March - April 2020
ISSN: 0193-4120 Page No. 8068 - 8076

Wall Following and Motion Control System for Robot Cleaner

Muhammad Ikhsan Sani[1], Simon Siregar[2], Lilik Zahra[3]
[123]Computer Engineering Department, Faculty of Applied Science, Telkom University,Bandung, Indonesia.
[1]m.ikhsan.sani@tass.telkomuniversity.ac.id, [2].simon.siregar@tass.telkomuniversity.ac.id, [3].lilikzahra7@gmail.com.

Article Info
Volume 83
Page Number: 8068 - 8076
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 09 April 2020*

Abstract

The investigation of indoor navigation system presents an intriguing study especially in the field of floor cleaning robot research. However, controlling an indoor robot is still challenged by complexity of the uncertainty and obstacle detection modeling. Various methods with different algorithm are required to determine and control robot position. Wall following algorithm was suggested as an alternative to more complex computation methods i.e. Simultaneous Localization and Mapping (SLAM). This paper proposed an alternative solution for navigating robot by implementing four low-cost ultrasonic sensors as proximity sensor for wall following purpose. The system was used to manage robot movement. Experiments involving wall detection and motion control test demonstrate that the robot can be implemented for domestic purpose.

Keywords; *floor cleaning; robot; navigation; wall detection, proximity, wall following*

I. INTRODUCTION

The investigation of indoor robot presents both an intriguing and challenging fields of research. In the fields of research on the navigation control theories and methods, several works have been carried out. Such research is crucial for domestic robot development i.e. floor cleaning robot. With the consideration of major factors contributing to the heterogeneity of previous findings, a solid architecture or algorithm has not been determined yet.

Various researches about autonomous indoor or domestic robot have been published. Although commercial domestic cleaning robots have been available on the market today, there are still several glitch remained to be investigated, especially on how to detect obstacle inside the room and control the robot movement. The research topics are mainly focused on how to control and navigate properly by installing several type of sensors. The sensors are utilized to monitor the surrounding environment. Various methods such as sensor data fusion, fuzzy logic, artificial neural network and genetic algorithms can be used as navigation system for moving the robot while avoiding obstacle along its path[1][2][3]. Another method for determining robot position is called Simultaneous Localization and Mapping (SLAM)

[4]. In SLAM, robot position is mapped without prior information of previous position[5]. While SLAM is popularly seen as main key component of any truly autonomous robot, this method is considered require complex computation.

Unlike the outdoor robot which can use a GPS for their navigation system, indoor robots have limited options for determining their position. Although navigating without GPS is considered difficult, an autonomous robot can utilized a method of obstacle detection or wall following to navigate itself inside the closed room. The robot is move along it path

while maintaining a close proximity to the wall [6]. An algorithm, using computer-based stereoscopic vision, wireless network, 2D sensor and human-

Published by: The Mattingley Publishing Co., Inc.

machine interaction are typically used for cleaning robot [7][8][9].

Another important factor for wall following navigation system is sensor selection. Sensor quality will influence the outcome[10]. Several wall following robot are equipped with laser scanner, sonar, or even IR sensor [10][11]. Ultrasonic sensor is one of highly popular spatial sensor for autonomous robots. Points of interest of ultrasonic sensor are generally lies on the cheapest price and their compatibility for detecting any object surface. Their low resolution can be increased by using several sensor on different fixed position or placed on rotating platform [12][13][14][15]. Ultrasonic sensor typically used as an obstacle avoidance robotic vehicle using ultrasonic sensors for its movement [16]. The sensor also served as distance measurement apparatus for determining safe limit between robot and object [17]. Previous research presented that ultrasonic sensor also can be used as relative positioning sensor for multi robot localization [18].

In this paper, research was conducted using RONER (Robot Cleaner), a prototype floor cleaning robot that developed by Embedded and Network System (ENS) research group from Telkom University. This paper proposes a low cost solution for controlling RONER by navigation. This work aims to develop wall following system using ultrasonic sensor that can be used on indoor. The rest of this paper is organized as follows. Section II describes a proposed solution. Meanwhile, result and discussion are presented in section III. Finally, section IV shows the concluding remarks.

