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Research Article

Fuzzy Logic of Sugeno Method for Controlling Line Follower Mobile Robot

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Abstract

The industrial world has been increasingly using robots for production purposes. One type of robot used is a line follower robot for the purposes of transportation of production materials. Various research and competitions of line follower robots were held to improve its performance. This study proposed a fuzzy logic algorithm using Sugeno method for a line follower mobile robot. This algorithm received input from the readings of 8 sensors mounted on the bottom of the robot and generated the speed of each left and right motor. This speed was used to keep the robot on track. The performance of this algorithm was compared with the fuzzy logic algorithm of the Mamdani method. The proposed fuzzy logic algorithm was superior in terms of speed. The results of this study can be used as material to study the application of fuzzy logic algorithm in real time.

Keywords: Fuzzy Logic Control; Line Follower; Mobile Robot; Sugeno Method.

Introduction

Nowadays, robots have an important role in various fields. In the industrial sector, robots can increase production efficiency, for examples, robots in goods production, component of transportation systems, and warehouse management robots. Robots also have a role in the field of security, for example a bomb squad robot. In addition to these two fields, in the education sector they are starting to use robots for learning, especially learning about programming [1].

In general, robots are divided into 2 types, autonomous robots and human controlled robots. In an automated robot, control is carried out by a controller. One example of an autonomous robot is a line-follower robot. Many studies related to line follower robots have been carried out. Controling the robot can be done in various ways, including the on-off method [2][3][4][5][6], Proportional Integral Derivative (PID) [7][8], and intelligent systems. The on-off method tends to be fast but the robot's movement is intermittent. PID control produces movements that tend to be smoother than on-off control. Meanwhile, control with an intelligent system produces better performance, for example, backpropagation and fuzzy logic [9][10]. The backpropagation method produces smoother movements but requires a long processing time, while the fuzzy logic method is faster than the backpropagation method and produces smooth movements [9].

Sugeno fuzzy logic has been widely used in various fields with quite good performance, including for determining the optimal path [11], determining rewards in educational games [12], predicting the selling price of used motorcycles [13][14], predicting the value of tuna exports [15], predicting of bread sales [16], determining the amount of bread production [17], and predicting nutritional status of body mass index [18]. Fuzzy logic with the Mamdani method has been used in line follower robots with quite good performance [10], but failures still occured at certain speeds. On the other hand, the Sugeno fuzzy logic method has better performance, efficiency and resource requirements than Mamdani. For this reason, this study proposed the Sugeno fuzzy logic method for controlling line follower robots.

Method

The research was divided into 2 parts, namely hardware development that is line follower robots and development of fuzzy logic controllers using the Sugeno method.

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A. Hardware of Line Follower Robot

The design of the line follower robot hardware used in this study is as shown in **Figure 1**. This hardware consists of receptors, actuators, and control units.

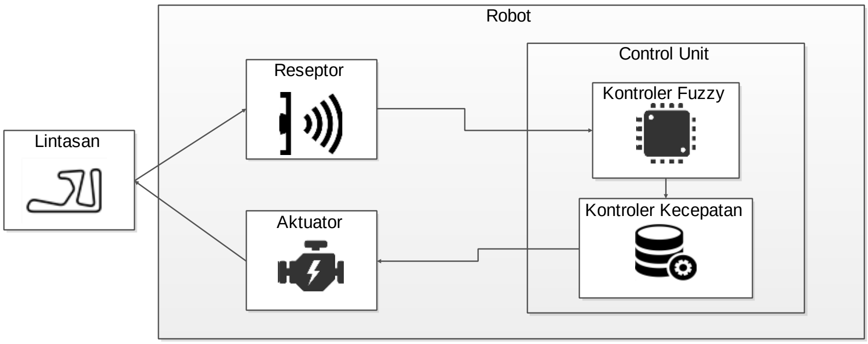

Figure 1. Design of line follower mobile robot

- Receptors consisted of 8 sensor circuits which were divided into 2 groups, namely the left sensor group and the right sensor group, each consisting of 4 sensors. The sensor circuit used a TCRT5000 line sensor, 470 Ω resistor, 10K Ω resistor, and 1µ F capacitor. Resistors were used to adjust the current strength to match and not damage the components, while the capacitor would continue the current if it was fully charged. The charging duration of the capacitor towards the threshold value depending on the resistance level of the TCRT5000 line sensor. If the sensor detected black then the resistance would be low and the duration of charging the threshold value would be fulfilled so that the value was read as 1. Vice versa if the sensor detected white, the sensor reading value was then processed based on the sensor group by multiplying the value with the sensor value. The circuit diagram of this receptor is as shown in **Figure 2**.

