Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 6, December 2023, pp. 3288~3297
ISSN: 2302-9285, DOI: 10.11591/eei.v12i6.5950

Autonomous and smart cleaning mobile robot system to improve the maintenance efficiency of solar photovoltaic array

Prisma Megantoro[1], Abdul Abror[1], Muhammad Akbar Syahbani[1], Antik Widi Anugrah[1], Sigit Dani Perkasa[1], Herlambang Setiadi[1], Lilik Jamilatul Awalin[1], Pandi Vigneshwaran[2]
[1]Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga, Surabaya, Indonesia
[2]Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India

Article Info

Article history:

Received Feb 7, 2023
Revised May 25, 2023
Accepted Jun 4, 2023

Keywords:

Microcontroller
Mobile robot
Photovoltaic system
Proportional integral derivative control
Renewable energy

ABSTRACT

A solar photovoltaic (PV) array is part of a PV power plant as a generation unit. PV array that are usually placed on top of buildings or the ground will be very susceptible to dirt and dust. Thus, this dirt and dust will be able to reduce the performance and work efficiency of the generation unit. Cleaning PV arrays by manpower requires high effort, cost, and risk, especially in higher location. This study presents the design of a mobile robot that is used to replace human labor to clean PV arrays. That way, the PV array maintenance steps can reduce operational costs and risks. This intelligent controlled mobile robot can maneuver safely and efficiently over PV arrays. gyroscope and proximity sensors are used to detect and follow the sweep path over the entire PV array area. Proportional integral derivative (PID) control test makes the robot can stabilize in about 5.72 seconds to keep on the track. The smart PV cleaning robot has average operation time about 13 minutes in autonomous mode and 20-24 minutes in manual mode. The operation of the robot is effective to give more efficiency on the use of energy, time, and maintenance costs of PV array system.

Corresponding Author:

Prisma Megantoro
Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga
60115 Surabaya, Indonesia
Email: prisma.megantoro@ftmm.unair.ac.id

1. INTRODUCTION

Solar photovoltaic (PV) power plants are arranged by integrating PV modules to be electrically interconnected. The arrangement of PV modules is connected by cables in an electrical network called a solar array [1]. Solar arrays are mounted on the roof of a building (roof-mounted) or on the ground (ground mounted), where it is free from shades [2]. The installation position in this place makes the array surface vulnerable to dust and dirt. The presence of dust and dirt on the surface of the array can reduce the performance and efficiency of the generating unit [3], [4]. The research shows an 11% decrease in electricity generation after one week of exposure to dust [5]–[7]. In addition, when dust and dirt have hardened and burned, it will cause permanent damage to the surface of the solar cell [8], [9]. Thus, periodic maintenance is necessary to maintain the efficiency of the panel's performance to remain optimal in absorbing energy. Solar cell maintenance is done by cleaning the surface of the solar array. However, cleaning the surface of solar modules by human operator requires high effort, cost, and risk, especially if the location is at a high altitude. There needs to be a technology to do the job, one of which is with the device designed in this research, namely a robot to help clean the array to be efficient [10]. Thus, a PV array sweeper (Arvos) robot system that uses automatic and manual control was developed to solve these problems.

Research development by Parrot *et al.* [11] conducted in Saudi Arabia successfully developed a specialized robotic platform for dry-cleaning solar panels. The research discussed the effectiveness of silicone rubber foam brushes in cleaning solar arrays. However, the benefit of silicone rubber foam brushes is not more significant than the nylon tassels on the Arvos. Silicone rubber foam brushes will rub harder on the surface of the solar array, which results in degradation of energy absorption. Mousavi *et. al.* [12] created the MFv01 robot by cleaning the solar array using a suction system. However, the movement of the MFv01 robot uses wheels that can only move perpendicularly. Due to that fact, the MFv01 robot has limited motion and difficulty adjusting the trajectory when losing position control. Research by Fan *et al.* [13] in China created a robot similar to Arvos that operates in places where water is scarce. The water-free cleaning robot only has a manual drive mode. Manual drive mode will complicate the movement of the robot and reduce the work effort of a solar array cleaning. Research by Antonelli *et al.* [14] in Italy created the Ecopia E4 robot with two degrees of freedom (DOF) movement. The Ecopia E4 robot uses stiff brushes that can scratch intensely on the surface of the solar array. The mass of the EcopiaE4 robot prototype is 15 kg, which can press stronger on the array's surface and reduce the solar array' efficiency time.

Moreover, researchers also developed a mobile robot system with four independent driving wheels controlled by proportional integral derivative (PID) algorithm. The system is designed in two modes, such as autonomous and manual. In manual mode, it uses a remote controller with express long-range system (ELRS) protocol and an FPV camera which can be used by the operator to clean the solar PV array. It has 2 sweeper rollers on the front and back to sweep the dirt and dust. The devising is constructed by implementing of mechanical, electrical, and firmware design. The mechanical system is related to analyzing the frame structure for damage or physical defects. While in the electrical, the assembly is carried out on the wiring, driving system performance, and yaw position control.

2. METHOD

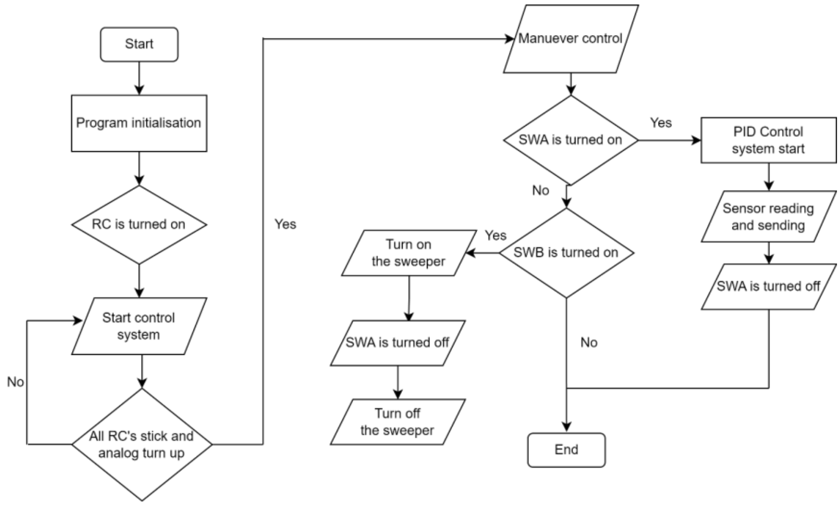
2.1. System and equipment

Figure 1 shows the system prototype of the Arvos robot. The mobile robot system uses three types of sensors, namely proximity sensor [15], inertial measurement unit (IMU) sensor [16], and rotary encoder sensor [17]. The mobile robot system drive uses DC motor drivers. Meanwhile, the sweeper roller uses 2 channel relays to connect manual and automatic modes.

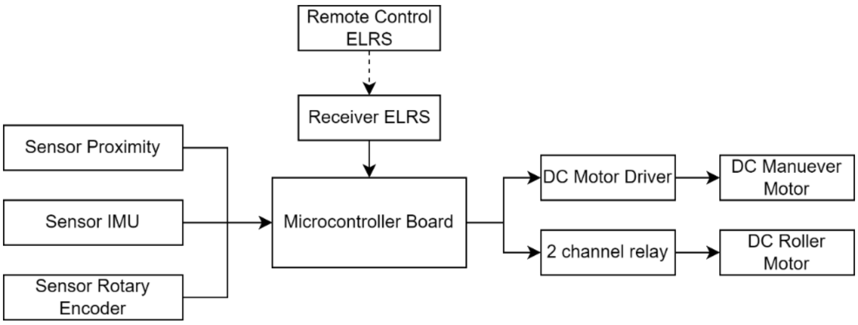
Figure 1. Prototype of mobile robot sweeper system

The mobile robot system works intelligently and is controlled by a microcontroller board Arduino Mega 2560. Usage of the microcontroller board is considered by the number of digital I/O pins, analog pins, pulse width modulation (PWM) pins, and its capability to run advanced control [18]–[22]. Autonomous mode is based on PID control by the input from IMU reading [23]. The MPU 6050 IMU sensor consists of an accelerometer and a gyroscope [24], [25]. IMU is used to maintain the stability of the 6 degree of freedom maneuver controlled by intelligent control techniques [26], [27]. The mobile robot system maneuvers using four mecanum wheels driven by dc motor drivers. While manual mode can be controlled wirelessly and remotely using an ELRS remote control. The Zorro ELRS master radio control (RC) the manual mode of the mobile robot system with the ELRS Matek R24-P radio signal receiver module. Then the sweeper roller is made with nylon tassels resistant to dust and dirt.

Figure 2(a) shows the operational flow diagram of the mobile robot system. Then Figure 2(b) shows it block diagram. The mobile robot system is turned on by pressing the power switch button on the robot and starting on the RC. Then, the mobile robot system will detect and connect with the RC.



(a)



(b)

Figure 2. Arvos mobile robot system; (a) workflow diagram and (b) block diagram

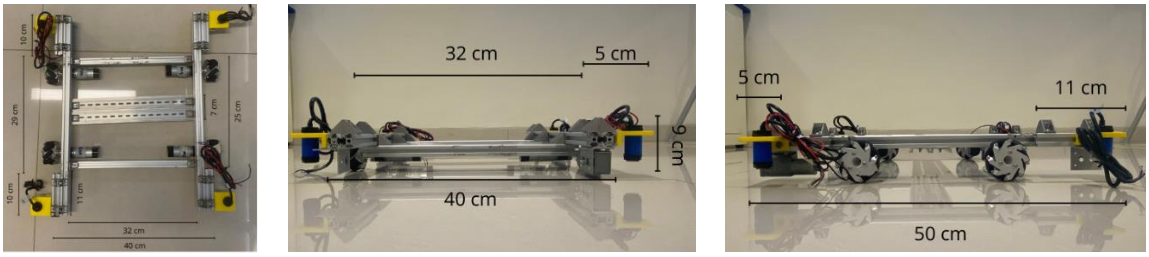
When the RC stick and analog appear, maneuver control will continue. Control will be available in two modes, namely manual and automatic. During manual mode, the maneuver control process uses a remote control to determine the direction of motion of the mobile robot system to the right, left, forward, backward, and stationary. Meanwhile, the automatic mode will be controlled by the PID control system. The PID program has been entered to the program commands accordingly.

3. IMPLEMENTATION

3.1. Hardware design

The mobile robot system has an operational system with many features. In addition, the devising of mobile robot systems also considers mechanical design so that performance can be effective and efficient. The following is the mechanical design of the mobile robot system. Figure 3 shows the mechanical design configured using the aluminum frame. This robot has a mechanical design in the form of a frame, body or cover, sweeping roller, and motor location with mecanum wheels. On the front and back of the mobile robot system, a 32 cm nylon tassel is installed which moves around to sweep dust and dirt. Placing the sweeping roller in that position increases the effectiveness of cleaning the solar array.

This wheeled robot uses a PG28-type motor as a mecanum wheel drive. The PG28-type motor installed on all four wheels has 1,000 rotations per minute (RPM) and a torque of 7 kg/cm. The motor is equipped with a 7 ppr rotary encoder and can be supplied with a maximum voltage of 24 V. Figure 3(a) shows from the upper view, Figure 3(b) from the front view, and Figure 3(c) from the right view.



(a) (b) (c)

Figure 3. The mechanical design of the mobile robot system, motor equipped with 7-ppr rotary encoder; (a) from top view, (b) from front view, and (c) from right view

The installed mecanum wheel has a diameter of 60 mm with an aluminium frame, which allows the robot to maneuver in 2 dimensions and facilitates its movement in sweeping the entire surface of the solar panel array. Meanwhile, the roller sweeper uses a motor type GW4632-370 12 V 150 RPM which is connected to a nylon tassel. The motor has an angled shaft making it easy to mount on the robot frame.

A proximity sensor is placed at each corner of the robot's frame to detect the solar array frame. Then in the middle is the Arvos frame which links the printed circuit board (PCB) and electrical components. Electrical components of the mobile robot system include motor drivers, step-down, Arduino Mega, DC relays, DC motors, and ELRS receiver.

3.2. Electrical design

As Figure 4 shows the schematic diagram of the Arvos robot system, Arduino Mega 2,560 used as the primary system controller and data processing unit for all sensors. These sensors and the Bluetooth HC-05 module will be connected through a socket onboard. The actuator consists of 2-channels relay to control manual or automatic drive mode. The maneuver uses 4 motor drivers for direction and speed control of each right and left motor. A Tattu R-Line, which consists of 4-cell 10,000 mAh battery and a 5 V step-down, will supply the driver motor all onboard components on the robot.

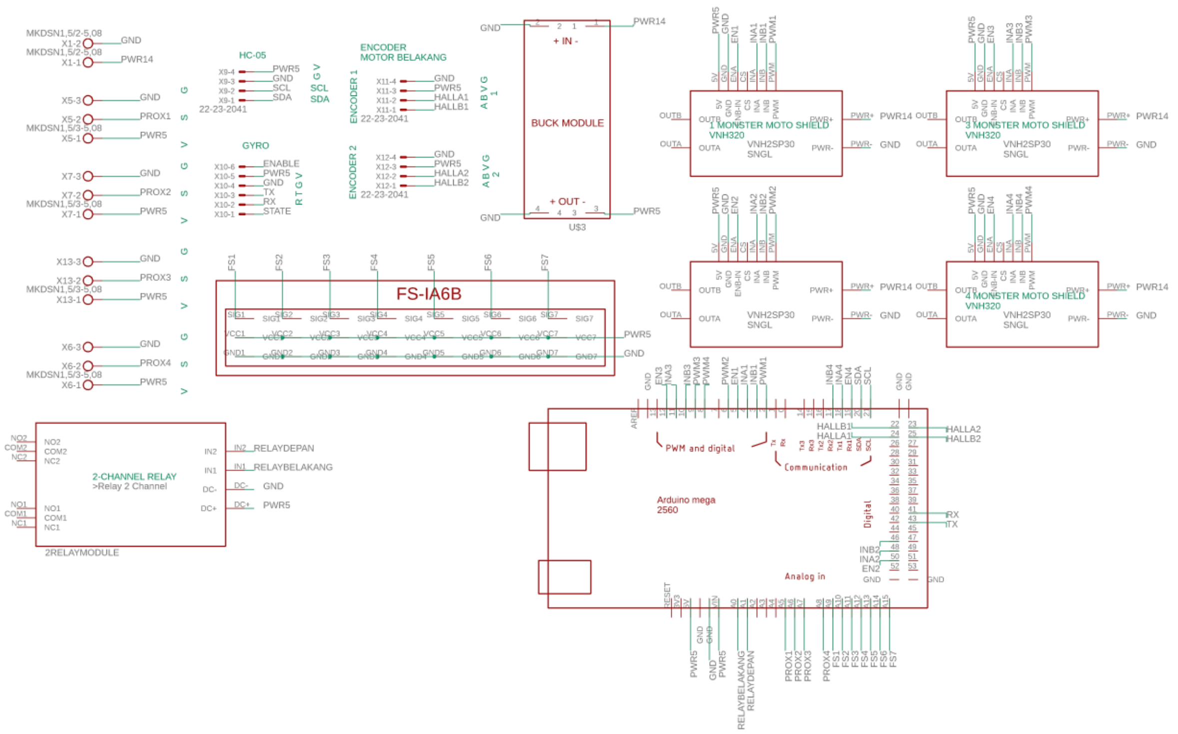


Figure 4. Schematic diagram of the Arvos robot system

Arduino Mega 2,560 is the main controller of all processes in the mobile robot system. It controls the motor drivers, sensory readings, and communication control. The remote controller is used in manual mode by receiving data from the ELRS receiver module. The motor driver is using monster moto shield with type VNH2SP30. This driver is installed for each robot driving motor. A single chip motor driver can be supplied with a maximum voltage of 16 V and a current rating of 30 A. This scheme is very advantagious because the robot uses a 4-cell battery with a maximum voltage of 16.4 V. With a large enough current rating, the driver can drive a PG28 motor smoothly and with high torque.

3.2. Program design

The program embedded in this robotic system is the core of operations. The program was created using the Arduino IDE version 1.18.9. The program shown in Figure 5 runs both autonomous and manual modes. The program will switch to an autonomous maneuver when the user activates the autonomous mode. Data read from the sensors will be used as input feedback on the PID controller, so that the robot stays on its route. In addition, it also reads the proximity data on each corner of the robot frame which is used to detect the edges of the solar panel array. Then manual mode will allow the robot to be controlled wirelessly with the ELRS remote control. The data from the remote control is in the form of a 2.4 GHz signal, which contains the pulse width data generated by the ELRS receiver.

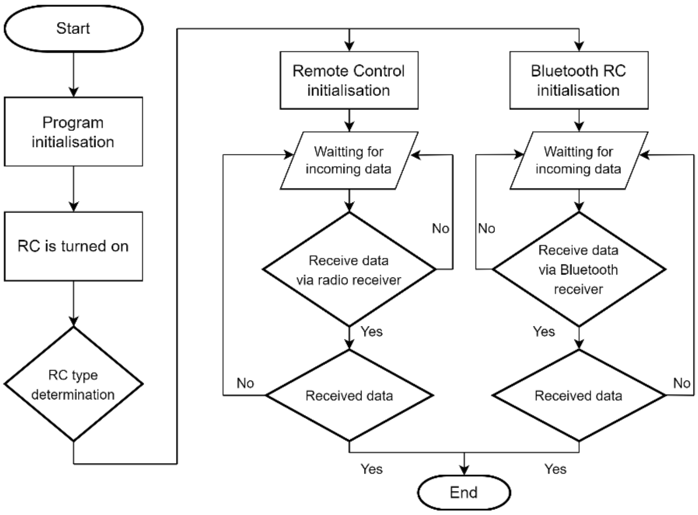


Figure 5. Arvos sender and receiver controller workflow

The remote control generates a signal with a pulse width that varies depending on the position of each channel. Each channel uses the hall sensor output on 2 analog sticks on the remote control. Channel 1, the left analog stick in the up and down position, is used to determine the speed of the robot. Channel 2, the left analog stick in the right and left position, is used for yaw maneuvers. Channel 3, the right analog stick in the up and down position, is used for forward and backward maneuvers. Channel 4, the right-left analog stick, is used for pitch maneuvers. Additionally, serial communication with the Bluetooth module is also used to transmit robot operational data.

3.3. Proportional integral derivative control algorithm

The PID implemented in the program used to manuevering robot over the solar PV array. Figure 6 shows the block diagram of the PID. It uses the reference of yaw position and input feedback from IMU sensor.

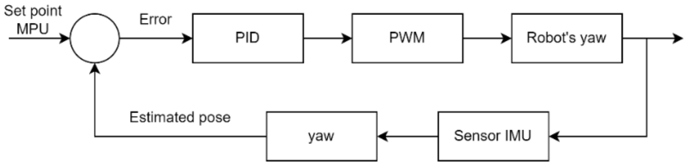


Figure 6. PID block diagram of the mobile robot system

As the robot moving on the top of solar PV array, this PID control will keep the robot stay on the track. PID as a control system that will be implemented on the robot, is used as many as three controllers. PID controller with yaw value input, so that the robot goes straight, and on pitch and roll input to balance the robot's position. The setpoint is 0 because the initial position after calibration is 0. The PID design is based on (1), the value u(t) being the value control that comes from the error value of $e(t)$.

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (1)$$

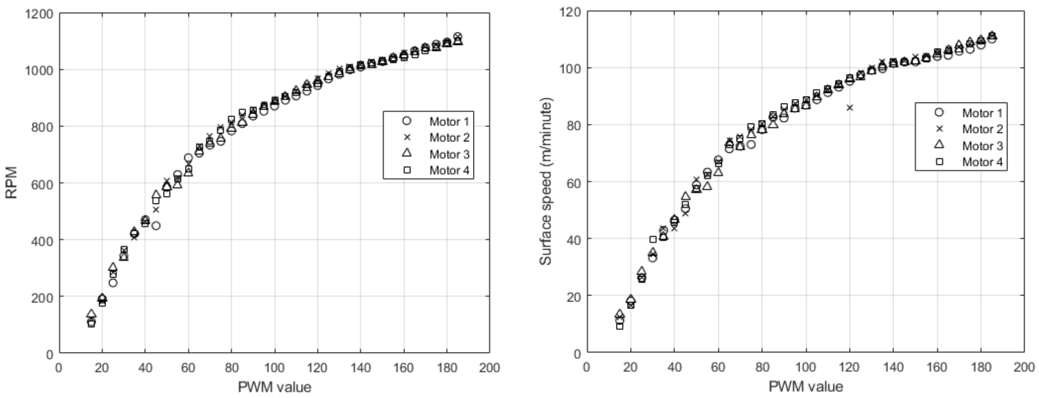
With K_p is proportional constant, K_i is integral constant, and K_d is differential constant.

4. RESULTS AND DISCUSSION

The results of the mobile robot system design used to clean the solar panel array are presented in the robot's maneuver performance and PID control characters. The robot's maneuvering performance is tested to determine how reliably the robot's wheels can move the whole body. The PID control character is also tested to stabilize the robot's movement. The PID character is based on the reading of the IMU sensor to detect the direction of the robot's movement in 3 dimensions. It is also supported by a proximity sensor that detects the edges of the solar panel array to prevent the robot from falling during cleaning operations.

4.1. Drive system

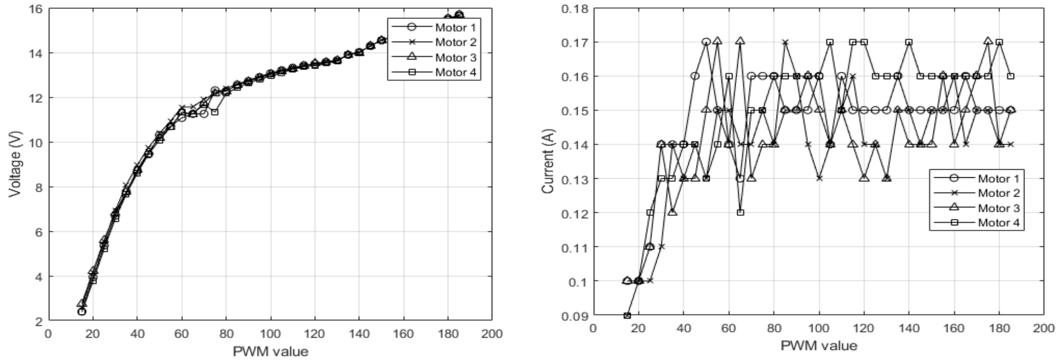
Tests were conducted to determine the performance of the four motors. The performance tested is the change in rotational speed expressed in RPM and surface speed. Surface speed combines a physical quantity and an imperial customary unit. It is defined as the number of linear feet that a location on a rotating component travels in one minute. Figure 7 shows the test with speed measurement considering generating the PWM signal from the microcontroller board. The test is carried out by changing the PWM value from 15 to 185 with an interval of 5. The resulting voltage generation has the same trend as the rotational speed and surface velocity, as shown in Figures 7(a) and (b).



(a) (b)

Figure 7. The 4 motors performance from speed test; (a) PWM vs RPM and (b) PWM vs surface speed

From the test above, it can be seen that the increase in speed on each motor changes directly proportional to the change in the PWM value. The generated PWM value is the same for each pin on the microcontroller board connected to each motor driver. However, from this, it is also seen that the four motor's speed changes are not linear following the PWM changes. From the test, it was found that the level of linearity error for RPM motor 1 is 12.4%, for motor 2 is 11.5%, for motor 3 is 11.7%, and for motor 4 is 12.6%. Motors 1 and 2 are positioned in the same direction, in front of the robot frame. Furthermore, motors 2 and 4 are positioned in the back of the robot. Thus, both motors in the front have the same characteristic. There is also a difference in the speed of each motor driven with the same PWM value. Then it can be calculated that the difference is the standard deviation of each motor to changes in the PWM value, namely 276.6, 275.7, 270.1, and 274.3. Thus, the difference in speed on the same PWM control will result in instability in maneuvering on all four wheels. The testing result shows that the speed of each motor also depends on the voltage driven by each motor driver. Figure 8 shows the voltage in Figure 8(a) and the output current in Figure 8(b) generated by the motor driver at each change in the PWM value.



(a) (b)

Figure 8. The 4 motors respond to each PWM value; (a) supply voltage for motors and (b) supplied current for motors

The response of all motors is highly related to the change in PWM value. PWM value that generates the same for each motor driver gave almost the same response to the motor's voltage. Thus, the response could be more linear. The current supplied for each motor is different from the other. Many fluctuating peaks can make the motor not stabilize.

4.2. Proportional integral derivative control stabilization

A yaw position change detection test is carried out by the IMU before determining the PID control design. This test was conducted to determine the accuracy of yaw position detection. As shown by Table 1, the average error in each test can be used as a reference error in the PID controller.

From the results of the yaw position accuracy test above, it was found that the average error generated by the IMU sensor was 2.5%. Then, testing on a solar PV array with an elevation of 13 degrees, the robot can walk straight following the route at an average speed of 0.43 m/s. Secondly shown in Figure 9, testing the PID value on the yaw axis was carried out with Ziegler-Nichols to get the gain value. Tests on the PID control for the yaw axis has a settling time of 5.72 seconds, rise time of 0.83 seconds, and steady state error of 0.32.

Table 1. Yaw position accuracy test result

Yaw position angle (degree)	IMU yaw output (degree)	Error angle (degree)	Error (%)
-40	-40.8	0.8	2.0
-30	-30.6	0.6	2.0
-20	-20.2	0.2	1.0
-10	-10.7	0.7	6.5
10	10.3	0.3	2.9
20	20.2	0.2	1.0
30	31.2	1.2	3.8
40	40.3	0.3	0.7

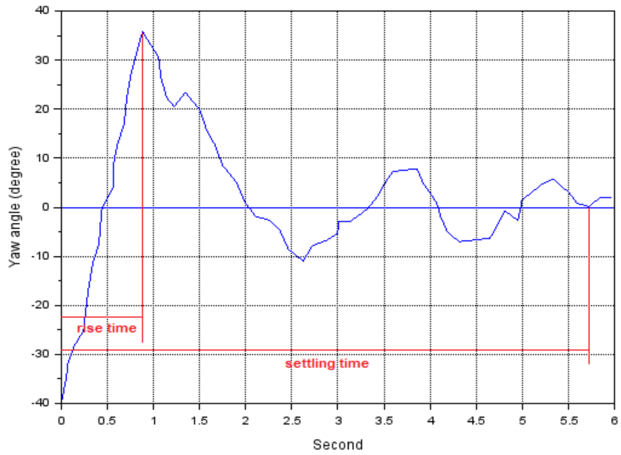


Figure 9. PID control for yaw axis

5. CONCLUSION

With a 56 square meters solar PV array located on the rooftop of Universitas Airlangga (UNAIR) C Kuliah Bersama building floor 10, this robot can clean the entire area in about 13 minutes autonomously. Meanwhile, in manual mode, the cleaning process takes about 20-24 minutes. The mobile robot system is supported by a frame made of aluminium profile and its body made from 2 mm acrylic. The overall body size is 49 cm long and 32 cm wide with 4.8 kg weight. Each motor can run about 1,100 RPM at 15.8 V maximum. Each sweeper roller has a motor that can run 1,000 RPM at 12 V. With 4 cell LiPo battery 10,000 mAh, the mobile robot can operate for about 42 minutes. The maximum elevation of the solar PV array that this robot can handle is 15 degrees. The use of the mecanum wheel on the robot has the advantage that the robot can maneuver 6 DOF, the robot can move back and forth, swipe right and left without spending space and time to turn. However, the drawback of using a mecanum wheel is that it is easy to slip, especially on slippery solar panel surfaces. On the other hand, PID control test shows that the robot can stabilize it self in about 5.72 seconds to keep on the track. In conclusion, this robot's use has proven to be more effective in helping solar PV system operators clean solar PV arrays from dirt and dust. These robots can contribute to more efficient use of energy, time, and maintenance costs of solar power systems.

ACKNOWLEDGEMENTS

The authors would like to thank the Faculty of Advanced Technology and Multidiscipline, Airlangga University for providing this assignment research grant and LPPM Universitas Airlangga for the commitment to the program. We also thank all colleagues and students of the research center for new and renewable energy, Faculty of Advanced Technology and Multidiscipline, Airlangga University for their support of this research.

REFERENCES

[1] C. M. M. Rocha, C. M. Batista, W. F. A. Rodríguez, A. J. F. Ballesteros, and J. R. N. Álvarez, “Challenges and perspectives of the use of photovoltaic solar energy in Colombia,” *Int. J. Electr. Comput. Eng.*, vol. 12, no. 5, pp. 4521–4528, Oct. 2022, doi: 10.11591/ijece.v12i5.pp4521-4528.

[2] P. Megantoro, P. Anugrah, Y. Afif, L. J. Awalin, and P. Vigneshwaran, “A practical method to design the solar photovoltaic system applied on residential building in Indonesia,” *Indones. J. Electr. Eng. Comput. Sci.*, vol. 23, no. 3, pp. 1736–1747, 2021, doi: 10.11591/ijeecs.v23.i3.pp1736-1747.

[3] J. Bei and C. Wang, “Renewable energy resources and sustainable development goals : Evidence based on green finance, clean energy and environmentally friendly investment,” *Resour. Policy*, vol. 80, no. November 2022, p. 103194, 2023, doi: 10.1016/j.resourpol.2022.103194.

[4] B. Yu and Y. Jung, “Performance analysis of a residential photovoltaic string under partial shading,” *International Journal of Electrical and Computer Engineering*, vol. 13, no. 1, pp. 85-93, 2023, doi: 10.11591/ijece.v13i1.pp85-93.

[5] M. J. Adinoyi and S. A. M. Said, “Effect of dust accumulation on the power outputs of solar photovoltaic modules,” *Renew. Energy*, vol. 60, pp. 633–636, 2013, doi: 10.1016/j.renene.2013.06.014.

[6] E. M. H. Arif, J. Hossen, G. Ramana Murthy, M. Z. H. Jesmeen, and J. Emerson Raja, “An efficient microcontroller based sun tracker control for solar cell systems,” *International Journal of Electrical and Computer Engineering*, vol. 9, no. 4, pp. 2743–2750, 2019, doi: 10.11591/ijece.v9i4.pp2743-2750.

[7] B. Fatima, C. Mama, and B. Benaissa, “Design methodology of smart photovoltaic plant,” *International Journal of Electrical and Computer Engineering*, vol. 11, no. 6, pp. 4718–4730, 2021, doi: 10.11591/ijece.v11i6.pp4718-4730.

[8] D. Deb and N. L. Brahmbhatt, “Review of yield increase of solar panels through soiling prevention, and a proposed water-free automated cleaning solution,” *Renew. Sustain. Energy Rev.*, vol. 82, pp. 3306–3313, 2018, doi: 10.1016/j.rser.2017.10.014.

[9] P. Megantoro, M. A. Syahbani, I. H. Sukmawan, and S. D. Perkasa, “Effect of peak sun hour on energy productivity of solar photovoltaic power system,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 5, pp. 2442–2449, 2022, doi: 10.11591/eei.v11i5.3962.

[10] N. Ronnaronglit and N. Maneerat, “A cleaning robot for solar panels,” *Proceeding - 5th Int. Conf. Eng. Appl. Sci. Technol. ICEAST 2019*, pp. 0–3, 2019, doi: 10.1109/ICEAST.2019.8802521.

[11] B. Parrott, P. C. