Task Oriented Behavior-Based State-Adaptive PID (Proportional Integral Derivative) Control for Low-Cost Mobile Robot

Igi Ardiyanto
Electrical Engineering Department
Gadjah Mada University (UGM)
Yogyakarta, Indonesia
e-mail : igi@te.ugm.ac.id

Abstract--**This paper describes how state-adaptive PID (Proportional Integral Derivative) control can be applied to a low-cost mobile robot. Behavior-based state-adaptive control for this mobile robot behaviors was designed using only three infrared sensors, a low-cost 8 bit microcontroller, and an electronic compass, with size of 22cm x 21cm x 16cm. The task oriented behavior-based approach is implemented as two tasks, wall following and goal seeking. Adaptive control used in this robot is PID algorithm using LMS (Least Mean Square) approach. Robot is given a map and run in an artificial corridor representing the map. The results demonstrate that each task works correctly and can run simultaneously. Experimental result shows that robot can run at maximum speed of 100 cm/s without any collision with the corridor. Robot can follow the wall, go to the goal, and avoid obstacles detected by the infrared sensors.**

Keywords—**autonomous mobile robot, indoor navigation, behavior-based robotics, adaptive control, PID.**

I. INTRODUCTION

According to S. Parasuraman et al [3], the real world environment during mobile robot navigation has the following problems: a) Knowledge of the environment is partial, uncertain, imprecise and approximate, b) The environment is vast and dynamic and the obstacles can move, appear or disappear and c) Due to the quality of the ground, sensors data received are not completely reliable. The issues (a) and (b) affect the behavior rule selection and (c) affects the sensors input space to match the complex environment into robot's output. In the past, several works relating to robot navigation have been done which describe mathematical models and fuzzy logic systems for behavior selection, but the limitations are the insufficient knowledge based perception of the environment and absence of decision making capability similar to human driver.

Behavior-based approaches have been established by S. Thongchai et al [2] as a main alternative to conventional robot control in recent years. Those approaches can be implemented and tested independently. The system architecture, in their application implemented in the IMA, has three levels. The highest level behavior is the task-oriented behavior which consists of two subtasks: wall following and goal seeking. The middle level behavior is an obstacle-avoiding behavior. The lowest is an emergency behavior.

Kazumi Oikawa et al [1] have shown that decision making for mobile robot can be built using a simple system; wheel-driven mobile robot with 8 position-sensitive detectors (PSDs) as distance sensors, 1 electronic compass, a landmark sensor for receiving landmark signals from 7 directions, and an H8 microcontroller.

We propose building behavior-based state-adaptive control for small mobile robot using simple system. The main goal of this project is to implement task oriented behavior-based as two main tasks, wall following and goal seeking. We use adaptive control on a PID algorithm instead fuzzy control or other high-level algorithm in order to make computation fast and fits in a 8-bit low cost microcontroller. We also want to show that a proper algorithm can be used to make a robust system, although it is not a complex algorithm.

II. FUNDAMENTAL THEORY

The used discrete PID controller is characterized by the following equation (1).

$$u_t = Kp_t e_t + Ki_t T_s \sum_{k=0}^{t} e_k + Kd \frac{e_t - e_{t-1}}{T_s} \quad (1)$$

Where *e(t)* is the error of the system response in the t instant , *Ts* is the signal sampling period and *Kp*, *Ki* and *Kd* are the proportional, integral and derivative controller gains, respectively.

This algorithm, associated with the error calculation, is of very fast execution, however its parameters should be previously and appropriately adjusted.

Actually, there are various calculation and parameters adjustment methods for PID controllers (*Kp*, *Ki* and *Kd*). From static parameters adjustment methods, like Ziegler – Nichols and Kitamori methods, to methods where the parameters are dynamic, depending on the system response, as, for example, the ones based on Fuzzy Logic systems,

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Neural Network systems or Neuro-Fuzzy systems [5]. The disadvantage of these last ones is the need of too many processing resources, being therefore usually slower.