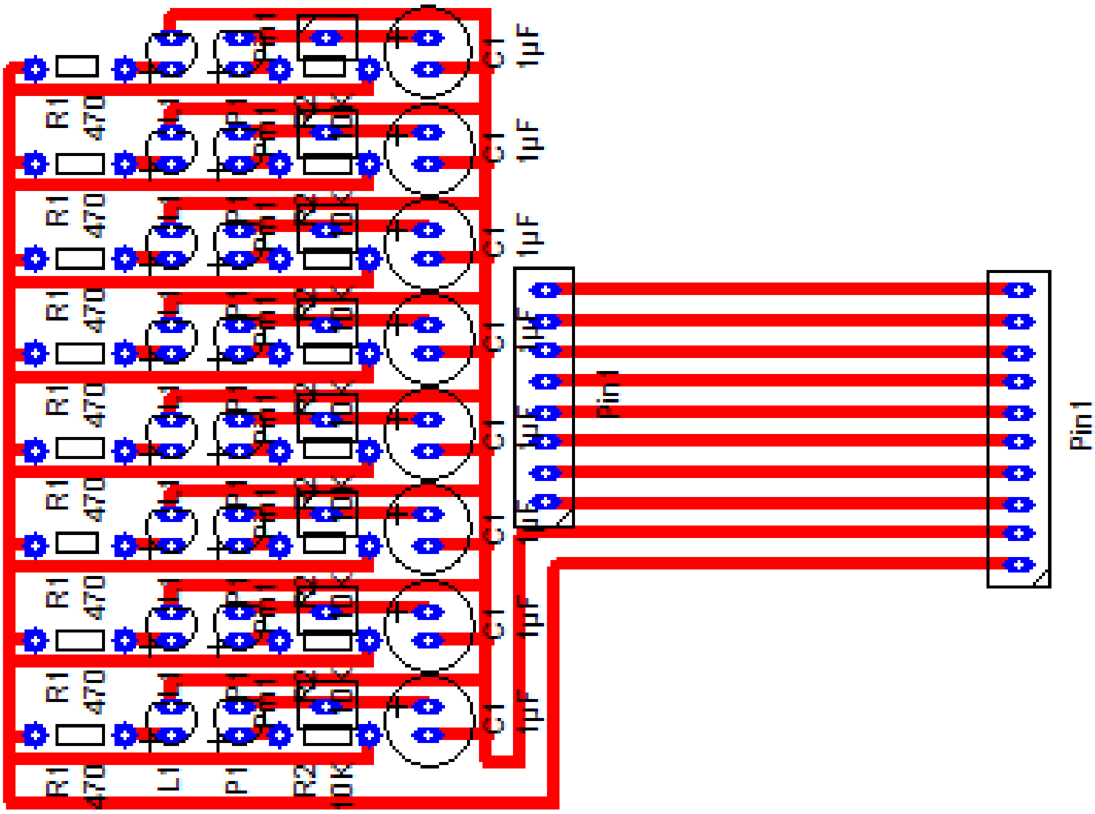

Figure 2. Reseptor of circuit diagram

- Control Units consisted of a Raspberry pi 2 Mini PC model B, as shown in **Figure 3**. This section was connected via the GPIO pin with the receptor section to receive sensor input then executed calculations with the fuzzy logic controller and the results were forwarded to the PWM control to send electrical waves to the actuator used to drive the motor according to the speed value generated by the fuzzy controller.

