

# Optimization of Circular Robot Size Using Behavior Based Architecture

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**Abstract**—This study discusses the attempt to optimize the circular robot dimension with the planned robot work area. This research is necessary because for building robot it faced problem in determine of size, load, resource and flexibility of the robot movement maneuver. This optimization supports to make robots work effectively. The robot movement uses differential drive principle and implements a behavior-based architecture. The proposed model is tested on robots that have several different dimensions in wall following behavior and obstacle avoiding behavior. Each robot is designed in a circular shape with the distance between wheels of the robot has a diverse diameter. It is hoped that this research will make it easier for the robot designers to optimize the process of building an effective robot. Generally, based on several experiments have been performed, the robots are able to perform their work completely. The optimal dimension of the robot diameter has a ratio of 0.8 compared to the minimum width of the robot area.

**Index Terms**—Behaviour Base Architecture; Circular Mobile Robot; Differential Drive; Dimension Optimization;

## I. INTRODUCTION

Mobile robots are finding increasing use in many areas such as education, military, disaster recovery, home cleaning, advertisement, assistance for people with disability, exploration and transfer of goods. Thus, a mobile robot system is still a popular topic among students, robotic researchers and educators around the world [1]. Understanding the construction and control of mobile robots has therefore become a necessity for many electrical and electronic engineers. In mobile robots, the navigation problem includes several sub-tasks such as path planning, and tracking, localization, collision avoidance and point stabilization [2]. These tasks can be considered as independent modules working collectively.

There are several aspects of the robot that are attractive to be discussed. The shape, size and method of movement are some examples of the dimensions discussed in robotics research [3]-[4]. The shape and dimensions of a robot to be designed should be in accordance with the purpose and application of the design of the robot [5]-[6]. Generally, robot size is determined by trial and error in accordance with the desired work area and function planned [7]. However, often, these trial results are not appropriate in the actual design of the robot [8]. Thus, many resources are unused effectively. In addition, the discussion of the size of the robot is not much discussed analytically, so there are not many theories that try to discuss it.

This paper offers an empirical study to determine the optimal size of a mobile robot suitable to the work area and its function plan. The mobile robot used is circular shaped

with a certain diameter. The differential drive system will be used [9]-[12]. Experimental studies based on mathematical models are used to optimize the size of robots by implementing behavioral based architecture principles [13-18]. Some behaviors will be performed to test the robot in several work areas.

## II. MOBILE ROBOT MODEL

In this work, a mobile robot model is used for verification and performance analysis of the proposed algorithm. The dimension of the robot is as follows:  $D$ ,  $r$ , and  $W$ , where  $D$  is diameter of robot base,  $r$  is the radius of wheels and  $W$  is distance between two wheels, respectively. Usually,  $W$  is equal to  $D$ . Figure 1 illustrated a model of mobile robot for simulation exercises for the proposed algorithm. The mobile robot is positioned on a two dimensional Cartesian workplace, in which a global coordinate  $\{X, O, Y\}$  is defined. The robot has three degrees of position that are represented by a posture  $p_c = (x_c, y_c, \theta_c)$ , where  $(x_c, y_c)$  indicate the spatial position of the robot guide point in the coordinate system and  $\theta_c$  is the heading angle of the robot counter-clockwise from the x-axis [9]-[10].

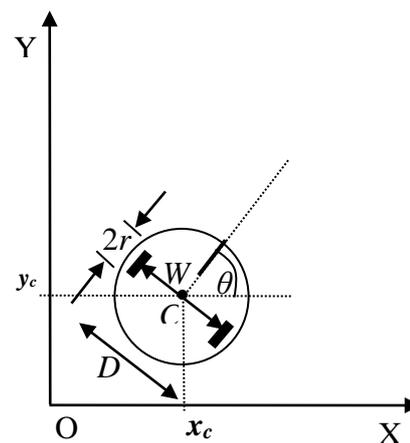


Figure 1: Model of Mobile Robot

The mathematical model for the robot movement can be obtained with differentially steered drive system or known as differential drive system. Differential drive system is one of the most widely used structures of locomotion for such autonomous mobile ground robots and ground vehicles. Differential drive robot has independently actuated right and left wheels. There may be an additional passive wheel in the front for smooth movement of the robot. The motion of the

