JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering

Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

Motion Control of 5-Degree of Freedom Humanoid Robot Arm System Using Fuzzy Logic Algorithm

Ike Bayusari[1], Darma Sandi[2], Rahmawati[3], Sri Agustina[4], Suci Dwijayanti[5], Bhakti Yudho Suprapto[6]
[1,2,3,4,5,6] Electrical Engineering, Universitas Sriwijaya, Palembang-Prabumulih street KM. 32, Inderalaya, Ogan Ilir 30662, Indonesia

ARTICLE INFO

Article historys:

Received : 23/12/2023
Revised : 22/01/2024
Accepted : 01/04/2024

Keywords:

Fuzzy Logic; Humanoid Robot; Robotic Arm; Sugeno Method

ABSTRACT

Humanoid robots are the evidence of the rapid advancement of technology in robotics. One of their applications is replacing humans in certain tasks, such as moving goods. For this type of activity, humanoid robots need arms; however, their arm system is not effective enough because of the material used. Thus, this study proposes the use of filament as the material of frames in robot arms. A 5-degree of freedom (DoF) robot arm system was implemented, and the motor worked as the driving force. The movement of this robotic arm was based on proximity and camera sensor readings. Then, the movement control used fuzzy logic with the Sugeno method. During experimental testing, the humanoid robot arm could grip and move objects from one place to another at varying times according to the object type. The length of time obtained depends on the reading of the proximity sensor on the gripper. In another experiment, the humanoid robot arm could shake hands with humans in real time within 36 sec. In conclusion, the results verified the effectiveness of the proposed fuzzy logic controller with the Sugeno method.

Corresponding Author:

Bhakti Yudho Suprapto
Electrical Engineering Universitas Sriwijaya, Palembang-Prabumulih street KM. 32, Inderalaya, Ogan Ilir 30662, Indonesia
Email: bhakti@ft.unsri.ac.id

1. INTRODUCTION

Industrial technology has been rapidly developing; currently, industry 4.0 has automated many systems. Human work has begun to be replaced by machines or robots for various tasks, such as cleaning houses, communicating with humans, walking, and moving and lifting objects from one place to another. For these purposes, artificial intelligence and the Internet of Things (IoT) have been used[1,2]. In addition, robots have been designed to perform physical interactions with humans, such as shaking hands, lifting, moving, and assembling objects. A robot arm system works automatically using control assistance to maintain movement and the process of lifting and placing an object. It can also be combined with sensors and cameras to detect an object and determine its coordinates. The object detection and coordinates are the inputs processed using image processing; the automatic movement of the robot arm is the output [3].

Several studies have been conducted on robot arms, including 5-degree of freedom (DoF) position control for a kinematic controller for handshaking on humanoid robots [4], 2-DoF robotic arms based on the adaptive neuro-fuzzy inference system (ANFIS) [5,6], and the fuzzy logic algorithm for controlling the movement of 4-DoF robotic arms [7, 8]. However, the robot arms in these studies could not automatically shake hands, and the robots moved slower compared with human dynamics [4]; thus, it

Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

took more time to automatically lift and move objects. Moreover, the distance to reach the object was very limited [5]. Additionally, using a manual system requires a lot of time and energy; hence, such robot arms are inefficient and ineffective [9]. Therefore, in this study, we designed the robot arm with 5 DoF to extend the robotic arm range. The proposed robot arm could lift and move objects, and shake hands. The input used in this study was based on camera and proximity sensor readings. The fuzzy logic algorithm was utilized as a controller due to its simplicity, ease of understanding, flexibility, and tolerance for inaccurate data, making it suitable for moving humanoid robotic arms. This fuzzy logic algorithm has been widely used in various fields such as economics [10], manufacturing industry [11,12], transportation [13, 14], environmental and social sciences, businesses [15], and pico hydro systems [16] because of these advantages. The difference in this research compared to previous studies lies in the utilization of a 5-degree-of-freedom (5 DOF) robotic arm, which facilitates both movement and reach. Additionally, it incorporates a handshake capability based on a Fuzzy Logic controller employing several membership functions.

2. RESEARCH METHOD

The process of lifting and moving items by a humanoid robot arm was carried out in several stages, as shown in Fig. 1. The humanoid robot arm was designed to make it easier to place the servomotor and components, as shown in Fig. 2. The humanoid arm was made of filament and printed using a 3D printer.