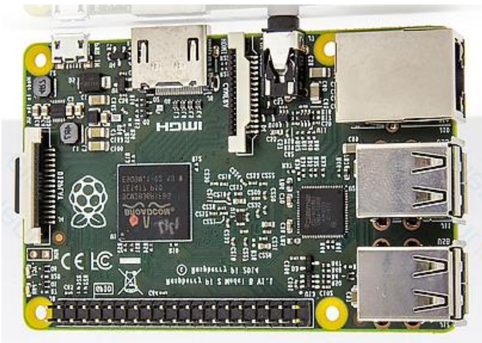

Figure 3. Mini PC Raspberry Pi

- Actuators on the robot consist of an L293D driver, a 12V battery, 2 12V DC motors. This actuator receives an electric wave according to the speed value resulting from fuzzy logic calculations. The design of the actuator circuit to the control unit was as shown in **Figure 4**.

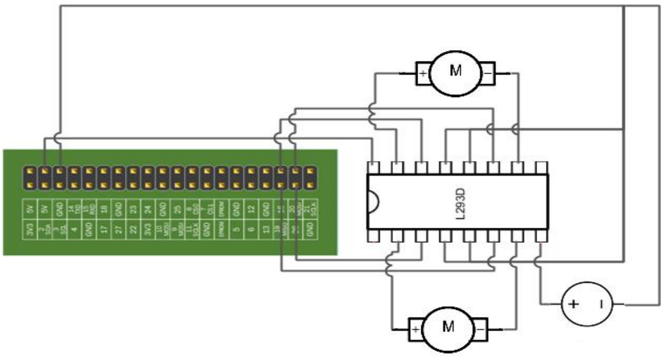

Figure 4. Circuit diagram of actuator

B. Fuzzy logic controller of Sugeno method

The control of the fuzzy logic robot used in this study was the Sugeno method. The process flow for applying this method to robots is as shown in **Figure 5**.

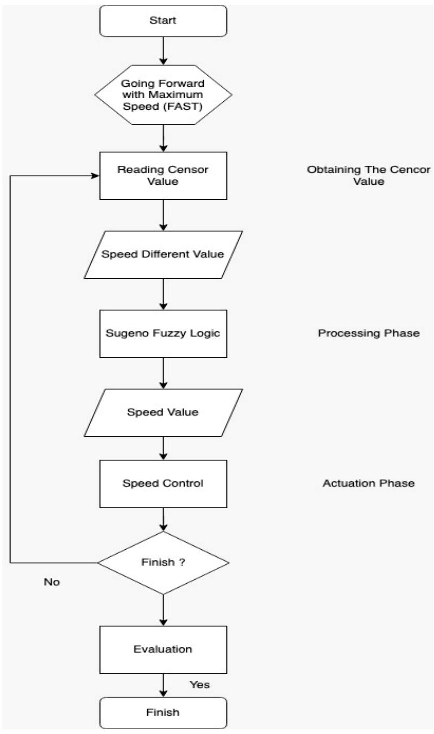

Figure 5. The process flow of the Fuzzy logic algorithm implementation of the Sugeno method on the line follower mobile robot

The input variable of this system was the speed_difference variable between the right and left sensors and had a domain of -50 to 50. The velocity_difference variable was divided into 4 fuzzy sets, namely LARGENEGATIVE, SMALLNEGATIVE, LARGEPOSITIVE, and SMALLPOSITIVE, a description of each input fuzzy set can be seen in **Table 1**.

Table 1. Description of the input variable fuzzy set

No	Fuzzy Set	Description
1.	LARGENEGATIVE	The difference between the left and right sensors has a large negative value
2.	SMALLNEGATIVE	The difference between the left and right sensors has a small negative value
3.	LARGEPOSITIVE	The difference between the left and right sensors has a large positive value
4.	SMALLPOSITIVE	The difference between the left and right sensors has a small positive value

The speed difference variable is represented as shown in **Figure 6**, while the membership function uses Equation 1, 2, 3, and 4 respectively.

$$\mu_{LARGENEGATIVE}(x) = \begin{cases} \frac{0-x}{50}; & -50 \le x \le 0 \\ 0; & 0 \le x \le 50 \end{cases} \quad (1)$$

$$\mu_{SMALLNEGATIVE}(x) = \begin{cases} \frac{x+50}{55}; & -50 \le x \le 5 \\ 1\ ; & 5 \le x \le 50 \end{cases} \quad (2)$$

$$\mu_{LARGEPOSITIVE}(x) = \begin{cases} 0; & -50 \le x \le 0 \\ \frac{x}{50}; & 0 \le x \le 50 \end{cases} \quad (3)$$

$$\mu_{SMALLPOSITIVE}(x) = \begin{cases} 1\ ; & -50 \le x \le -5 \\ \frac{50-x}{55}; & -5 \le x \le 50 \end{cases} \quad (4)$$