The considered adaptive algorithm intends to have the advantage of simplicity and to be implemented with few hardware resources and simultaneously to obtain a reduced implementation time (processing cycle time). The question related with the processing time is very important because it limits the quickness of the control signal, the quickness of the controller parameters adaptation and consequently it limits the set performance and behavior in the reference signal tracking.

One of implementation of adaptive system is transversal structure using linear adaptive [4]. Output signal the N order adaptive system for single input and output is

$$y(k) = W_k^T X_k \tag{2}$$

where $\boldsymbol{W}k^T$ = [$w0\ (k)\ w1(k)\ \ldots\ wN\text{-}\ 1(k)$] is weight vector, $\boldsymbol{X}k^T$ = [$x(k)\ x(k\text{-}1)\ \ldots\ x(k\ \text{-}N\ \text{+}1)$] is input vector, T define transpose, and k is time index. In adaptive system, weight of Wk is adjusted so that $y(k) = d(k)$, with $d(k)$ is desired value. Value of $x(k)$ is taken from sampling.
According LMS algorithm, weight adjusting is derived

$$W_{k+1} = W_k + 2\mu e(k)x(k) \tag{3}$$

where μ = constant >0, and

$$e(k) = d(k) - y(k).$$

III. Methods

Robot system is built as block diagram in figure(1)

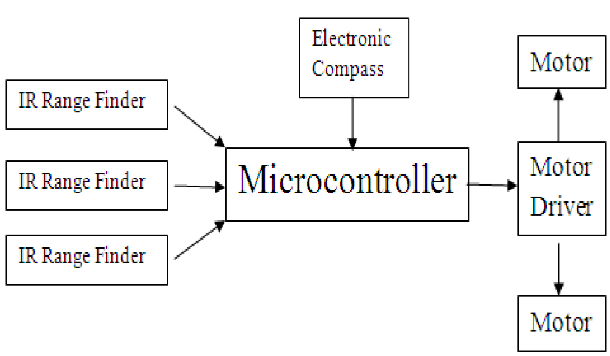

Fig. 1. Block diagram of robot's hardware system

Robot only has 3 SHARP GP2D12 infrared (IR) sensor, an electronics compass CMP03, and an 8-bit AVR microcontroller. Sensor position is described in figure(2.b)

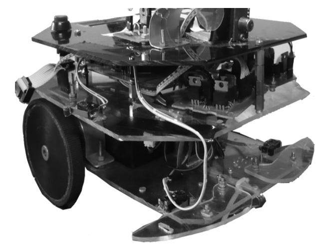

Fig. 2.a. Snapshot of Robot

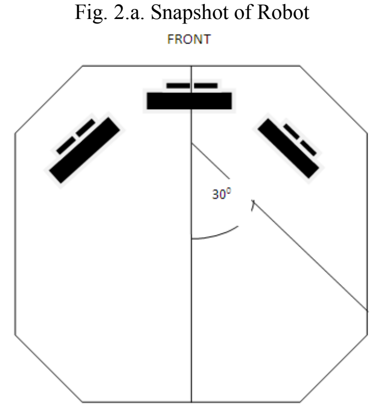

Fig. 2.b. IR Sensor Position

The main problem of collecting data from sensors is that the sensors have a non-linear response and have an inversely proportional with distance. The response of IR sensor is shown in figure(3)

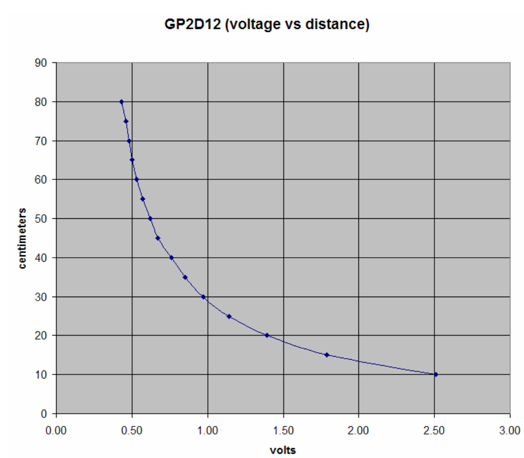

Fig. 3. SHARP GP2D12 IR Range Finder's response

To overcome this non-linearity, we use IF-THEN rules so that sensor's data is plotted in centimeters. With this "linear" sensor's data, we can use it as input of our system, as shown in figure(4)

