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Fuzzy logic track control of an automated lawnmower

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ABSTRACT

Automation of agricultural and horticultural operations keeps received great attention for over a decade. The control parameters adopted depend on the location and characteristics of likely obstacles and navigation requirements. An automated lawnmower (ALM) with fuzzy logic control is presented in this study. Fuzzy logic was chosen to improve a previous work which was controlled via Bluetooth. Three ultrasonic sensors and two proximity sensors served as the eyes of the ALM for navigation and obstacle avoidance while the cutting blade was made of stainless steel and controlled by a brushless direct current (BLDC) motor. A fuzzy algorithm was implemented on an Arduino controller with the inputs and outputs as directional instructions. Obstacle avoidance was achieved by setting a range of values for the sensors interpreted by the fuzzy logic for the corresponding output in the form of navigations. Three trials tests were conducted on the ALM on a 5 m^2 portion of land with an average grass height of 0.09 m. The average cut area was 4.46 m^2, therefore achieving an efficiency of 89.2%, which is highly productive. It was observed that the power consumption was minimal compared to the previous design because at the end of the three trials 46% of the battery was left after over 3 hours of operation.

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1. INTRODUCTION

Environmental health is considered a cardinal objective of the sustainable development goals largely because of its contribution to overall health, air environmental quality, and societal wellbeing. More so, the current trend in urbanization and globalization supports the green revolution since the population of flora and fauna constitutes significantly of theory green space and open spaces of many parts of urban settlements. Wholesome lawns and well-trimmed landscapes are established to prevent tidally and water erosion, enhance the flood and facilitate environmental quality air while improving visual appeal around the neighborhood. Urban planners in urban centers consider lawn planning as a vital subset of the sustainable environment for balance amongst the trio of aesthetics, ecological and social worldview.

In the Western world, lawn mowing is mechanized regardless of the scale of the landscape while the case is contrary in the developing world. The arable approach to lawn mowing in the third world is largely due to the agrarian vocation of the sub-region which precludes the utilization of machines during the early days of green-urbanization [1], [2]. The fact that lawn mowing has become a vital aspect of domestic chores in homemaking in the present day requires sufficient investment, time, and effort. This is consequently attended by the rising cost of machinery for lawn mowing operations which is estimated to be

US $27.5 billion by 2025 [3]. In addition to the initial cost of lawn mowing machineries, maintenance of mechanized lawn mowing operations accrues the cost of procurement of landscaping machineries.

The operation of gasoline-powered lawn equipment could contribute to the carbon footprint in the urban settlement where landscaping and green beautification are considered to be of aesthetic and recreational value [4]. Recent scientific attempts at innovating the operation of mowing machinery have been reported in many pieces of literature. Solar-powered lawn mowing machines are being innovated to eliminate internal combustion systems and dependence on fossil fuels as tools for addressing environmental pollution [5]. A simplified design involves a solar panel with the traction and rotary blade being powered by the direct current (DC) source while the battery is being recharged by renewable facilities attached to the mower systems [6]. The case hydrocarbon emission from lawnmowers in the United States (US) is found to increase by 13% for which crusade for innovative solar-powered lawn-cutting engines is heralded.

Device automation is considered the hallmark of green technology which is dependent on renewable energy sources. Since smart technology has already gained significant deployment in farming practices in the developed world, this technology is constantly gaining popularity in agriculture related occupations [7]. Lawn operations like farming occupations could be facilitated by automation as means to create sustainability in small-sized grass-cutting and landscaping machines. Some automation paradigms have been established for the manufacture of mobile robotic machines which could be easily translated for automating the operation of lawn mowing devices [8]–[10]. For instance, fuzzy logic controllers are cheaper and offer more robust control compared to proportional integral derivative (PID) controllers because they can handle a wider range of input and output combinations [8], [9]. In addition, it is an adaptation of human thinking, so it gives a closer output to that obtainable from human thinking [8], [11]–[14]. It has therefore found acceptability for various applications where autonomous navigation is planned. It has been discovered that it allows effective control for autonomous navigation in applications with large volumes of uncertainty, especially when associated with operations in natural environments [15], [16].

