP3 is modified in response to the size of the control error. And the data $\mathbf{K}^{new}$ is stored in the data-base. The modification method is as follows.

$$\mathbf{K}^{new}(t) = \mathbf{K}^{old}(t) \quad \boldsymbol{\eta}\frac{\partial J(t+1)}{\partial \mathbf{K}(t)}$$

$$\boldsymbol{\eta} \equiv [\eta_P, \eta_I, \eta_D]$$

where $\boldsymbol{\eta}$ denotes learning coefficient, J is evaluation norm of error defined as follows.

$$J(t+1) \equiv \frac{1}{2}\epsilon(t+1)^2$$

$$\epsilon(t) \equiv y_r(t) \quad y(t)$$

where $y_r(t)$ is output of reference model. It is difficult to construct the reference model of the blimp robot. Therefore, we propose to replace above equation as follows.

$$\epsilon(t) \equiv r(t) \quad y(t)$$

PID parameters can be brought close to the target value following PID parameters.

[STEP5] Deletion of the redundant data

Redundant data is deleted from the data-base to reduce the calculation time. The procedure consists of the following two stages.

Stage1

$$d(\phi(t), \phi^i) \qquad {}_1, \quad i = 1, 2, \quad , N(t) \quad k$$

Stage2

$$\sum_{l=1}^{3} \left\{ \frac{\mathbf{K}_l^i \quad \mathbf{K}_l^{new}(t)}{\mathbf{K}_l^{new}(t)} \right\} \qquad {}_2$$

If two or more deletion candidates exist, the data with the lowest value of above equation is deleted.

3.2 PID controller for indoor blimp robot

In our PID controller, the manipulated variables $m(t)$ is given as the ratio of the rotation time for each propeller in sampling time ΔT. The manipulated variables $m_x(t)$, $m_y(t)$, $m_z(t)$ are decided by the relative velocity from the blimp robot to the target point. The manipulated variable $m_\theta(t)$ is calculated by the relative angular. These manipulated variables are defined as follows.

$$m_x(t) = K_{Px}(t)e_x(t) + K_{Ix}(t)\sum e_x(t)\Delta T + K_{Dx}(t)\frac{De_x}{\Delta T}$$

$$m_y(t) = K_{Py}(t)e_y(t) + K_{Iy}(t)\sum e_y(t)\Delta T + K_{Dy}(t)\frac{De_y}{\Delta T}$$

$$m_z(t) = K_{Pz}(t)e_z(t) + K_{Iz}(t)\sum e_z(t)\Delta T + K_{Dz}(t)\frac{De_z}{\Delta T}$$

$$m_\theta(t) = K_{P\theta}(t)e_\theta(t) + K_{I\theta}(t)\sum e_\theta(t)\Delta T + K_{D\theta}(t)\frac{De_\theta(t)}{\Delta T}$$

where K_P(t) is proportional gain, K_I(t) is integral gain and K_D(t) is derivative gain, and $De(t) = e(t) \quad e(t \quad \Delta T)$. Thrusts $M_0(t)$,...,$M_5(t)$ generated for propellers $ch0$,...,$ch5$ are determined by using $m_x(t)$,$m_y(t)$,$m_z(t)$,$m_\theta(t)$ as follows.

$M_0(t) = m_y(t) + m_\theta(t)$, $M_1(t) = m_x(t) + m_\theta(t)$, $M_2(t) = m_y(t) \quad m_\theta(t)$, $M_3(t) = m_x(t) \quad m_\theta(t)$, $M_4(t), M_5(t) = m_z(t)$.

4 Experiment

4.1 Experimental setup

We show the effectiveness of the parameter tuning using the Memory-based PID controller that modifies PID parameters ongoingly by the target value.

Our experimental environment is shown in Fig. 2. The experiment space is set over 300[cm] at width, depth, and height. The blimp recognizes its position information from landmarks placed on the ground (see [2]). The blue and red circle are arranged with a diameter of 50[cm] at intervals of 75[cm] to the floor at the space for the experiment.

To confirm the effectiveness of our proposed method, a simple task is set as follows. The blimp robot is required to move 150[cm] and 250 [cm] high for Z coordinate alternately. Initial data-base consists of input/output data and the PID parameters made by the Ziegler-Nichols step response method. Table1 shows parameters on Memory-based PID controller that are used in this experiment. We compared the Memory-based PID controller with the fixed PID controller.

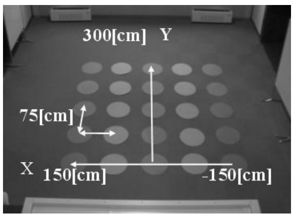

Figure 2: Experimental environment

Table 1: Parameters on Memory-based PID controller

parameters	values
Orders of the information vector	$n_y = 2$ $n_u = 2$
Number of neighbors	k =6
Coefficients to inhibit the data	$_1$ =1000 $_2$ =1000
Initial number of data	$N(0) = 40$

4.2 Result

Figure 3 shows Z coordinate transition of the blimp robot. In Memory-based PID control, the time of the overshoot and undershoot is less than the fixed PID control. Figure 4 shows transition of PID parameters corresponding to Fig. 3. The PID parameters are changing in response to the environment and undershoot is suppressed. We conclude that the parameter tuning using the Memory-based PID controller that modifies PID parameters ongoingly by the target value is effective.

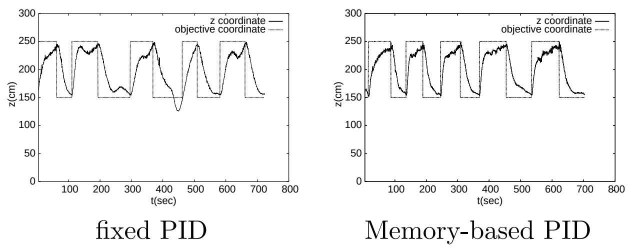

Figure 3: Z coordinate transition of the blimp robot

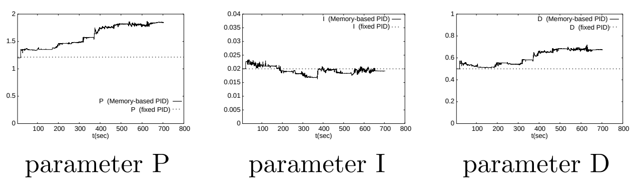

Figure 4: Transition of PID parameters(solid line) (The dotted line represents the fixed PID parameters used in Fig. 3.)

5 Conclusion

In this paper, we reported the effectiveness of parameter tuning using the Memory-based PID controller that modifies PID parameters ongoingly by the target value. In the experiment, we showed the PID parameters were tuned in an on-line manner. By using this method, the blimp robot move more stably than the one using fixed PID controller.

In the future work, we will use this technique to bridge the gap between a simulation and a real world. The initial data-base could be prepared in the simulation first, and then it could be used for controllers of the real blimp robot.

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