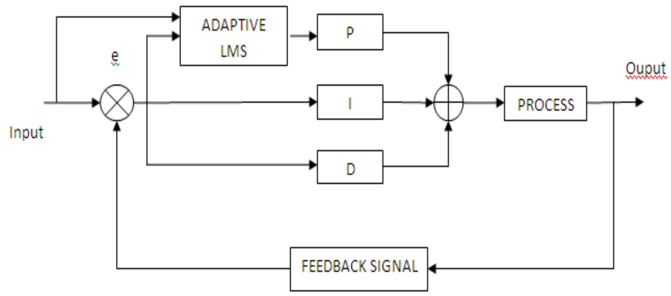

Fig. 4. Block Diagram of Wall Following Task

The tasks given to robot are divided into two tasks; the main task is to seek the goal and the other is to follow the wall as part of goal seeking task. To fulfill the main task, robot is given an artificial corridor with several intersection, as shown in figure(5). The width of corridor is 50 cm.

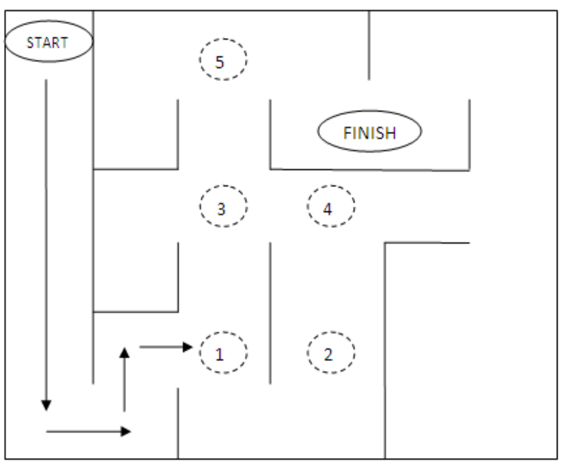

Fig. 5. Maze with Several State for Robot

To reach the goal, State-machine algorithm is applied into robot. There are several states shown at fig.(5) that must be handled by robot, as path for reaching goal. On each state, robot follows the corridor using wall following algorithm until next state. Robot uses all of three IR sensors and electronic Compass to determine the state, and only two IR sensors uses in wall following task. These tasks run simultaneously. In other word, robot must handle two different algorithms in a time.

To perform wall following task, we use adaptive PID algorithm (1), with LMS (Least Mean Square) approach. In this project, only proportional constant (Kp) that is adjusted by adaptive algorithm. The weight of Kp is adjusted by LMS algorithm where Wk in eq.(3) is substituted by Kp.

$$Kp_{t+1} = Kp_t + 2\mu e(t)x(t)$$

(4)

where μ = constant >0, and

$e(t) = d(t) - y(t)$.

where x(t) is actual recent sensor's response and d(t) is desired recent sensor's response. The users determine desired distance between robot and the wall in the code.

To implement the PID control system on the microcontroller, the PID should be changed into the discrete equation. Equation (1) is derived,

$$\frac{u}{dt} = Kp\frac{de}{dt} + Ki\frac{d}{dt}\int edt + kd\frac{d^2e}{dt^2} \quad (5)$$

$$\frac{u}{dt} = Kp\frac{de}{dt} + Kie + kd\frac{d}{dt}\left(\frac{de}{dt}\right) \quad (6)$$

Then multiply by Ts,

$$\frac{\Delta u}{Ts} = Kp\frac{\Delta e}{Ts} + Kie + kd\frac{\Delta}{Ts}\left(\frac{\Delta e}{Ts}\right) \quad (7)$$

$$\Delta u = Kp\Delta e + KieTs + kd\Delta\left(\frac{\Delta e}{Ts}\right) \quad (8)$$

Where Ts is time sampling.

Here is flowchart of robot to fulfill the tasks.

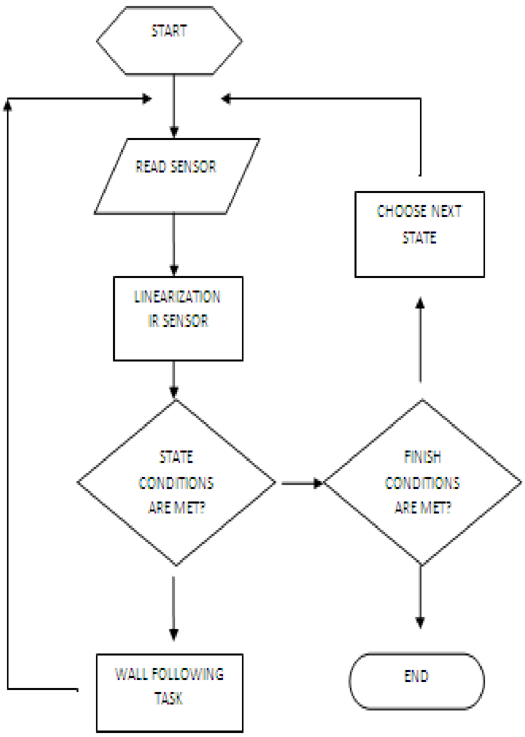

Fig. 6. Flowchart of Robot

IV. Experimental Results

Experiment is divided into two parts; wall following test, and goal seeking test.

In wall following test, robot runs in corridor without concerning the state. We test the robot under several robot's speed and shape of wall. Table 1 is the table of wall following test. Each experiment is performed 10 times, and calculated the number of successful experiment. Experiment is considered successful if robot doesn't hit the wall.

TABLE 1
Result of Wall Following Test

Max Speed	Straight -path	90-degree Bend	180-degree Bend
60 cm/s	**10**	**10**	**10**
80 cm/s	**10**	**10**	**10**
100 cm/s	**10**	**10**	**10**
110 cm/s	**10**	**10**	**8**
120 cm/s	**10**	**9**	**7**

In goal seeking test, we test the ability of robot to recognizes state and reaches the goal. There are several possible paths for robot to complete the task. According to fig.(5), Robot may follow these state :

1. START – 1 – 3 - 5 – FINISH
2. START – 1 – 2 – 4 – FINISH (turn right)
3. START – 1 – 2 – 4 – 3 – 5 – FINISH
4. START – 1 – 3– 4 – FINISH

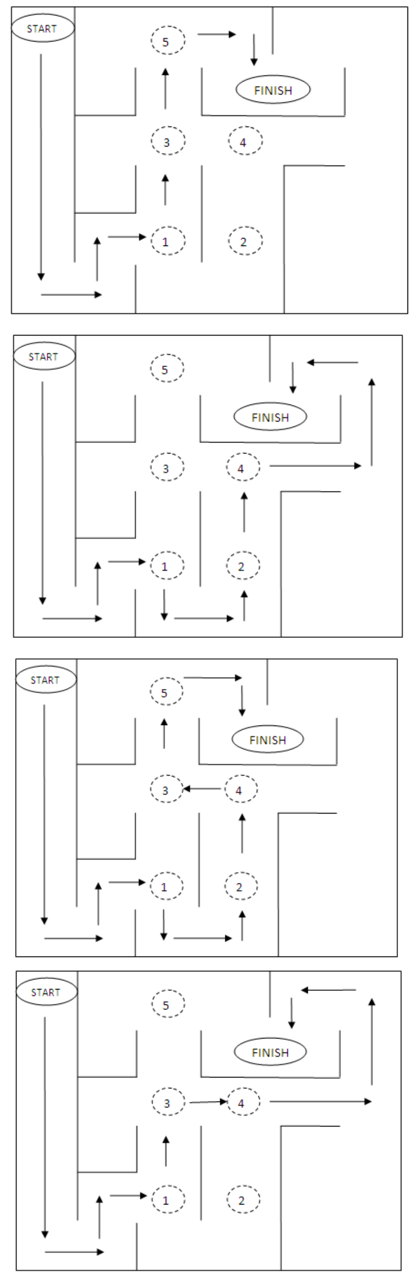

Fig. 7. Possible Path for Robot

Each experiment is performed 10 times, and calculated the number of successful experiment. Experiment is considered successful if robot can finish the task completely.

TABLE 2
RESULT OF GOAL SEEKING TEST

State Combination	Successful Experiment
1	10
2	10
3	10
4	10

To know the advantages of adaptive algorithm compared with traditional PID algorithm, we hold some experiments. For this case, robot is tested in 90-degree bend with different algorithm, adaptive algorithm and traditional PID algorithm, and the distance needed by robot to reaches steady-state condition is measured. Experiments are carried out by setting the desired value on 20 cm. Steady-state condition is defined as a condition in which the oscillation range of the robot is at 5% of the desired value. The result can be seen in the following table.

TABLE 3
COMPARISON OF ADAPTIVE AND PID ALGORITHM

Algorithm	Steady-state After
Adaptive	20 cm
PID	50 cm

From experiment, we can conclude that this adaptive algorithm has increased the performance of robot, better than if we only use traditional PID algorithm.

V. CONCLUSIONS

This work presents task oriented behavior-based approach has been successfully implemented as two tasks, wall following and goal seeking, using adaptive control approach. Robot can run in an artificial corridor representing the map. The results demonstrate that each task works correctly and can run simultaneously. Experimental result shows that robot can run at maximum speed of 100 cm/s without any collision with the corridor. Robot can follow the wall, go to the goal, and avoid obstacles detected by the infrared sensors.

The main advantage of the presented system is that it does not need any kind of adjustment or PID calibration. It has the advantage of the adaptive systems, quickly compensating the disturbances that can appear in the system control functioning. The *Kp* adjusting is simply implemented using adaptive algorithm based on LMS algorithm. More of all, it has shown that a simple system can be built as a behavior-based mobile robot with sufficient reliability.

In the future, more sensor should be attached on the robot, to increase reliability of robot in the matter of environmental recognition.

REFERENCES

[1] K. Oikawa, H. Takauji, T. Emaru, T. Tsuchiya, and S. Okubo, “Decision making of a mobile robot using potential function”, Journal of Robotics and Mechatronics Vol. 19 No. 3, 2007.
[2] S. Thongchai, S. Suksakulchai, D. M. Wilkes, and N. Sarkar, “Sonar Behavior-Based Fuzzy Control for a Mobile Robot”, Proc of IEEE International Conference on Systems, Man, and Cybernetics, 2000
[3] S.Parasuraman, V.Ganapathy, and Bijan Shirinzadeh, “Behavior based Mobile Robot Navigation Technique using AI System: Experimental Investigations”, presented at ARAS 05 Conference, CICC, Cairo,Egypt, 2005.
[4] Priyatmadi and B. Sutopo, “Implementation of LMS Adaptive Algorithm on TMS320C25”, available : www.te.ugm.ac.id/~bsutopo/pri.pdf (Indonesian)
[5] J. Chainho, P. Pereira, S. Rafael, and A.J. Pires, “A Simple PID Controller with Adaptive Parameter in a dsPIC; Case of Study”, available : www.aedie.org/9CHLIE-paper-send/337_CHAINHO.pdf
[6] Parallax Inc. , “Sharp GP2D12 Analog Distance Sensor”, Tech Support , available : www.parallax.com/dl/docs/prod/acc/SharpGP2D12Snrs.pdf