This control was adapted for use in an indoor lighting system where daylight is used as illumination for energy saving. In this application, various levels of lighting intensity were achieved with the dependent variables being location, season, latitude, and cloudiness [17]. Another application was the development of an automated indoor robot where the robot follows a predefined path as it also avoids obstacles along its path. These robots are used in hospitals, homes, hotels, and recreational centers [18] for path control and tracking [19]–[23]. A systemic adaptation that incorporated fuzzy logic into DC converters was developed by [24]. The fuzzy logic controller eliminated the loss of power associated with temperature and irradiation effects on a solar power station.

Another similar application [25] was for the control of a DC motor for specific speed requirements which is unaffected by varying loads. This system achieved a smooth speed control cutting down overshoot and oscillations effects drastically. Asides from control methods, renewable sources of power have also been incorporated into lawnmower automation, especially solar power [26] which seems most accessible in certain areas. However, as stated earlier, automation has been applied to farming operations and robots have been developed with various controls such as Bluetooth automation and autonomous [27]. This work presents an autonomous lawnmower (ALM) incorporating a fuzzy logic track control for navigation and obstacle avoidance.

From the foregoing lawning machinery have shown not much attention for path planning during landscaping and green-cultivation operation. The fuzzy logic technique in robotic machinery has been proven to enhance automation and device productivity in machining operations. Hence, the capability of fuzzy logic for the design of operational path-planning to effect energy-minimized operations of lawning machinery is justified. Although previous reports have shown the plausibility of Bluetooth via android gadgets the present study intends to obliterate the interaction of human effort during mowing activities by devising path-planning mowing based on an established fuzzy-controlled architecture.

In this study, fuzzy-mediated autonomous lawn mowing operation is demonstrated using low-cost materials for energy-minimized machinery that could find usefulness in grass-cutting and landscaping in remote settlements. The fuzzy-logic controlled architecture was utilized for path planning while mowing was achieved on the backbone of an existing conventional-type lawnmower with the incorporation of associated sensorial components such as an obstacle avoidance mechanism. An elaborate integration of fully implementable fuzzy-logic controllers incorporated into the autonomous path guidance of the robotic lawn machines is elaborately presented.

2. RESEARCH METHOD

This section describes the materials and methods selected for the development of the fuzzy-controlled ALM.

2.1. Materials

The materials were used for the development of the ALM are i) perspex sheet, ii) 12V DC motor, iii) brushless DC (BLDC) motor, iv) cutting blade, v) Arduino Mega 2560, vi) ultrasonic sensor with bracket, vii) IR proximity sensor, viii) motor driver shield L 293 D, and ix) Vero board.

The by properties that were put into consideration during the material selection process are i) strength, ii) lightness and flexibility, iii) corrosion resistance, iv) availability, and v) cost.

The material for this kind of task should possess sufficient strength to be able to bear the weight of the various parts. Such weight as the power battery, cutting blade motor and the driving wheel motors, the bracket for the driving motor, and the electrical components. The properties of the chassis and cutting blade are presented in Table 1. In addition, the lightness of the material reduces the gross weight of the whole body and thus reduces the torque required to drive the system while making navigation lighter.

Table 1. Table of properties of the main body and the blade

Main body	
Description	Value
Dimension	16" × 48" × 0.4"
Material	Perspex
Density	1.19 gcm^{-3}
Tensile strength	75 MPa
Cutting blade	
Material	Stainless steel
Tensile strength	

On the other hand, the cutting blade was made from stainless steel because of its tensile strength greater than mild steel and high corrosion resistance. This is partly because the blade might accidentally hit a hard surface so that the blade does not break or bend easily. To further adjudge its suitability, it contains chromium which offers it a great advantage of resistance to corrosion thus making the blade suitable for the moist cutting environment, and the strength needed from the blade to be able to work under given cutting conditions. A brushless DC motor was selected to drive the cutting blade because of the high speed possessed by the motor.