robot is controlled by controlling the left and right rear wheel velocities,  $v_l$  (velocity of left wheel) and  $v_r$  (velocity of right wheel). While the velocity of each wheel varies, the robot will rotate based on a point that lies along their common left and right wheel axis. The point is known as the Instantaneous Center of Curvature (ICC), as shown in Figure 2 [19]-[21].

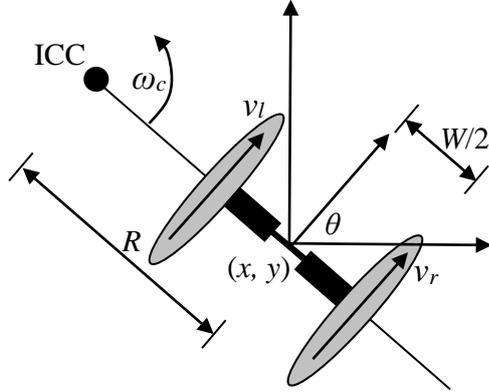


Figure 2: Differentially Drive Systems

By varying the velocities of the two wheels, the trajectory that the robot takes will vary as well. Since the rate of rotation  $\omega_c$  about the ICC must be the same for both wheels, it can be written as follows

$$\omega_c \left( R + \frac{W}{2} \right) = v_r \quad (1)$$

$$\omega_c \left( R - \frac{W}{2} \right) = v_l \quad (2)$$

where  $R$  is the signed distance from the ICC to the midpoint between the wheels,  $W$  is the distance between the center of the two wheels,  $\omega_c$  is the angular velocity of the robot, and  $v_r$  and  $v_l$  are the right and the left wheel velocities along the ground, respectively.

At any instance in time, Equation (1) and Equation (2) can be solved for  $R$  and  $\omega_c$  as:

$$R = \frac{W}{2} \left( \frac{v_r + v_l}{v_r - v_l} \right) \quad (3)$$

$$\omega_c = \left( \frac{v_r - v_l}{W} \right) \quad (4)$$

and

$$v_c = \left( \frac{v_r + v_l}{2} \right) \quad (5)$$

where  $v_c$  is the linear velocity of the robot.

There are three interesting cases with these kinds of drives based on Equations (3) to (5):

1. If  $v_l = v_r$ , then the robot moves in straight line with  $v_c$ .  $R$  becomes infinitive, and there is effectively no rotation, because  $\omega_c$  is zero.
2. If  $v_l = -v_r$ , the  $R$  is zero, and the robot pivots at the midpoint of the wheel axis.

3. If  $v_r$  is equal to zero, the robot rotates with the left wheel for turning right and  $R = W/2$ . The reverse is true if  $v_l$  is equal to zero.

Based on these combinations, the robot can move to different positions and orientations as a function of time. The derivatives of  $x$ ,  $y$  and  $\theta$  can be obtained as

Based on this system, the robot can move to different positions and orientations as a function of time. The derivatives of  $x$ ,  $y$  and  $\theta$  can be obtained as

$$\frac{dx}{dt} = v_c \cos \theta_c \quad (6)$$

$$\frac{dy}{dt} = v_c \sin \theta_c \quad (7)$$

$$\frac{d\theta}{dt} = \omega_c \quad (8)$$

where  $\omega_c$  is the angular velocity of the robot and where  $v_c$  is the linear velocity of the robot.

By applying the current position of the robot,  $p_c = (x_c, y_c, \theta_c)$ , the next position of the mobile robot is such as follows:

$$x_{c+1} = x_c + v_c \cos \theta_c * \Delta t \quad (9)$$

$$y_{c+1} = y_c + v_c \sin \theta_c * \Delta t \quad (10)$$

$$\theta_{c+1} = \theta_c + \omega_c * \Delta t \quad (11)$$

where  $\Delta t$  is a time step.