II. PROPOSED SOLUTION

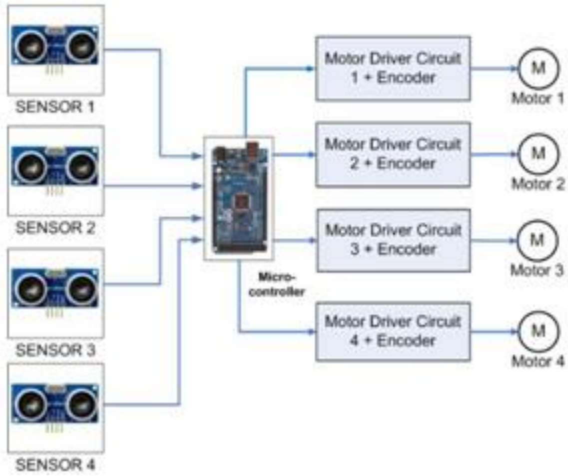


Fig. 1 Ronersystem block diagram.

The system is divided into two parts. They are wall following using ultrasonic sensors and motion control. The system's hardware block diagram is shown in Fig. 1. Four ultrasonic sensor are used as wall following sensor. Signals from sensors are then processed by microcontroller. Meanwhile, four DC motor are utilized as robot actuators.

A. Wall Following using Ultrasonic Sensor

Ultrasonic sensors are placed on four sides of the robot to facilitate wall detection scheme. This sensor can measure distances between 3 cm to 300 cm. The output of this sensor is a pulse which represents distance between sensor and the object. The pulse width varies from 115 µs to 18.5 ms. The sensor used 40 kHz signal generator, an ultrasonic speaker as transmitter and an ultrasonic microphone as receiver. The transmitter converts the 40 kHz signal into sound while the receiver serves as detector of the sound reflection.

Ultrasonic signal has limited sensing angle capability due to property of sound. The sensor must be configured accordingly. In RONER, the sensors are placed perpendicular each other to form a full scan radius of ultrasonic signal. Therefore, the sensors can develop an omnidirectional sensing capability[15][19]. Fig. 2 shows the sensor placement on RONER.

Published by: The Mattingley Publishing Co., Inc.

TEST Engineering & Management
March - April 2020
ISSN: 0193-4120 Page No. 8068 - 8076

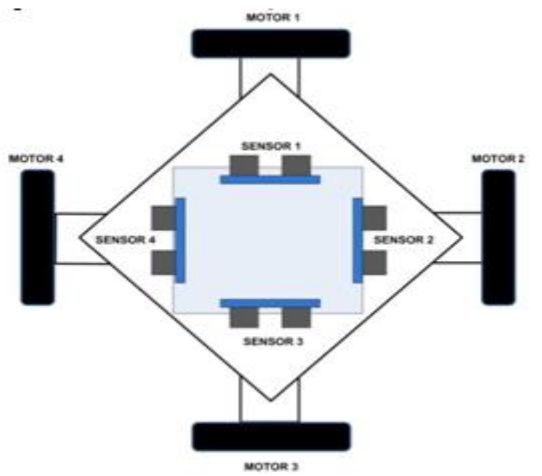


Fig. 2 Proposed ultrasonic sensors placement.

HC-SR04 signal pins can be directly connected to the microcontroller without any additional components. Sensor will only send ultrasonic sound when there are trigger pulses from the microcontroller (pulses are high during 5 μS). Ultrasonic sound with a frequency of 40 KHz will be emitted during 200 μS. This sound will propagate in the air at a speed of 344.424 m/s (or 1cm every 29,034 μS), hit the object and then bounce back to receiver. While waiting for reflections, sensor will generate a pulse. Therefore, the pulse width can represent the distance between sensor and object. Ultrasonic sensors can cover 2 cm to 400 cm distance range. The specifications of this sensor can be seen in TABLE I.

Table I. Ultrasonic Sensor Specification.

Working Voltage	5 V (DC)
Working Current	15 mA
Working Frequency	40 Hz
Max. Range	4 m
Min. Range	2 cm
Measuring Angle	15 degree
Trigger Input Signal	10 μS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion

B. Motion Control

To provide a proper motion control, specific DC motors and omniwheels are needed. Four DC motor is used as a robot's prime mover. 10 inch diameter omniwheels also installed with the motors. For this paper, KR13128 DC motor is chosen. With 258 rpm speed and 13 Kg.cm torque, this type of motor is sufficient actuator for the robot. KR13128 DC motor's specification is presented in TABLE II.