2.2. Control

The processing was made up of; the microcontroller and its accessories, the programming language, and the control system.

2.2.1. The microcontroller and its accessories

Typical of most robotic prototype development, affordable and simplified controllers are used. For this mower, an Arduino Mega 2560, based on an Atmega 2560 AVR microcontroller was selected.

2.2.2. Ultrasonic sensor

Ultrasonic sensing works by differentiating the feedback after a transmitted signal is sent back after reaching an obstacle, hence the distance between the sensor and the object is determined as (1).

$$distance = \frac{speed\ of\ sound \times time\ taken}{2} \tag{1}$$

2.2.3. Working principle of the autonomous lawnmower

The control architecture for the lawnmower is made up of three main modules. The velocity planner, the path-tracking controller, and obstacle avoidance.

2.2.4. Velocity planning

In velocity planning; trajectory and velocity for the system are based on the object detection, curvature, and external factors such as tire characteristics, road slope lateral, and longitudinal accelerations. Therefore, as a guide for the trajectory, the immediate position is usually supplied as the input. Then the next position and the reference velocity become input into the path control.

2.2.5. Path control

The path controller (PC) controls the movement of the robot over a predefined path. To achieve this, the errors between the desired pose and actual pose are made as inputs into the fuzzy logic module which subsequently converts the output of the rule as commands to affect the movement pattern. While this is being done, the error in the positioning and the heading error is measured simultaneously for each iteration. The errors are however evaluated in terms of the coordinate system $\{P_x, P_y\}$ defined to have its origin located at the perpendicular projection of the current vehicle location onto the planned path as shown graphically in Figure 1. Furthermore, according to Abel *et al.* [28], the errors are described mathematically.

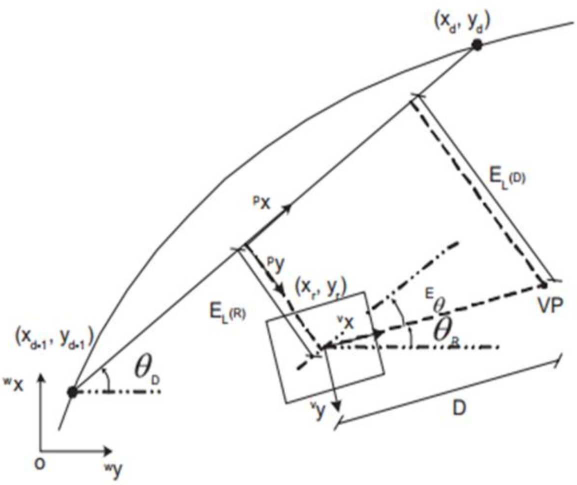

Figure 1. Position and heading errors [28]

Lateral error $E_L = P_{yv}$ (2)

$\{P_{xv}, P_{yv}\}$ are the coordinates of the velocity planning in the coordinate system.

The heading error $E_\Theta = \Theta_D - \Theta_R$ (3)

The differential errors;

$$\Delta E_L = E_L(k) - E_L(k-1) \quad (4)$$

$$\Delta E_\theta = E_\theta(k) - E_\theta(k-1) \quad (5)$$

2.2.6. Obstacle avoidance

In obstacle avoidance and object recognition, machine vision has played a significant role. However, when mowing a lawn or a field, the mower has to avoid both known and unknown obstacles. This, therefore, makes machine vision insufficient because all obstacles that may be encountered cannot be accounted for, which leaves a wide range of obstacles out of the spectrum of the obstacle list. Therefore, a more reliable alternative is the use of sound projection; an ultrasonic sensor suitably fits this application. This creates an encompassing system for the robot to deal with obstacles, thereby making the design robust and capable of handling real-world situations and environments where there may be several unpredictable obstacles.