Then, as assuming the value of  $\Delta t$  is a unit time step, the next position of the robot,  $p_{c+1} = (x_{c+1}, y_{c+1}, \theta_{c+1})$ , in simple form is:

$$x_{c+1} = x_c + v_c \cos \theta_c \quad (12)$$

$$y_{c+1} = y_c + v_c \sin \theta_c \quad (13)$$

$$\theta_{c+1} = \theta_c + \omega_c \quad (14)$$

Based on the principle of differential drive system and the dimensions of the robot in Figure 1, there is a corresponding relationship between the distance  $W$  and the ICC as the robot turning point of the mobile robot movement. The optimal value of the robot diameter can produce robotic movements that are reliable according to the robot area where the robot will be implemented.

### III. BEHAVIOR-BASED ARCHITECTURE

Control architectures of robot form the backbone of complete robotic system [22]. They provide a set of principles for organizing a control system. They specify the structure of a control system: how the system is divided into subsystems, how those subsystems interact, and the computational concepts that underlie a given system.

Behavior-based control architecture is an alternative to hybrid systems that use a bottom-up approach that involves decomposing the main objective into smaller ones; in such way that main objective is achieved as a result from the execution of simpler behaviors and from their interaction.

In this system, intelligence is achieved through coordination of a set of perception-action units, called behaviors [14]-[15]. All behaviors are taking inputs from the robot's sensors and sending outputs to the robot's actuators with simple controller algorithm. However, behaviors must

completely independent of each other. The parallel structure of simple behaviors allows a real-time response with low computational cost. A coordinator is needed in order to send only one command at a time to the motors. The coordinator plays an important role to combine the outputs from several conflicting behaviors. Behavior-based control architecture has demonstrated its reliable performance in standard robotic activities such as navigation, obstacle avoidance, terrain mapping, object manipulation, cooperation, learning maps and walking.

Nowadays, behavior-based robotics are widely used and investigated since introduced initially by Rodney Brooks [14]. This field has attracted researchers from many and diverse disciplines such as biologist, neuroscientists, philosophers, psychologists, and of course, people working with computer science and artificial intelligence. Some proponents of behavior-based systems claim that the system would be a better model cognition. Others employ them purely from pragmatic motivation, including their ease of system development and the robustness of the results. There are also some interactions among behaviors if two or more behaviors are active in one particularly time, such as independent, combination, suppression, and sequence. In independent interaction, two or more independent behaviors are performed at the same time. In combination interaction, two or more behaviors are combined into a resulting emerge behavior, for example, a robot may have to follow left and right wall concurrently. Moreover, in suppression interaction, a behavior inhibits a competing one, for example if two conflict behaviors are active. Finally, in sequence interaction, a behavioral pattern is developed as a sequence of simple behaviors.

Based on the robot's target behavior, the proposed approach decomposed the task of robot into three behaviors, namely: left wall following behavior, right wall following behavior, and obstacle avoiding behavior. Wall following behaviors navigate the robot to follow wall in order to help goal completion. Based on some distances measured between the mobile robot and the walls, the mobile robot would maintain some fixed distance between both robot and the wall even at edges. Wall following behavior trajectory example is shown in Figure 3.

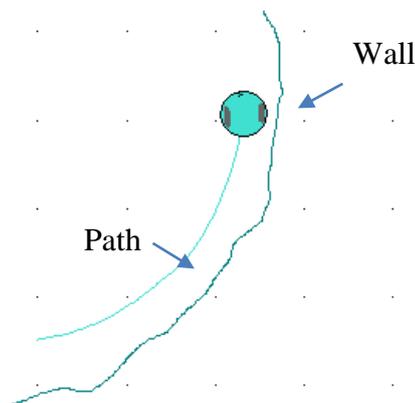


Figure 3. Trajectory of Right Wall Following Behavior

Moreover, obstacle avoiding behavior is responsible to control the robot from colliding with objects in the environment. Actually, the obstacle avoiding is a complex behavior. The mobile robot has to detect first whether there

are any obstacles or not. Then, the direction should be determined to avoid the obstacles. Some distances between the mobile robot and obstacles should be measured to complete the task of this behavior. Figure 4 shows obstacle avoiding behavior trajectory in a line obstacle.