Table II. KR13128 DC Motor Specification.

No.	Motor Parameters	Values
1.	Working Voltages	12 Volt DC (for motor) 5 volt DC (for back encoder)
	Gear Type	Planetary Gear (2 stages/ 2 level planetary gear set)
2.	Gear Ratio	1/24 (Efficiency in full load 72%)
3.	Rated Speed	258rpm
4.	Rated Torque	1.3 Nm (13 Kg.cm)

Data from this table can be used to formulate a system's optimal movement. Fig. 3 shows how all motors and wheels are installed on robot's frame.

Fig. 3.DC motor installed on RONER.

Motion control algorithm is adopted to control motor and help navigation process. This configuration allows all wheels to rotate together to

Published by: The Mattingley Publishing Co., Inc.

move in a certain direction. By combining the motion of each wheel, robots can move freely avoiding any obstacles. The motion control flowchart is shown in Fig. 4.

The process begins with sensor and motor initialization. Default move of RONER is moving forward until it detected the wall or obstacle. Distance between sensor and wall can be configured manually for input set point. Set point will determine how close robot to wall. Each sensor's data are read and processed by microcontroller to compare the current distance value. If the value less than set point, the robot will be shifted to the corresponding position. The default movement of the robot is moving forward. If sensor 1 and sensor 4 value's less than or equal to distance set point, the robot will be shifted to the right. This also applies to condition when sensor 3 and sensor 4 value's less than or equal to distance set point. The robot will be shifted to right when sensor 1 and 2 value's less than or equal to distance set point.

The flowchart further presented an algorithm to handle RONER movement. It was designed through considering the trade-off between sensor low accuracy and wall detecting capability. A duty cycle controller is divided into nine level from 10 to 100%. Each duty cycle is corresponded with PWM signal that sent to motor driver.

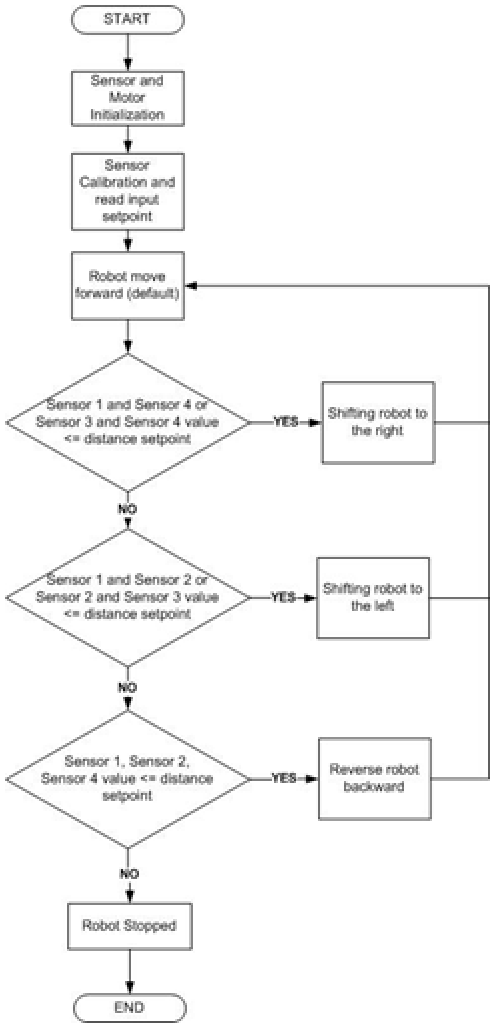


Fig. 4. RONER motion control flowchart

The robot position in the room will be adjusted relative to the position of the previous point. The illustration of the RONER position is shown in TABLE III. This table shows six different motion schemes can be performed. The RONER movement is described as follows.

a. Forward movement is performed when motor 2 and motor 4 rotate clockwise and counter clockwise respectively.

b. Reverse movement is performed when motor 2 and motor 4 rotate counter clockwise and clockwise respectively.

c. Shift left movement is performed when motor 1 and motor 3 rotate clockwise and counter clockwise respectively.