The ultrasonic sensor sends a pulse signal to determine the distance and range of the obstacle, while the time range of feedback of the signal gives the distance of the obstacle concerning the sensor. This cycle is repeated every millisecond. The fuzzy system was integrated into the sensor to interpret the signal generation and feedback to provide the best output in terms of movement decisions for the robot. Therefore, to avoid an obstacle, the fuzzy system maps its membership functions with the input of the ultrasonic distance range. The lawnmower is thus steered by the fuzzy logic output converted to a crisp value which is then transmitted as rotation parameters for the motor driver.

An important aspect of the steering is the determination of the amount of wheel rotation. This depends on the angle required to steer the mower, the diameter of the wheel, and the distance between the wheels. In determining the distance moved by the wheels; the circumference of the wheel must be known.

The circumference of a circle can be calculated as (6).

$$c = \pi \times d \tag{6}$$

For the proposed wheel's diameter to be used for the mower (d), equals 56 mm, therefore the circumference (c) of the wheel can be calculated as (7).

$$c = (22/7) \times 56 = 176\, mm \tag{7}$$

This means that when the wheel rotates 360°, the mower moves 176 mm. Therefore, if the wheel rotates at 45° covers, it covers as (8).

$$\left(\frac{45}{360}\right) \times 176 = 22\, mm \tag{8}$$

2.2.7. Fuzzy logic control of the lawnmower

The code was written in (c) language on Arduino IDE. The procedure for achieving the control programming is presented in Figure 2.

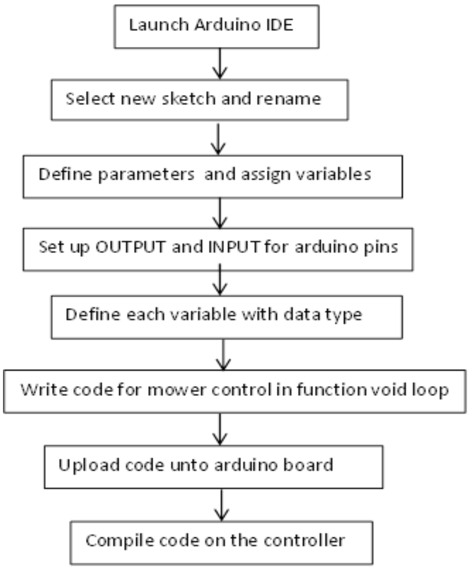

Figure 2. Flowchart for the Arduino programming

Integrated into the fuzzy inference control system (FIS) were five inputs and three outputs. The input parameters are values from the left ultrasonic sensor (LUS), center ultrasonic sensor (CUS), right ultrasonic sensor (RUS), left and right IR proximity sensor. The output parameters were the values for the motor driver shield to command the left and right motor speed and the steering angle of the mower. However, the mapping from the ultrasonic sensor into a fuzzy rule utilizes these four membership functions; Very far, far, near, and very near. The algorithm for this procedure is presented in Figure 3.

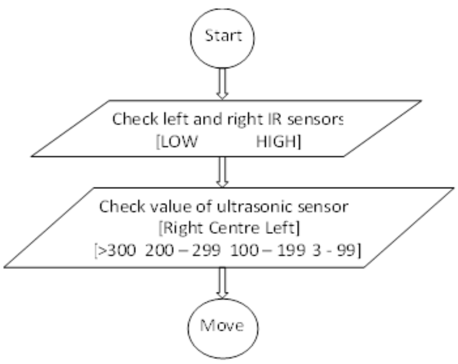

Figure 3. Fuzzy logic algorithm

An infrared sensor was used to track the predefined path, give the ALM direction and pattern of cut. The predefined path is a white track carpet fixed on the lawn for the IR sensor to sense. When the right IR sensor and the left IR sensor detect the track, the ALM moves in a forward direction but when any of the IR sensors do not sense the white track (i.e. the ALM is moving out of the predefined path), the ALM adjust back to the track in respect to the IR sensor not detecting the white path.

The movements are made possible by the two IR sensors so that the ALM can follow the pre-defined paths. When the right IR senses the white track due to reflected infrared light by the white body, it means that the ALM moves towards the left direction, the ALM tries to correct its movement by reducing the speed of the right wheel. When the left IR senses the white track, it means the ALM is moving in the right direction and the ALM tries to correct its movement also by reducing the left wheel speed.