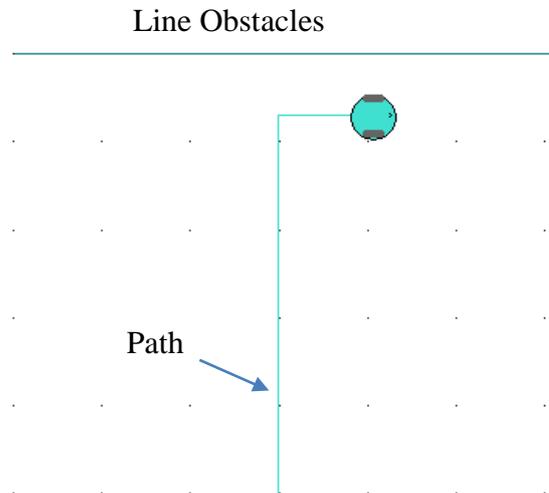


Figure 4. Trajectory of Obstacle Avoiding Behavior

All of behaviors are activated based on several distance sensors are placed in mobile robot. In this work, three distance sensors are used and placed such as shown in Figure 5. Sensor<sub>0</sub> and Sensor<sub>2</sub> used for right and left wall following behavior and Sensor<sub>1</sub> used for obstacle avoiding behavior.

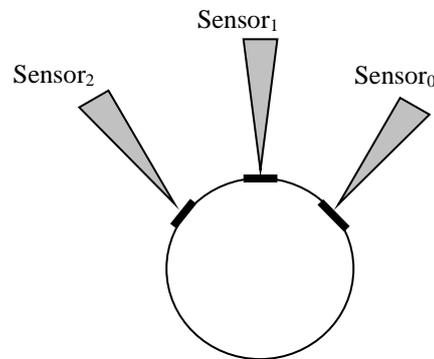


Figure 5. Distance Sensors Placement

A block, named as Behavior Coordinator serves to determine which behaviors are active at a particular time according to behavior context. If there is more than one behavior is active, then a special technique will be determined to coordinate these active behaviors [22]. The whole block diagram system designed is shown in Figure 6.

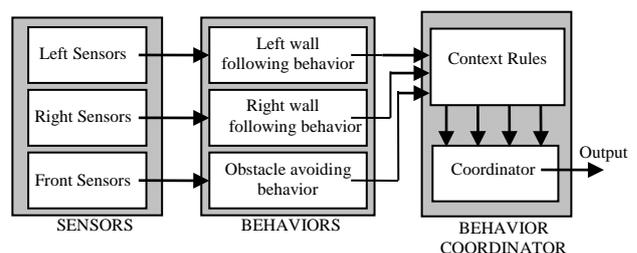


Figure 6. Behavior-Based System Design

IV. RESULTS AND DISCUSSION

Several experiments are designed by deriving the equations that have been discussed, from Equation (12)-(14). The whole equation is applied to the circular robot model as shown in Figure 1. The model is then used as the basis for the experimental process to produce the optimal robot diameter in each particular behavior. Then, the model is applied to a computer simulation process using a specific application, named as MobotSim version 1.0.

Two types of experiments have been conducted to determine the optimal robot size. The experiments are conducted by applying the robot movement to certain behaviors in a particular robot area. Each of experiment is done to get the best result. Behaviors tested are obstacle avoiding behavior and wall following behavior.