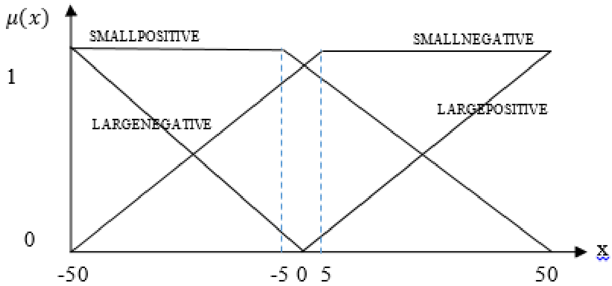

Figure 6. Membership function of the speed difference input variable

The output of this fuzzy controller was the speed variable for the right motor and left motor. Speed variables for the Mamdani and Sugeno methods used the same set, namely SLOW and FAST with descriptions as in **Table 2**. Mamdani fuzzy logic used the fuzzy set speed variables represented in **Figure 7** with membership functions in Equation 5 and 6, while Sugeno's fuzzy logic used a fuzzy set velocity variable represented as a singleton as shown in **Figure 8**. The fuzzy rules used can be seen in **Table 3**. Mamdani's defuzzification process used the centroid method with a discrete approach while for sugeno it used a weighted average method.

Table 2. Speed variables classification

No	Fuzzy Set	Description
1.	FAST	Fast motor speed
2.	SLOW	Slow motor speed

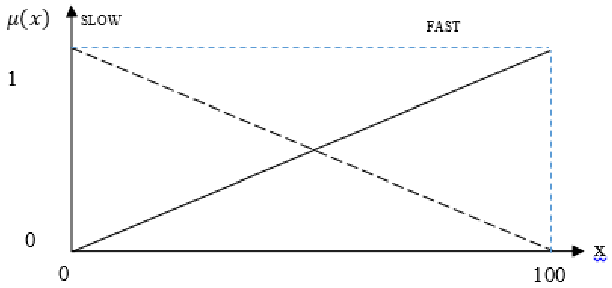

Figure 7. Output of fuzzy Mamdani speed and variables

$$\mu_{SLOW}(x) = \begin{cases} \frac{100 - x}{100}; & 0 \leq x \leq 100 \\ 0; & \end{cases} \quad (5)$$

$$\mu_{FAST}(x) = \begin{cases} \frac{x}{100}; & 0 \leq x \leq 100 \\ 0; & \end{cases} \quad (6)$$

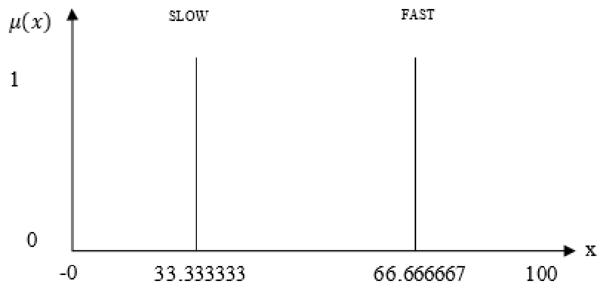

Figure 8. Variable fuction output of Sugeno's fuzzy speed

Tabel 3. Fuzzy Rules

Rules	Description
1	IF different_speed is SMALLPOSITIVE THEN right_motor IS FAST
2	IF different_speed is LARGEPOSITIVE THEN right_motor IS SLOW
3	IF different_speed is SMALLNEGATIVE THEN left_motor IS FAST
4	IF different_speed is LARGENEGATIVE THEN left_motor IS SLOW

Results and Discussion

Tests in this study were conducted to determine the performance of Sugeno's fuzzy logic in tracking black and white lines. The proposed fuzzy logic method was then to compare with Mamdani's fuzzy logic [9]. The test was carried out by running the robot on a track with a length of 100 cm and the shape of the track as shown in **Figure 9**.