The ALM responds as presented in Table 2 to different feedback from the ultrasonic sensor and decides when to stop, pause, reduce speed, and avoid the obstacles detected. The ALM makes use of three ultrasonic sensors (center at 90^0, left at $120^{0,}$ and right at 30^0 to the vertical axis of the chassis respectively) such that when the center ultrasonic sensor detects an obstacle at a different distance, the left and right ultrasonic sensor checks for obstacles at their angles to determine which direction the ALM will turn to avoid the center obstacle. If the three ultrasonic sensors detect obstacles at a very close range together, the ALM stops for some minute in case it is a movable obstacle before moving backward while it checks for the preferable direction to move. The brushless motor was powered by an 11.1 V Lipo battery.

Table 2. Fuzzy navigation parameters for the IR and ultrasonic sensors

IR sensor		IR sensor range (cm)		Ultrasonic sensor range (cm)	Decision
Right	Left	Right	Left	Centre	
Low	Low	250	250		Forward
High	Low	100	-	>=300	Turn left
Low	High	-	True		Turn right
Low	Low	180	180		Forward
High	Low	100	False	200 - 299	Turn
Low	High	100	True		Turn
Low	Low	120	120		Forward
High	Low	100	False	100 - 199	Turn
Low	High	100	True		Turn
				3 - 99	Stop/Pause

The electronic component arrangements are as shown in Figure 4, while Figure 5 is showing the view of the ALM, Figures 5(a) is showing the front view and Figure 5(b) is showing the end view.

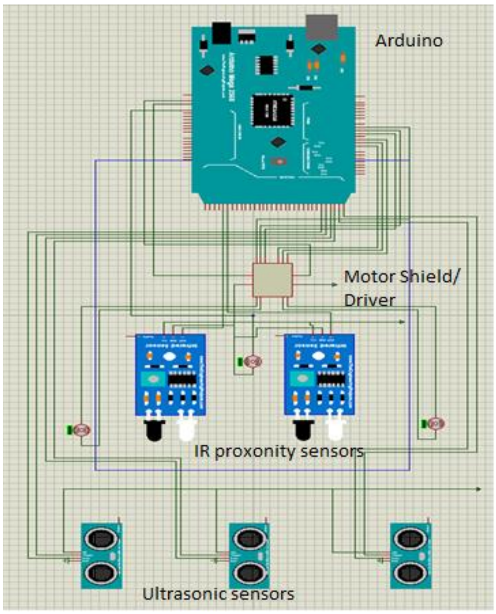

Figure 4. Schematic diagram of the ALM using proteus

Figure 5. View of the ALM (a) front view and (b) end view

3. RESULTS AND DISCUSSION

The objective of the project as stated earlier is to design and develop an autonomous lawnmower using fuzzy logic control to follow a predefined path and avoid any obstacle along its path by incorporating sensors into the ALM.

For the laboratory testing, the mower was operated in a rectangular pattern front and back for a precise amount of distance. A white predefined path Figure 6 was created for the mower within the boundary of the cutting area. Since the only obstruction recognized by the mower is a concrete wall, humans begin approaching the system, object obstacles such as trees, and stone. When the lawnmower detects an obstacle from a specified distance, it reduces its speed of approach towards the obstacle to decide if it's a moveable obstacle that can leave its path or a stationary obstacle. If the obstacle remains in its path at a specified distance, the robot navigates around the encountered objects.