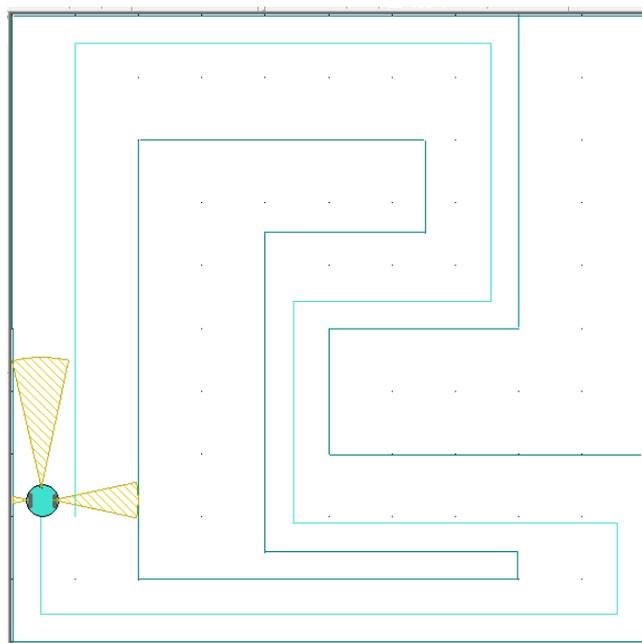
The first experiments are the obstacle avoiding behavior performance test. In these experiment is designed an area that has a horizontal wall type, such as an office. There is a narrow and wide corridor, where the narrowest corridor is 100 cm, and the widest is 200 cm. Several diameter sizes,  $W$ , of mobile robot were tested, from 50 cm to 110 cm. The Width Ratio is a ratio of diameter size of mobile robot,  $W$ , with the narrowest corridor. The results of the experiments are shown in Table 1. Trajectories of the robot movement are shown in Figure 7. Distance sensors measurement result analysis is depicted in Figure 8.

Table 1. Results of Obstacle Avoiding Behavior Experiments

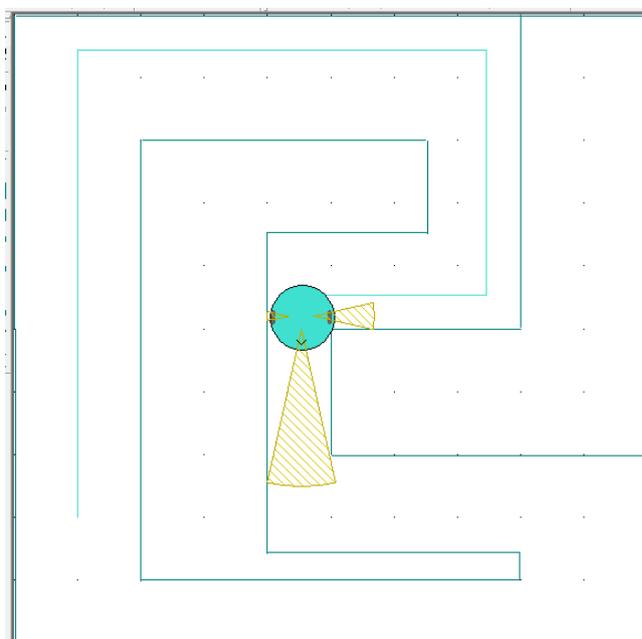
No	$W$ (cm)	Time	Status	Width Ratio
1	50	37'56'5	Ok	0.50
2	55	37'55'5	Ok	0.55
3	60	37'54'5	Ok	0.60
4	65	37'57'3	Ok	0.65
5	70	37'56'4	Ok	0.70
6	75	37'55'1	Ok	0.75
7	80	37'56'1	Ok	0.80
8	85	44'20'5	Fail	0.85
9	90	44'21'2	Fail	0.90
10	95	30'42.2	Fail	0.95
11	100	30'43.5	Fail	1.00
12	105	30'41.8	Fail	1.05
13	110	30'43.3	Fail	1.10

Table 1 shows the robot work to complete the Obstacle Avoiding Behavior task. This task is performed by avoiding obstacles if it has been detected at a certain distance, where the robot will move angularly by 90 degrees. Based on the data in Table 2, the task can be performed well in Experiments 1-7, for 37'55 second, with robot diameter ratio with the narrowest corridor up to 0.80. However, when the ratio is 0.85 and above, the task fails to be completed and stops at 30'43 second. The robot fails to complete the task because of the dimension of the robot is not suitable enough to the corridor.