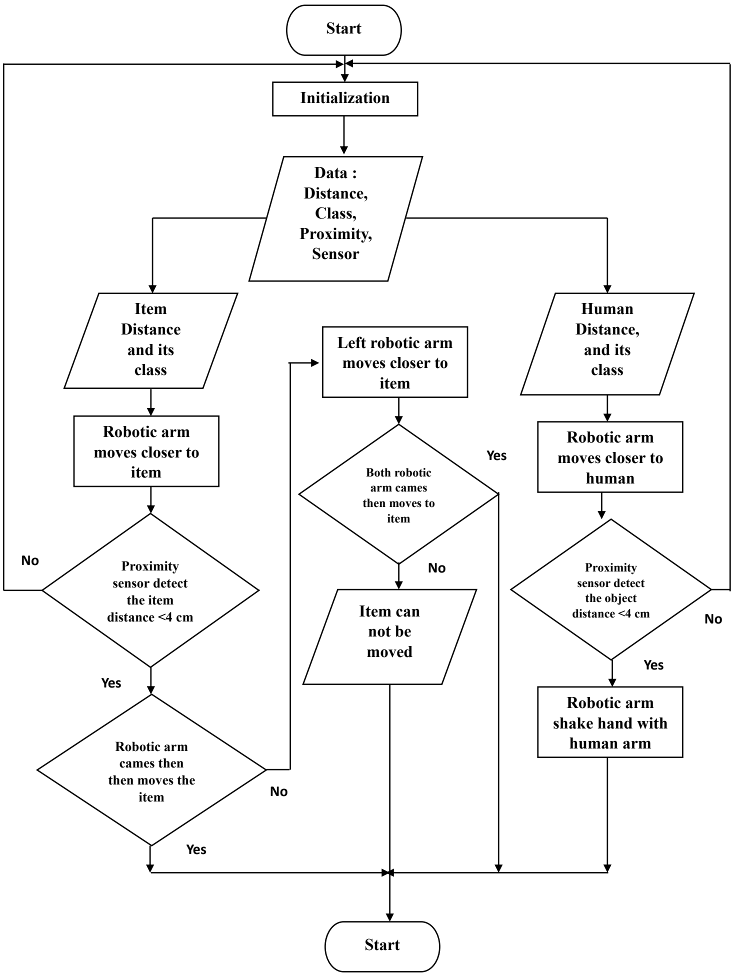


Figure 1. System flowchart

JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

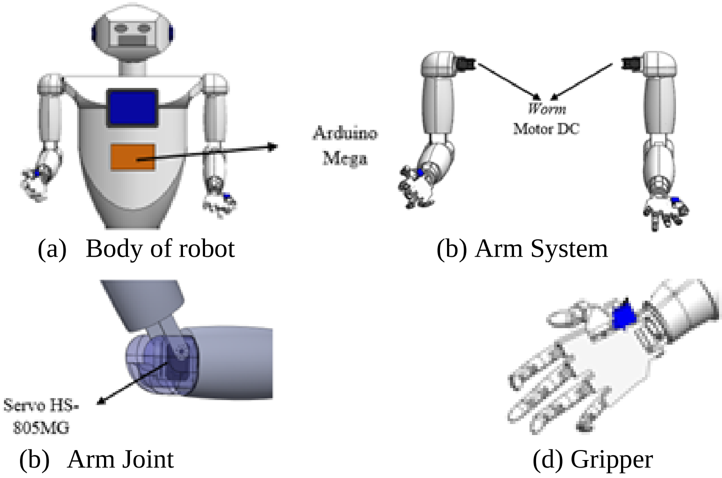


Figure 2. Design of robotic arm

The arm robot was made based on the design and printed with a 3D printer using filament material, as shown in Fig. 3. The components used in the arm robot include DC worm motors, servomotors, proximity sensors, limit switches, and other microcontrollers that were arranged inside the humanoid arm and body. The movement of the humanoid robot arm was controlled by the Arduino Mega microcontroller. The driving force of each arm was controlled using seven servomotors placed at the 3rd, 4th, and 5th DoF as grippers; and two 12V DC worm gear motors were placed at the 1st and 2nd DoF, which can be seen in Fig. 3. The robot arm was made using a filament as the base material, thus functioning as the substrate for the placement of the components and sensors used.