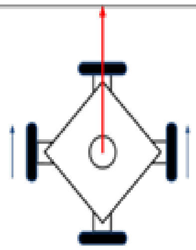
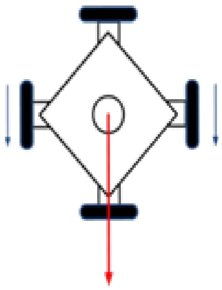
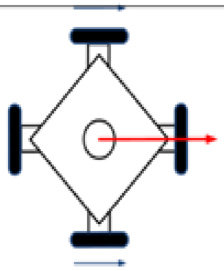
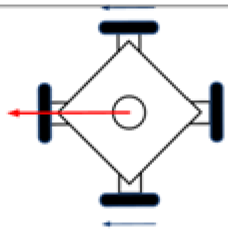
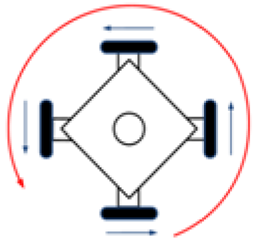
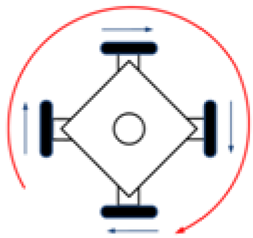
Published by: The Mattingley Publishing Co., Inc.

d. Shift right movement is performed when motor 1 and motor 3 rotate counter clockwise and clockwise respectively.

e. Clockwise rotation movement is performed when all motor are rotated counter clockwise.

f. Counter clockwise movement is performed when all motor are rotated clockwise.

Table III. RonerMotion Scheme.

III. RESULTS AND DISCUSSION

A. Wall Detection Experiment Results

This experiment is conducted for verifying theperformance of ultrasonic sensor. Robot is placed near the wall and the sensor value output is observed. The robot is tested in ten points along the wall (Fig. 6). The test is performed to evaluate sensor accuracy while maintaining close proximity to the wall. Meanwhile, a campus hallway (Fig. 5) is used as a testing area. This hallway provides a challenging task for the robot since the distance between robot and wall is not constant. While the hallway wide is about 2 meter, the doors and building concrete column are expected to provide various sensor measurement result.

Published by: The Mattingley Publishing Co., Inc.

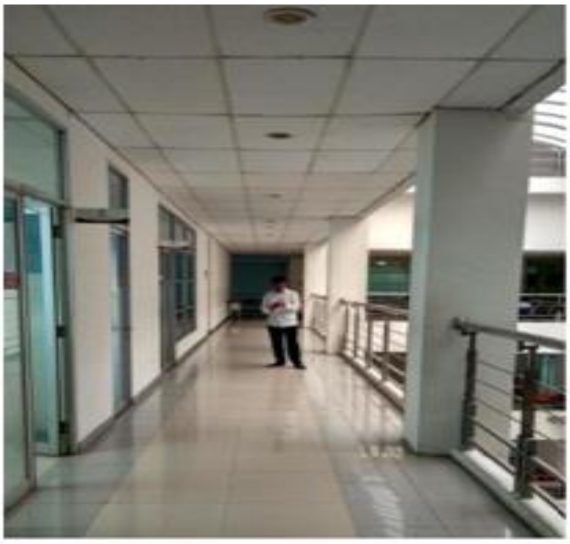


Fig. 5. Campus hallway as a robot's testing area.

The test result is shown in TABLE IV. The result shows relative linear association of actual distance with sensor value. First column of the table conveys sensor 1 distance measurement data from ten points along hallway. The average measured distance value is 38.928 cm. While the real distance value between robot and wall is 40 cm, the average distance error is 1.072 cm. Another result from the observation was that sensor 2, 3 and 4 measurement data has provided slightly better accuracy than other sensors with error margin 0.074, 0.01, and 0.302 respectively.

Table IV. Ultrasonicsensor test.