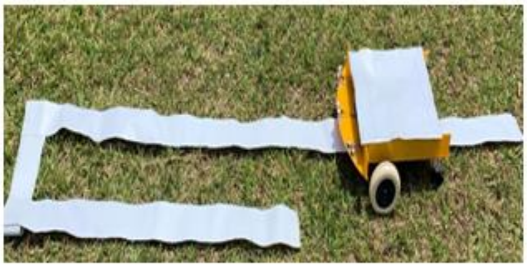

Figure 6. The ALM during path tracking operation

Different patterns of cut were achieved by changing the direction of the predefined path for the mower. The cutting blade dimension was 20 cm by 5 cm which implies that a single cut would make a 200 mm circular cut. The path was made of a white reflected material for the robot to track for the path to follow. If the left-wheels and the right-wheels turn clockwise, the ALM moves forward and if counter-clockwise the ALM moves backward. If left-wheels turn clockwise and right-wheels either stops or turns with low speed in comparison to the left-wheel, the ALM will turn in the right direction, and also if the right-wheel turns clockwise and left-wheel either stops or turns with low speed in comparison to the right-wheel, the ALM turns to the left direction.

The ALM can be used for mowing grasses of height below 9 cm and after the operation, the grasses' height will be 5 cm. The blade height is adjustable by adjusting the height of the brushless motor. Testing operation for the cutting operation carried out revealed by the result as presented in Table 3 for three trials on a 5 m^2 portion of grassland.

Table 3. Performance output of the ALM testing

Trial	Cutting proportion (m^2)	Time (sec)	Power consumed (%)
1	4.50	600	90.0
2	4.45	660	70.0
3	4.45	720	45
Mean $\underline{x} = \frac{\sum_{i=1}^{n} x_i}{n}$	4.46	660	68.3

To determine the cutting efficiency, equations (9) which compare the uncut portion with the total portion to be cut was used, while the percentage uncut area was determined using (10).

$$Cutting\ Efficiency = \frac{Total\ cutting\ portion - Portion\ uncut}{Total\ cutting\ portion} \times 100\% \quad (9)$$

$$= \frac{5-(5-4.46)}{5} \times 100\%$$
$$= 89.2\%$$

The percentage uncut area was determined as (10).

$$Percentage\ uncut = \frac{Total\ cutting\ portion - Portion\ cut\ (\underline{x})}{Total\ cutting\ portion} \times 100\% \quad (10)$$

$$= \frac{5-4.46}{5} \times 100\%$$
$$= 10.8\%$$

From the cut area and uncut area, the ALM performance was high at 89.2% which is very close to that achieved [29], [30]. Most of the work done on automated lawn machines does not present the cutting efficiency but reports mostly on the power source [29] and how the machine works [3], [8] hence it is commendable that this work presented the cutting efficiency of the machine. The power consumption is also commendable given the fact that it operated for over three hours without draining the battery. This was possible because the power source was distributed for the various components powered. The need for solar power in agricultural machines is usually to ensure the machine works for long hours without depleting the power supply, however, the fuzzy path planning and design arrangement here presented better power management compared to previous designs [29], [30] where 95% mower availability was achieved due to solar power while still having 5% unavailability for a five hour operation.

4. CONCLUSION

The ALM is an offshoot of ongoing research work into automated farming and horticultural services. A Bluetooth lawnmower was initially developed and the performance was satisfactory. However, the path control needed to be fine-tuned hence the need to incorporate a proven control algorithm for control. The ALM was designed, prototype built and tested on a 5 m by 5 m portion of grassland. The performance evaluation in terms of cut portion showed 89.2% successful cutting. This shows that fuzzy logic path control gave a better track control for the ALM and thus can be adopted for further work in the development of automated farming and horticultural machines.

REFERENCES

[1] A. Aliyu and L. Amadu, “Urbanization, cities, and health: The challenges to Nigeria – A review,” *Annals of African Medicine*, vol. 16, no. 4, p. 149, 2017, doi: 10.4103/aam.aam_1_17.

[2] M. Hove, E. T. Ngwerume, and C. Muchemwa, “The urban crisis in Sub-Saharan Africa: A threat to human security and sustainable development,” *Stability: International Journal of Security and Development*, vol. 2, no. 1, p. 7, Mar. 2013, doi: 10.5334/sta.ap.

[3] A. E. Patterson, Y. Yuan, and W. R. Norris, “Development of user-integrated semi-autonomous lawn mowing systems: a systems engineering perspective and proposed architecture,” *AgriEngineering*, vol. 1, no. 3, pp. 453–474, Sep. 2019, doi: 10.3390/agriengineering1030033.