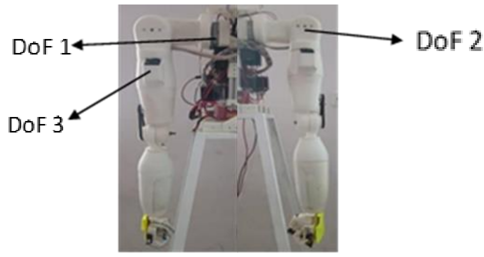


Figure 3. Design of robotic arm

Whereas a fuzzy membership represents the distance input and readings from the crisp distance sensor that is changed into a fuzzy set. The membership function of this fuzzy system uses three variables: object and human distance, x-distance, and ultrasonic sensor distance. In this study, a fuzzy set was used to determine the movement of the humanoid robot arm. The set was divided into five classes: very far, far, medium, close, and very close. The membership function of each variable can be seen in Figs. 4, 5, and 6, in the form of object and human distance variables, x-distance variables, and ultrasonic sensor distance variables, respectively.

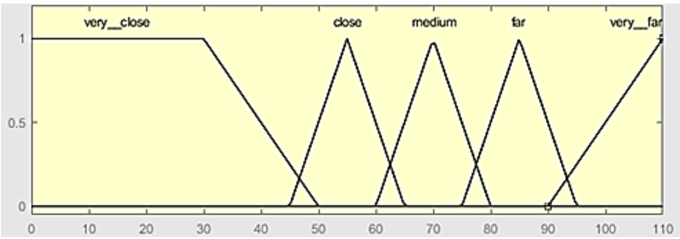


Figure 4. Distance variable curves of objects and human

JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

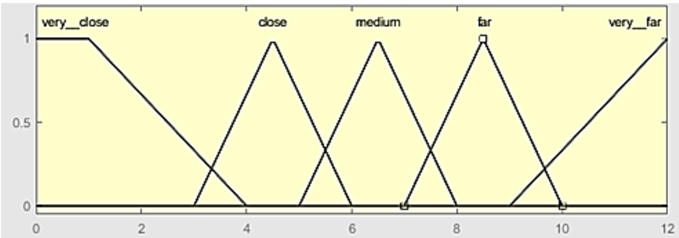


Figure 5. X-distance variable curve

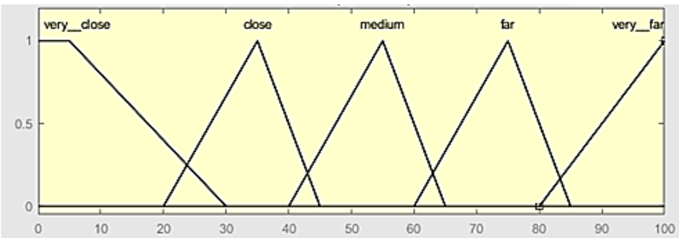


Figure 6. Ultrasonic sensor distance variable curve

After determining the membership function, the next step is to compile fuzzy rules used as a reference for the process of acquiring the output of the robot arm movement. In this study we used three types of variables with five membership functions in order to obtain the fuzzy rules, that is, we had 125 rules in total.

3. RESULTS AND DISCUSSION

3.1 Humanoid Robot Performance Testing

First, the robotic arm was tested for movement without using the fuzzy logic method. These tests included the movements of the 1-DoF, 2-DoF, 3-DoF, and 4-DoF. Next, the gripper was evaluated for opening and closing, and the proximity sensor readings on the gripper were also tested. The test was carried out to ensure that the components worked well so that the robotic arm as a whole would work well in moving objects using the Sugeno fuzzy logic method. The test of the robotic arm using the Sugeno fuzzy logic method was carried out six times: (1) standby position, as the start and end positions of the robotic arm; (2) lifting eggs; (3) lifting an empty mineral water bottle; (4) lifting a filled mineral water bottle; (5) lifting a glass of water; and (6) shaking hands directly with humans. The humanoid arm test was performed 20 times with changes in the object's distance from the robotic arm. Table I presents the distance data of the object to be moved from the robotic arm.