Figure 7 shows the robot's movement to complete the obstacle avoiding behavior task on an office like corridor. Figure 7 (a) shows the robot being able to complete the task properly. The trajectory shows that robot able to avoid several obstacles in front of it by turning 90 degrees very precisely. However, in Figure 7 (b), the task does not work properly while the robot stops in a fairly narrow corridor. This is because of the robot dimension is no longer able to move in accordance with existing environmental conditions.



(a)



(b)

Figure 7. Result of Obstacle Avoiding Behavior: (a) OK and (b) Fail

Figure 8 shows the robot movement based on distance sensors. At the beginning, the front sensor,  $Sensor_1$ , shows the distance between robot and obstacle is 5 m, due to the maximum sensor measurement capability. When approaching the obstacle at about 650 seconds, the robot turning right. This is indicated by changing on the front sensor,  $Sensor_1$ , and the right sensor,  $Sensor_0$ . Likewise, on the other turning right at 1300 second and 1700 second. Similarly, in contrast, at 2050 seconds, when the robot turns to the left.

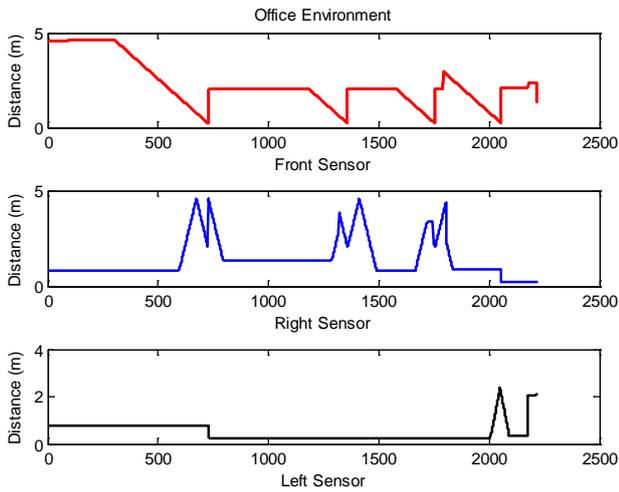


Figure 8. Sensors Analysis of Obstacle Avoiding Behavior

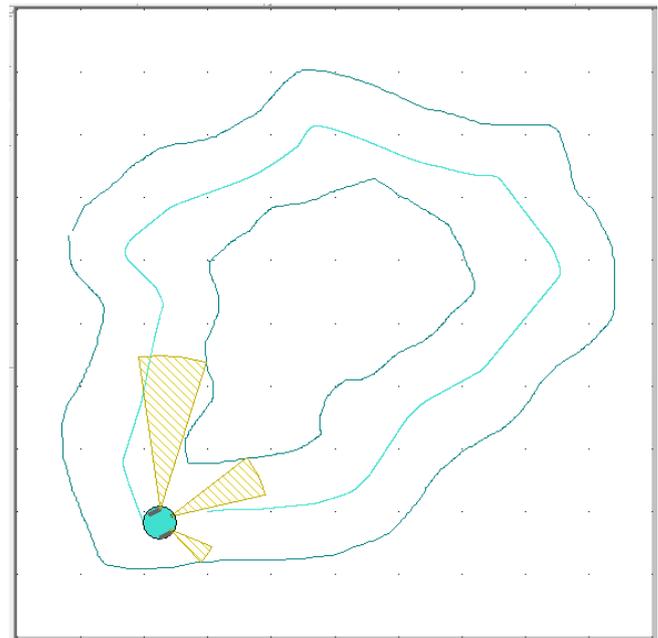
The next experiment is the wall following behavior. In this experiment, it has been designed an area that has a variety types of wall, either on the right or left of robot as well. There is a narrow and wide corridor, as well, where the narrow corridor is 150 cm, and the width is 350 cm. Several diameter sizes were performed, from 50 cm to 110 cm. The results of the experiments are shown in Table 2. Trajectories of the robot movement are shown in Figure 9.