Point numbers	Sensor 1 Measured Distance (cm)	Sensor 2 Measured Distance (cm)	Sensor 3 Measured Distance (cm)	Sensor 4 Measured Distance (cm)
1.	38.45	40.02	59.99	48.50
2.	38.88	40.10	59.99	49.78
3.	41.53	40.12	59.99	49.32
4.	39.41	40.12	59.99	48.93
5.	38.56	40.12	59.99	50.07
6.	38.88	40.12	59.99	49.69
7.	39.30	40.02	59.99	50.13
8.	38.13	40.12	59.99	50.17
9.	38.03	40.00	59.99	50.17
10.	38.11	40.00	59.99	50.22
AVG	**38.928**	**40.074**	**59.99**	**49.698**
Actual Distance Value (cm)	**40**	**40**	**60**	**50**
Distance error (cm)	**1.072**	**0.074**	**0.01**	**0.302**

The experiment results indicate that sensor is successfully used for wall detecting and distance measurement. Not only the sensor is detecting wall, but also doors and concrete column (Fig. 6). This data provide strong initial evidence. The variations of sensor value against actual distance but within a tolerable condition. Aside from margin of error, this series of sensor's data are useful for robot motion control.

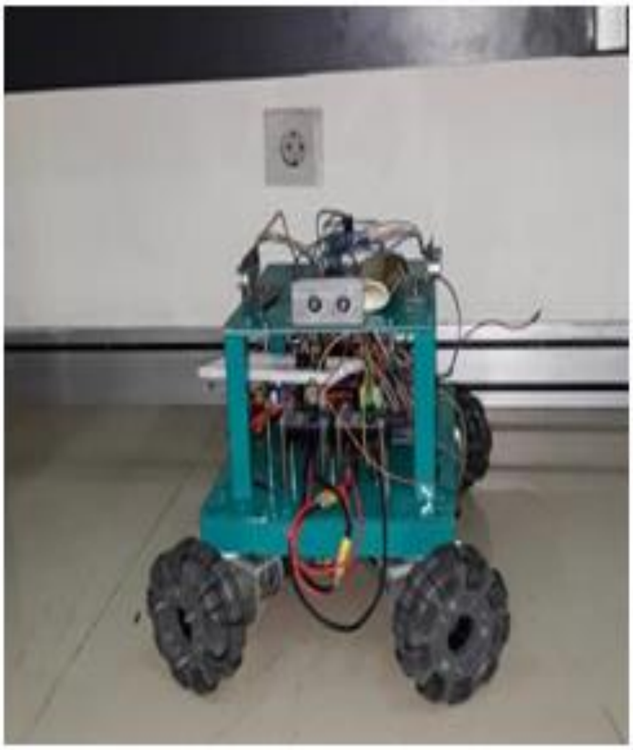


Fig. 6.Wall following sensor experiment.

B. Motion Control Experiment Results

The experiment is started with maximum duty cycle scenario (100%). PWM data on Arduino is set on 255 values. The voltage value at 100% duty cycle is measured at 12 volt. The duty cycle is then lowered incrementally. It should be noted that at 50% duty cycle, the motor is can't move the robot. Hence, the results for duty cycle percentage below 50% . TABLE V presents the results of effect on motor PWM value/duty cycle to each motor. These results suggest the effect of duty cycle variation on motor rotation/output. The system demonstrates optimal results between 60-100% duty cycle.

March - April 2020
ISSN: 0193-4120 Page No. 8068 - 8076

Table V. Motor PWM Test.

Duty Cycle (%)	PWM values	Voltage (V)
10	26	6
20	51	7
30	77	8
40	102	8
50	128	9
60	153	10
70	179	10
80	204	11
100	255	12

RONER wall following scenario is shown in Fig. 7. Robot is placed on the corner of the 2 x 2 meter room. Then, robot is activated. Robot will detect the surrounding wall and move accordingly. The wall following experiment results are shown on TABLE VI. This results indicate that the controller can detect obstacle and activate motor to corresponding movement.