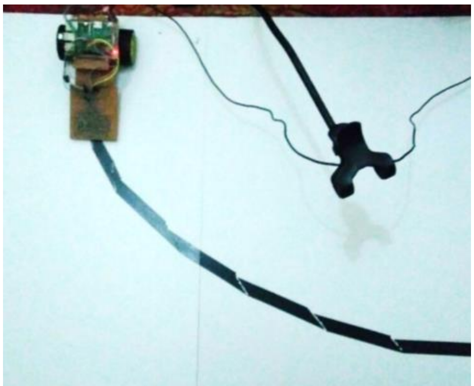

Figure 9. Line Follower Track

The test was carried out 15 times and the average travel time was taken. In addition, the number of failures in tracking the line was calculated. The test variables used were the maximum speed of the robot 15 cm/s, the minimum speed of the robot 0 cm/s, and the sensor reading time of 0.09 seconds.

The results of this test are as shown in **Table 4**. The table shows that Sugeno's fuzzy logic has a higher success rate and a faster average travel time than Mamdani's fuzzy logic. From 15 times of testing, Sugeno's fuzzy logic method was able to run successfully 13 times or 87%, while the Mamdani method ran successfully 12 times or 80%. The average time to pass using Sugeno method was 6.88 seconds and the Mamdani method was 7.22.

Failure occurred in both Sugeno's and Mamdani's fuzzy logic in tracking the track line caused by the inconsistent initial push of the robot's motor and inconsistent sensor readings, so the robot immediately walked off the track. It can be concluded that Sugeno's fuzzy logic has better performance.

Table 4. Testing result of Line Tracking

No	Sugeno (second)	Mamdani (second)
1	5,79294800758	fail
2	fail	5,67535805702
3	6,53157687187	6,69035291672
4	9,74394893646	6,75756311417
5	6,95014500618	8,40565800670
6	7,57528090477	fail
7	fail	fail
8	7,77228403091	7,92545986176
9	5,48949193954	9,19890904427
10	6,41903495789	6,44360685349
11	6,58121490479	7,55209708214
12	6,77628183365	6,53507781029
13	6,51199579239	6,53962612152
14	5,64343905449	9,30467295647
15	7,69357204437	5,64160799980
$\bar{x}$	6,88317033	7,222499152

Conclusion

Based on the results of research on controlling the Sugeno method's fuzzy logic algorithm on line follower mobile robots, it can be concluded that Sugeno's fuzzy logic had a higher success rate and faster average travel time than Mamdani's fuzzy logic. This was due to the shorter duration of Sugeno's fuzzy logic calculations so that the entire process can take place before the robot leaves the track. However, there were still failures in traversing the track caused by inconsistent initial thrust of the robot's motor and inconsistent sensor readings.

Reference

[1] L. Hacker, "Robotics in Education: ROBOLAB and robotic technology As tools for …," 2003. [Online]. Available: https://sites.bc.edu/devtech/wp-content/uploads/sites/113/2022/02/LauraHackerThesis.pdf.

[2] K. Rishabh, "Design of autonomous line follower robot with obstacle avoidance," *Int. J. Adv. Res. Ideas Innov. Technol.*, vol. 7, no. 3, pp. 715–720, 2021, doi: 10.13140/RG.2.2.11652.86403.

[3] V. Barua *et al.*, "An Ultrasonic Line Follower Robot to Detect Obstacles and Edges for Industrial and Rescue Operations," *Int. J. Comput. Appl.*, vol. 176, no. 31, pp. 31–37, 2020, doi: 10.5120/ijca2020920364.

[4] F. Sanofel, "Perancangan Konfigurasi Sistem Robot Line Follower Pemantau Kondisi Jalan," *Epic J. Electr. Power, Instrum. Control*, vol. 2, no. 2, pp. 1–10, 2019, doi: 10.32493/epic.v2i2.2964.

[5] A. Latif, H. A. Widodo, R. Rahim, and K. Kunal, "Implementation of line follower robot based microcontroller atmega32a," *J. Robot. Control*, vol. 1, no. 2, pp. 70–74, 2020, doi: 10.18196/jrc.1316.