Based on the data in Table 1, the input value of the distance used varies, while the output of the linguistic variable was determined in advance from the calculation of fuzzy 'Gripping1' and 'Gripping' with the servomotor angle on the robot arm. When the input distance between objects and humans is 65, the x-distance is 30, and the sharp distance is between 5 to 12; the output of the fuzzy calculation is 'Gripping1', with the 1-DoF to 4-DoF servomotor angles being 140°, 100°, 120°, and 20°. Furthermore, when the input distance between objects and human is 65, the x-distance is between 20 to 45, and the sharp distance is less than 12; then, the result of Sugeno fuzzy logic calculation is 'Gripping', with the 1-DoF to 4-DoF servomotor angles being 140°, 100°, 10°, and 20°. The 5-DoF represents a gripper with a shape resembling a human hand's palm, equipped with five fingers as a tool for clamping objects. The output data from the gripper test on the humanoid robot arm can be seen in Table 2.

JURNAL ECTIPE Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

Table 1. Humanoid Arm Testing

No	Input			Output				
	Distance between objects & human	x-axis distance	Linguistic Variable	Distance between objects & human	x-axis distance			
					1	2	3	4
1	30	6	2	Gripping	140^0	100^0	120^0	20^0
2	45	10	4	Gripping	140^0	100^0	120^0	20^0
3	50	20	6	Gripping	140^0	100^0	120^0	20^0
4	55	8	3	Gripping	140^0	100^0	120^0	20^0
5	60	11	5	Gripping	140^0	100^0	120^0	20^0
6	65	16	8	Gripping	140^0	100^0	120^0	20^0
7	30	20	2	Gripping	140^0	100^0	120^0	20^0
8	34	25	5	Gripping	140^0	100^0	120^0	20^0
9	37	27	6	Gripping	140^0	100^0	120^0	20^0
10	40	30	8	Gripping	140^0	100^0	120^0	20^0
11	45	35	4	Gripping	140^0	100^0	120^0	20^0
12	50	40	10	Gripping	140^0	100^0	120^0	20^0
13	50	20	7	Gripping	140^0	100^0	120^0	20^0
14	53	25	10	Gripping	140^0	100^0	120^0	20^0
15	60	30	3	Gripping	140^0	100^0	120^0	20^0
16	65	33	6	Gripping	140^0	100^0	120^0	20^0
17	43	33	3	Gripping	140^0	100^0	120^0	20^0
18	48	37	7	Gripping	140^0	100^0	120^0	20^0

Table 2. Testing of Humanoid Arm Gripper

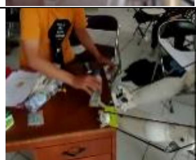
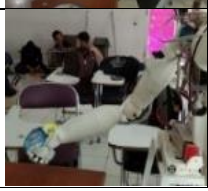
No	Objects	Thumb	Index	Middle	Ring	Pinkie
1	Egg	180^0	110^0	102^0	30^0	40^0
2	Empty water bottle	130^0	90^0	124^0	80^0	90^0
3	Full water bottle	130^0	100^0	77^0	70^0	80^0
4	Plastic glass of water	140^0	90^0	89^0	90^0	70^0
5	Human hand	90^0	70^0	50^0	70^0	83^0

Based on Tables 1 and 2, the output either changes the servomotor angle of each joint or the DoF of the humanoid arm during lifting and moving objects. This can be seen in the movement graphs of the humanoid robotic arm and the gripper. Then, the humanoid robot arm was tested 20 times with five different types of objects. Table 3 presents the results of a real-time humanoid robot arm test.

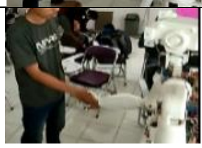
Table 3. Testing of Humanoid Arm Gripper

Test	Object	Photo	Information
1	Egg		The humanoid robotic arm successfully moves the object.
2	Egg		The humanoid robotic arm successfully moves the object.

Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

3	Egg		The humanoid robotic arm successfully moves the object.
4	Egg		The humanoid robotic arm successfully moves the object.
5	Empty water bottle		The humanoid robotic arm successfully moves the object.
6	Empty water bottle		The humanoid robotic arm successfully moves the object.
7	Empty water bottle		The humanoid robotic arm successfully moves the object.
8	Empty water bottle		The humanoid robotic arm successfully moves the object.
9	Full water bottle		The humanoid robotic arm successfully moves the object (both arms).
10	Full water bottle		The humanoid robotic arm unsuccessfully moves the object (both arms).
11	Full water bottle		The humanoid robotic arm unsuccessfully moves the object (both arms).
12	Full water bottle		The humanoid robotic arm unsuccessfully moves the object (single arm).
13	Plastic glass of water		The humanoid robotic arm successfully moves the object.

JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

14	Plastic glass of water		The humanoid robotic arm successfully moves the object.
15	Plastic glass of water		The humanoid robotic arm unsuccessfully moves the object.
16	Plastic glass of water		The humanoid robotic arm successfully moves the object.
17	Handshake		The humanoid robotic arm successfully moves the object.
18	Handshake		The humanoid robotic arm successfully moves the object.
19	Handshake		The humanoid robotic arm successfully moves the object.
20	Handshake		The humanoid robotic arm successfully moves the object.

Based on Table 3, the system of the humanoid robotic arm managed to move objects in real time. The humanoid robotic arm completed clamping and moving objects properly without deforming the object being moved. To determine the accuracy of the system's success in moving the objects with an overall accuracy rate of 65% based on Table III, the robotic arm has an accuracy of 50%, 75%, 75%, and 100% for moving eggs, moving the empty water bottle, moving the full water bottle, moving the plastic glass of water, and shaking hands with humans, respectively. The angular movement of each DoF of the humanoid robotic arm can be seen on each graph in Fig. 7.

4.1. Test of movement arm robot

The humanoid robotic arm was tested to lift and move a soft egg. It successfully moved the egg by clamping and lifting it, as shown in Fig. 7(a), without deforming or breaking it. Meanwhile, the robotic arm movement while lifting eggs is 50 second for a time duration.

(a) arm lifts the egg (b) arm lifts the full water bottle

JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482


(c) arm lifts the plastic glass of water


(d) handshaking test

Figure 7. The humanoid robotic arm testing

Fig. 7(b) shows the test of the robotic arm lifting a full water bottle. As using a single arm cannot move it the robotic system uses both arms to lift and move it. Fig. 7(c) shows that the humanoid robotic arm has successfully gripped and moved the plastic glass of water; it takes 50 second to move the plastic glass of water. Fig. 7(d) shows that the humanoid robotic arm successfully interacts with a human in real time and it takes 45 second the gripper movement while handshaking. To evaluate the humanoid robot arm using the Sugeno fuzzy logic method as seen in Table 4.

Table 4. Accuracy Type of Test

Action / object	**Experiments**	**Accuracy**
eggs	15	13.333%
empty mineral water bottle	12	58.333%
bottle filled with water	46	4.761%.
glass	6	66.666%.
shaking hands	5	100%

From Table 4, tests were carried out with five different types of objects, including eggs with an accuracy of 13.333% from 15 tests. This happened because it was difficult for the robot arm to clamp the egg due to its small diameter and round shape, which caused the distance sensor reading on the gripper to not be detected. The second test was carried out with an empty mineral water bottle where the robot obtained an accuracy of 58.333% from 12 experiments. In this test, the accuracy was higher because the diameter and height of the mineral water bottle exceeded the size of the gripper, thereby making it easy for the distance sensor to detect the mineral water bottle. The third test was conducted with a bottle filled with water, where both the arms of the humanoid robot were used. This test was carried out 42 times with a very small success of 4.761%. This was due to the fact that the gripper was too large, and it lacked the necessary clamping force. Thus, the robotic arm could not move the bottle filled with water. The fourth test, using a glass, was conducted six times, and the robot obtained an accuracy value of 66.666%. In this test, there were two attempts that were not successful, caused by the thumb on the gripper not clamping a part of the glass. The fifth and the last test involved interaction with humans by shaking hands. The humanoid robot arm showed good performance at shaking hands with humans, obtaining an accuracy of 100% from five experiments. This was due to the ability of the proximity sensor on the gripper to detect human hands very quickly and efficiently.

4. CONCLUSION

The implementation of the zero-order Sugeno fuzzy logic method in the movement of the humanoid robotic arm in moving objects or shaking hands has been successfully performed in an automated manner. The humanoid robotic arm was able to successfully move objects such as a water bottle (empty and full) and plastic glass of water; it could hold an egg for 30 second without breaking it. Additionally, it could shake hands directly with humans, taking 36 second to complete the handshake command. Future research will be implemented systemically so that this humanoid robot will be able to carry out activities like humans in providing services.