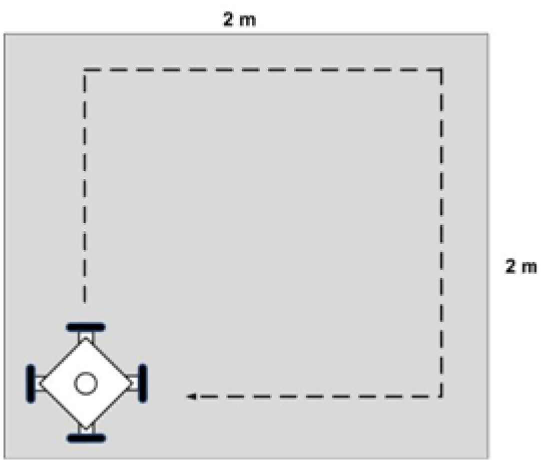


Fig. 7.RONER wall following scenario.

Meanwhile, to evaluate the whole system functionality, robot is placed inside the room and then activated. All sensors will scan the surrounding to determine next movement. TABLE VI described the result of integration between wall following and motion control algorithm. The seven different motion scheme tests have been conducted : forward, reverse, shift left, shift right and rotate 360o. Our findings are in general consistent with the initial design and theory. The result supports the hypothesis that ultrasonic sensor placement did give the different effect on wall detection system.

Compared to previous research, the system performance test provides an assessment whether the system can beimplemented on small room for household application. It also enables us to estimate with sufficient precision the effect of different obstacle to the robot's wall detection system. This finding is thus an important contribution for development of low-cost autonomous robot especially home cleaning robot. Nevertheless, this robot has certain limitations. A major concern in wall following robot using ultrasonic sensor is the problem of reliability on the occupied room application. Robot can be mistaken detecting human as wall or obstacle and the system can be confused. A further interesting issue worth exploring is implementing another more accurate sensor using sensor fusion algorithm.

Table VI. Integrationbetweenwall following and motion control experiment.

S1	S2	S3	S4	M1	M2	M3	M4	Results
D	-	-	D	C	-	CCW	-	Shift Right
D	-	-	-	C	-	CCW	-	Shift Right
-	-	D	D	-	C	-	CCW	Forward
D	D	-	-	-	CCW	-	C	Reverse
-	D	D	-	CCW	-	C	-	Shift Left
-	-	D	-	C	-	CCW	-	Shift Left
-	-	-	-	CCW	CCW	CCW	CCW	Rotate 360°

S1-S4 : Sensor 1 - 4
M1-M4 : Motor 1-4
D : Wall Detected
C : Clockwise
CCW : Counter Clockwise

IV. CONCLUSION

The paper presented here shows several points: combination between a low-cost ultrasonic sensor and motion control algorithm can be an alternative solution for robot's indoor navigation system.

Published by: The Mattingley Publishing Co., Inc.

March - April 2020
ISSN: 0193-4120 Page No. 8068 - 8076

Experimental results indicate that the system is effective for detecting wall in small room. in controlling the depth of the robot with negligible steady state error. The motion control system implementation on motor driver is able to manage activate motor from 50 - 100% duty cycle PWM level. This research could be expanded to include several more accurate navigation and proximity sensor i.e. Inertial Measurement Unit (IMU), LIDAR and camera for detecting object. The important point to note here is that sensor fusion method will increase effectiveness of navigation system on autonomous mobile robot [20].

V. ACKNOWLEDGMENT

This research was supported by PenelitianDasardanTerapan (PDT) PPM Telkom University. This research was a collaboration between Embedded and Network System Research Laboratory and Robotic SAS Research Laboratory, Faculty of Applied Science, Telkom University.

REFERENCES

[1] M. Almasri, K. Elleithy, and A. Alajlan, “Sensor fusion based model for collision free mobile robot navigation,” Sensors (Switzerland), vol. 16, no. 1, 2015.

[2] X. Li and D. Wang, “Behavior-based mamdani fuzzy controller for mobile robot wall-following,” Proc. - 2015 Int. Conf. Control. Autom. Robot. ICCAR 2015, pp. 78–81, 2015.

[3] C. Chen, H. Du, and S. Lin, “Mobile robot wall-following control by improved artificial bee colony algorithm to design a compensatory fuzzy logic controller,” in ECTI-CON 2017 – 201714th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2017, pp. 856–859.

[4] T. J. Chong, X. J. Tang, C. H. Leng, M. Yogeswaran, O. E. Ng, and Y. Z. Chong, “Sensor Technologies and Simultaneous Localization and Mapping (SLAM),” ProcediaComput. Sci., vol. 76, pp. 174–179, 2015.