[6] N. Sany, D. Sugiarto, and N. Hikmah, "Prototype Robot Penunjuk Lokasi Bidang Buku Berbasis Line Follower Perpustakaan Tangerang," *Innov. Creat. Inf. Technol.*, vol. 5, no. 1, pp. 50–57, 2019, doi: 10.33050/icit.v5i1.102.

[7] H. Miftahul, F. Firdaus, and D. Derisma, "Pengontrolan Kecepatan Mobile Robot Line Follower Dengan Sistem Kendali PID," *TELKA - Telekomun. Elektron. Komputasi dan Kontrol*, vol. 2, no. 2, pp. 150–159, 2016, doi: 10.15575/telka.v2n2.150-159.

[8] M. Alwan, A. Green, A. Noori, and A. Aldair, "Design and Implementation of Line Follower Arduino Mobile Robot Using Matlab Simulink Toolbox," *Iraqi J. Electr. Electron. Eng.*, vol. 17, no. 2, pp. 11–16, 2021, doi: 10.37917/ijeee.17.2.2.

[9] U. Farooq, M. Amar, M. Usman Asad, G. Abbas, and A. Hanif, "Fuzzy Logic Reasoning System for Line Following Robot," *Int. J. Eng. Technol.*, vol. 6, no. 4, pp. 244–248, 2014, doi: 10.7763/ijet.2014.v6.705.

[10] A. Wajiansyah, S. Supriadi, S. Nur, and A. B. Wicaksono P, "Implementasi Fuzzy Logic Pada Robot Line Follower," *J. Teknol. Inf. dan Ilmu Komput.*, vol. 5, no. 4, pp. 395–402, 2018, doi: 10.25126/jtiik.201854747.

[11] M. Mukaromah, "Penerapan Metode Fuzzy Sugeno Untuk Menentukan Jalur Terbaik Menuju Lokasi Wisata," *J. Mat. Sains, dan Teknol.*, vol. 20, no. 2, pp. 95–101, 2019.

[12] C. A. Oktavia, "Penerapan logika fuzzy sugeno untuk penentuan reward pada game edukasi aku bisa," *JUTI J. Ilm. Teknol. Inf.*, vol. 17, no. 2, pp. 117–124, 2019.

[13] D. P. P. Astuti and Mashuri, "Penerapan Metode Fuzzy Tsukamoto Dan Fuzzy Sugeno Dalam Penentuan Harga Jual Sepeda Motor," *Unnes J. Math.*, vol. 9, no. 2, pp. 74–78, 2020.

[14] A. H. Agustin, G. K. Gandhiadi, and T. B. Oka, "Penerapan Metode Fuzzy Sugeno Untuk Menentukan Harga Jual Sepeda Motor Bekas," *E-Jurnal Mat.*, vol. 5, no. 4, pp. 176–182, 2016.

[15] L. Rohimah, S. Rukiastiandari, and J. Siregar, "Penerapan Logika Fuzzy Metode Sugeno Untuk Optimalisasi Nilai Ekspor Ikan Tuna Hs 160414 Ke Italia," *J. Tek. Komput. AMIK BSI*, vol. 6, no. 1, pp. 31–36, 2020, doi: 10.31294/jtk.v4i2.

[16] S. A. Siallagan and W. Sahara, "Penerapan Fuzzy Sugeno dalam Usaha Roti Ketawa," *Kesatria J. Penerapan Sist. Inf. (Komputer dan Manajemen)*, vol. 1, no. 2, pp. 73–76, 2020.

[17] D. L. Rahakbauw, "Penerapan Logika Fuzzy Metode Sugeno Berdasarkan Data Persediaan Dan Jumlah Permintaan (Studi Kasus : Pabrik Roti Sarinda Ambon)," *J. Ilmu Mat. dan Terap.*, vol. 9, no. 2, pp. 121–134, 2015.

[18] D. Syahputra and Muhathir, "Perhitungan Metode Fuzzy Sugeno Dan Antropometri Dalam Memprediksi Status Gizi Indeks Massa Tubuh," *J. Informatics Telecommun. Eng.*, vol. 2, no. 1, pp. 16–22, 2018.