Volume 11, Issue 1, April 2024, pp. 46-54
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4482

Acknowledgments

This research was funded by Faculty of Engineering, Sriwijaya University, Fiscal Year 2022 with contract number 023.17.2.677515/2022 dated November, 17, 2021 and accordance with the Rector Decree number: 0390/UN9.FT/TU.SK/2022 dated on May, 13, 2022.

REFERENCES

[1] R. Pinillos, S. Marcos, R. Feliz, E. Zalama, and J. Gómez-García-Bermejo, "Long-term assessment of a service robot in a hotel environment," *Rob. Auton. Syst.*, vol. 79, pp. 40–57, 2016.

[2] A. Stăncioiu, "The Fourth Industrial Revolution 'Industry 4.0,'" *Fiabil. Şi Durabilitate*, vol. 1, no. 19, pp. 74–78, 2017.

[3] P. Tsarouchi *et al.*, "Robotized assembly process using dual arm robot," *Procedia CIrP*, vol. 23, pp. 47–52, 2014.

[4] A. Melnyk and P. Henaff, "Bio-inspired plastic controller for a robot arm to shake hand with human," in *2016 IEEE 36th International Conference on Electronics and Nanotechnology (ELNANO)*, 2016, pp. 163–168.

[5] A. Sambas and D. S. Rahayu, "Rancang Bangun Robot Arm 2 DOF Berbasis Adaptive Neuro-Fuzzy Inference System (ANFIS)," *Al-Jazari J. Mech. Eng.*, vol. 3, no. 2, pp. 41–45, 2018.

[6] A. S. Trisnawan and D. S. Rahayu, "Rancang Bangun Robot Arm 2 DOF Berbasis Adaptive Neuro-Fuzzy Inference System (ANFIS)."

[7] T. Dewi, S. Nurmaini, P. Risma, Y. Oktarina, and M. Roriz, "Inverse kinematic analysis of 4 DOF pick and place arm robot manipulator using fuzzy logic controller.," *Int. J. Electr. Comput. Eng.*, vol. 10, no. 2, 2020.

[8] K. Lochan and B. K. Roy, "Control of two-link 2-DOF robot manipulator using fuzzy logic techniques: a review," in *Proceedings of fourth international conference on soft computing for problem solving*, 2015, pp. 499–511.

[9] Salim Chennai, "Performance Analysis of Universal Power Quality Conditioner Systems Based on Seven-level NPC Inverter Using PD-SPWM with Fuzzy Control Scheme," *Period. Polytech. Electr. Eng. Comput. Sci.*, vol. 66, no. 4, pp. 315–324, 2022, doi: https://doi.org/10.3311/PPee.20140.

[10] V. Scherger, H. P. Vigier, and M. G. Barberà-Mariné, "Finding business failure reasons through a fuzzy model of diagnosis," *Fuzzy Econ. Rev.*, vol. 19, no. 1, p. 45, 2014.

[11] A. Susilawati, J. Tan, D. Bell, and M. Sarwar, "Fuzzy logic based method to measure degree of lean activity in manufacturing industry," *J. Manuf. Syst.*, vol. 34, pp. 1–11, 2015.

[12] I. J. Orji and S. Wei, "An innovative integration of fuzzy-logic and systems dynamics in sustainable supplier selection: A case on manufacturing industry," *Comput. Ind. Eng.*, vol. 88, pp. 1–12, 2015.

[13] A. Sarkar, "Application of fuzzy logic in transport planning," 2012.

[14] S. Rajak, P. Parthiban, and R. Dhanalakshmi, "Sustainable transportation systems performance evaluation using fuzzy logic," *Ecol. Indic.*, vol. 71, pp. 503–513, 2016.

[15] R. S. Santos, J. Soares, P. C. Marques, H. V. G. Navas, and J. M. Martins, "Integrating business, social, and environmental goals in open innovation through partner selection," *Sustainability*, vol. 13, no. 22, p. 12870, 2021.

[16] C. Y. Kang, H. Nabipour, H. S. Chua, and C. C. Kang, "Design of Battery Energy Storage System (BESS) with Fuzzy Control for Pico Hydro," 2021.