[5] S. Jose and A. Antony, “Mobile robot remote path planning and motion control in a maze environment,” in Proceedings of 2nd IEEE International Conference on Engineering and Technology, ICETECH 2016, 2016, no. March, pp. 207–209.

[6] G. Nugraha, R. A. Haris, A. W. Multazam, K. Mutijarsa, and W.Adiprawita, “Design and implementation of Active Object Computing Model for a wall following mobile robot,” in 2014 IEEE International Symposium on Robotics and Manufacturing Automation, IEEE-ROMA2014, 2015, pp. 258–262.

[7] Zhao, W. Chen, C. C. Y. Peter, and X. Wu, “A novel navigation system for indoor cleaning robot,” 2016 IEEE Int. Conf. Robot. Biomimetics, ROBIO 2016, pp. 2159–2164, 2016.

[8] G. A. Mutiara and G. I. Hapsari, “Design Prototype of Robot Explorer Terrain,” J. Theor. Appl. Inf. Technol., vol. 79, no. 3, pp. 493–498, 2015.

[9] J. Park, S. Lee, and J. Park, “Reliable wall estimation method with RGB-D camera for wall following,” in 2014 11th International Conference on Ubiquitous Robots and Ambient Intelligence, URAI 2014, 2014, pp. 616–618.

[10] L. H. Prayudhi, A. Widyotriatmo, and K. S. Hong, “Wall following control algorithm for a car-like wheeled-mobile robot with differential-wheels drive,” in ICCAS 2015 - 2015 15th International Conference on Control, Automation and Systems, Proceedings, 2015, pp. 779–783.

[11] C. W. Lo, K. L. Wu, and J. S. Liu, “Wall following and humandetection for mobile robot surveillance in indoor environment,” 2014 IEEE Int. Conf. Mechatronics Autom. IEEE ICMA 2014, vol. 1, pp. 1696–1702, 2014.

March - April 2020
ISSN: 0193-4120 Page No. 8068 - 8076

[12] C.-C. Hsu, C.-Y. Lai, C. Kanamori, H. Aoyama, and C.-C.Wong, “Localization of mobile robots based on omni-directional ultrasonic sensing,” SICE Annu. Conf. 2011, pp. 1972–1975, 2011.

[13] G. Wu, “Sparse-Sensing-Based Wall-Following Control Design for a Mobile-Robot,” 2016.

[14] U. Yayan, H. Yucel, and A. Yazıcı, “A Low Cost UltrasonicBased Positioning System for the Indoor Navigation of MobileRobots,” J. Intell. Robot. Syst. Theory Appl., vol. 78, no. 3–4, pp. 541–552, 2015.

[15] J. Lim, S. Lee, G. Tewolde, and J. Kwon, “Indoor localization and navigation for a mobile robot equipped with rotating ultrasonic sensors using a smartphone as the robot’s brain,” inIEEE International Conference on Electro Information Technology, 2015, pp. 621–625.

[16] K. Bhagat, S. Deshmukh, S. Dhonde, S. Ghag, and V.Waghmare, “Obstacle Avoidance Robot,” Int. J. Sci. Eng. Technol. Res., vol. 5, no. 2, pp. 439–442, 2016.

[17] M. Kelemen et al., “Distance Measurement via Using of Ultrasonic Sensor,” J. Autom. Control, vol. 3, no. 3, pp. 71–74, 2015.

[18] O. De Silva, G. K. I. Mann, and R. G. Gosine, “An ultrasonic and vision-based relative positioning sensor for multirobot localization,” IEEE Sens. J., vol. 15, no. 3, pp. 1716–1726, 2015.

[19] W. Y. Mu, G. P. Zhang, Y. M. Huang, X. G. Yang, H. Y. Liu, and W. Yan, “Omni-directional scanning localization method of a mobile robot based on ultrasonic sensors,” Sensors (Switzerland), vol. 16, no. 12, pp. 1–14, 2016.

[20] S. E. Li et al., “Kalman filter-based tracking of moving objects using linear ultrasonic sensor array for road vehicles,” Mech. Syst. Signal Process., vol. 98, no. January, pp. 173–189, 2018