[4] D. Sivaraman and A. S. Lindner, “A comparative life cycle analysis of gasoline-, battery and electricity-powered lawn mowers,” *Environmental Engineering Science*, vol. 21, no. 6, pp. 768–785, Nov. 2004, doi: 10.1089/ees.2004.21.768.

[5] G. . Dhumal, A.P.Patwekar, S.R.Vishwakarma, C.G.Phate, and A.R.Mujawar, “Design and fabrication of mulch cutting machine using non conventional Source,” *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, pp. 4–10, 2018.

[6] O. A. Tanimola, P. D. Diabana, and Y. O. Bankole, “Design and development of a solar powered lawn mower,” *International Journal of Scientific and Engineering Research*, vol. 5, no. 6, pp. 216–220, 2014.

[7] A. Villa-Henriksen, G. T. C. Edwards, L. A. Pesonen, O. Green, and C. A. G. Sørensen, “Internet of Things in arable farming: Implementation, applications, challenges and potential,” *Biosystems Engineering*, vol. 191, pp. 60–84, Mar. 2020, doi: 10.1016/j.biosystemseng.2019.12.013.

[8] S. M. Ramnani, B. R. Mekhe, A. B. Kuttamathu, S. S. Kotgire, and A. U. Rajale, “Unmanned automated lawn mower,” *International Research Journal of Engineering and Technology (IRJET)*, vol. 7, no. 6, pp. 2473–2484, 2020.

[9] P. P. Dutta, A. Baruah, A. Konwar, and Kumar.V, “A technical review of lawn mower technology,” *ADBU Journal of Engineering Technology(AJET)*, vol. 4, no. 1, pp. 179–182, 2016.

[10] M. Franzius, M. Dunn, N. Einecke, and R. Dirnberger, “Embedded robust visual obstacle detection on autonomous lawn mowers,” in *2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, Jul. 2017, pp. 361–369, doi: 10.1109/CVPRW.2017.50.

[11] Y. Yao Ting, H. Sheng Wang, and K. Lan Su, “Path planning of the fire escaping system using active detection module,” *IAES International Journal of Robotics and Automation (IJRA)*, vol. 6, no. 1, p. 21, Mar. 2017, doi: 10.11591/ijra.v6i1.pp21-30.

[12] P. A. Baziuk, S. S. Rivera, and J. Núñez Mc Leod, “Fuzzy human reliability analysis: applications and contributions review,” *Advances in Fuzzy Systems*, vol. 2016, pp. 1–9, 2016, doi: 10.1155/2016/4612086.

[13] B. Yao, H. Hagras, M. J. Alhaddad, and D. Alghazzawi, “A fuzzy logic-based system for the automation of human behavior recognition using machine vision in intelligent environments,” *Soft Computing*, vol. 19, no. 2, pp. 499–506, Feb. 2015, doi: 10.1007/s00500-014-1270-4.

[14] A. Chakraborty, A. Konar, U. K. Chakraborty, and A. Chatterjee, “Emotion recognition from facial expressions and its control using fuzzy logic,” *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 39, no. 4, pp. 726–743, Jul. 2009, doi: 10.1109/TSMCA.2009.2014645.

[15] M. Ros, M. Delgado, A. Vila, H. Hagras, and A. Bilgin, “A fuzzy logic approach for learning daily human activities in an Ambient Intelligent Environment,” in *2012 IEEE International Conference on Fuzzy Systems*, Jun. 2012, pp. 1–8, doi: 10.1109/FUZZ-IEEE.2012.6250770.

[16] J. Martínez-Miranda, M. Alvarado, A. Aldea, and R. Bañares-Alcántara, “Modelling human behaviour at work using fuzzy logic : the challenge of work teams configuration,” 2005.

[17] J. Liu, W. Zhang, X. Chu, and Y. Liu, “Fuzzy logic controller for energy savings in a smart LED lighting system considering lighting comfort and daylight,” *Energy and Buildings*, vol. 127, pp. 95–104, Sep. 2016, doi: 10.1016/j.enbuild.2016.05.066.

[18] M. T. AL-Akhras, M. O. Salameh, M. K. Saadeh, and M. A. ALAwairdhi, “An autonomous fuzzy-controlled indoor mobile robot for path following and obstacle avoidance,” *International Journal of Computers*, vol. 3, no. 5, pp. 387–395, 2011.

[19] M. A. Rashidifar, A. A. Rashidifar, and D. Ahmadi, “Modeling and control of 5DOF robot arm using fuzzy logic supervisory control,” *IAES International Journal of Robotics and Automation (IJRA)*, vol. 2, no. 2, p. 56~68, Jun. 2013, doi: 10.11591/ijra.v2i2.2974.

[20] A. Moltajaei Farid, “UAV controller based on adaptive neuro-fuzzy inference system and PID,” *IAES International Journal of Robotics and Automation (IJRA)*, vol. 2, no. 2, p. 73~82, Jun. 2013, doi: 10.11591/ijra.v2i2.1936.

[21] A.-A. S. Abdel-Salam and I. N. Jleta, “Fuzzy logic controller design for PUMA 560 robot manipulator,” *IAES International Journal of Robotics and Automation (IJRA)*, vol. 9, no. 2, p. 73, Jun. 2020, doi: 10.11591/ijra.v9i2.pp73-83.

[22] J. Kim and J. Lee, “An active virtual impedance control algorithm for collision free navigation of a mobile robot,” *IAES International Journal of Robotics and Automation (IJRA)*, vol. 6, no. 2, p. 99, Jun. 2017, doi: 10.11591/ijra.v6i2.pp99-111.

[23] J. Yang, Y. Zhuang, and C. Li, “Towards behavior control for evolutionary robot based on RL with ENN,” *International Journal of Advanced Robotic Systems*, vol. 10, no. 3, p. 157, Mar. 2013, doi: 10.5772/53992.

[24] I. Zein and Y. N. Petrenko, “Fuzzy logic controller implementation for photovoltaic stations,” *System analysis and applied information science*, vol. 4, no. 4, pp. 44–48, 2014.

[25] A. . Thorat, S. Yadav, and S.S.Patil, “Implementation of fuzzy logic system for DC motor speed control using microcontroller,” *International Journal of Engineering Research and Applications (IJERA)*, vol. 3, no. 2, pp. 950–956, 2013.

[26] V. K. Khemnar, S. S. Pawar, S. S. Uagale, S. S. Pagar, and V. S. Navare, “Solar powered automated lawn mower,” *International Research Journal of Engineering and Technology (IRJET)*, vol. 7, no. 6, pp. 1893–1895, 2020.

[27] A. Mendes, L. C. Bento, and U. Nunes, “Path-tracking controller with an anti-collision behaviour of a bi-steerable cybernetic car,” in *EFTA 2003. 2003 IEEE Conference on Emerging Technologies and Factory Automation. Proceedings (Cat. No.03TH8696)*, 2003, vol. 1, pp. 613–619, doi: 10.1109/ETFA.2003.1247763.

[28] A. Mendes, L. C. Bento, and U. Nunes, “Path-tracking controller with an anti-collision behaviour of a bi-steerable Cybernetic Car,” *Portuguese Science and Technology Foundation*, pp. 1–7, 2001.

[29] A. O. Adeodu, I. A. Daniyan, T. S. Ebimoghan, and S. O. Akinola, “Development of an embedded obstacle avoidance and path planning autonomous solar grass cutting robot for semi-structured outdoor environment,” in *2018 IEEE 7th International Conference on Adaptive Science & Technology (ICAST)*, Aug. 2018, pp. 1–11, doi: 10.1109/ICASTECH.2018.8506681.

[30] O. O.E and A. and S. Olajide, “Design and construction of automated lawn mower,” in *Proceedings of the International MultiConference of Engineers and Computer Scientists (IMECS)*, 2021, pp. 1–5.

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