Table 2. Results of Wall Following Behavior Experiments

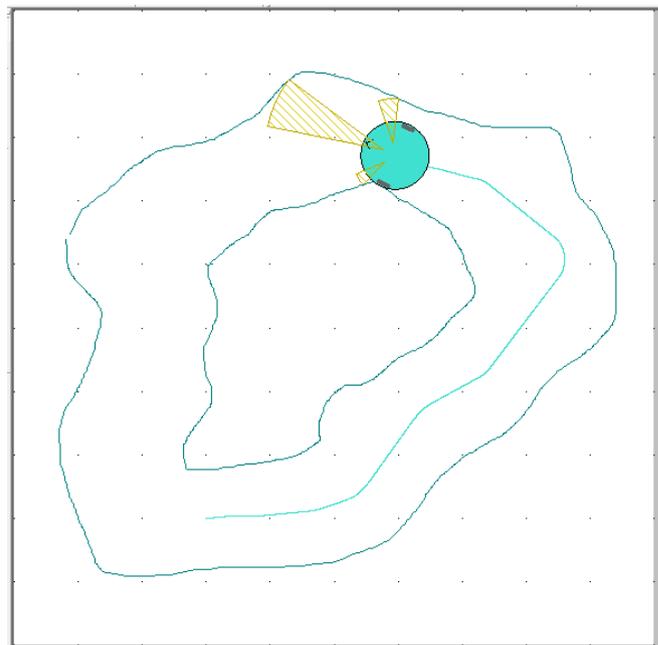
No.	W (cm)	Time (second)	Status	Width Ratio
1	50	23'3.5	Ok	0.50
2	55	23'4.5	Ok	0.55
3	60	23'2.8	Ok	0.60
4	65	23'2.5	Ok	0.65
5	70	23'3.7	Ok	0.70
6	75	23'2.9	Ok	0.75
7	80	23'3.2	Ok	0.80
8	85	23'3.1	Ok	0.85
9	90	23'3.2	Ok	0.90
10	95	23'4.1	Ok	0.95
11	100	12'58,0	Fail	1.00
12	105	12'02.4	Fail	1.05
13	110	13'55.2	Fail	1.10

Based on the data in Table 2, the robot is able to perform wall following behavior properly when the ratio with the narrowest corridor up to 0.95. While the ratio is and above 1.00, the robot fails to perform its task. Generally, the time takes for the robot to complete its function perfectly is 23'3 seconds (Experiment 1-10). However, due to dimensional problems, the robot function cannot be completed the task and stopped at 12'58 seconds (Experiment 11).

Figure 9 shows the robot's movement to complete the wall following behavior task on a corridor. Figure 9 (a) shows the robot being able to complete the task properly. It shows, the robot is able to set itself up to be able to walk 'like' in the middle of the corridor, until it is finish. Moving in the corridor is an emerging behavior when both behavior, left wall following behavior and right wall following behavior, are active. However, in Figure 9 (b), the task does not work properly, and the robot stops in a fairly narrow corridor. This is because the dimension of robot is no longer able to move in accordance with existing environmental conditions.



(a)



(b)

Figure 9. Result of Wall Following Behavior: (a) OK and (b) Fail

V. CONCLUSION

The design of model for mobile robot movement in the form of some mathematical equations based on differential drive has been done. The dimensions of the robot can be optimized according to the robot specified function. The model can be simulated and visualized the trajectory movement. The architecture of robots with behavior based approach has been designed, namely: wall following behavior and obstacle avoiding behavior. Each of these behaviors has been performed. Generally, the robots are able to perform their duties in each work area properly. The optimal dimension of the robot diameter has a ratio of 0.8 compared to the wide of the robot area corridor.

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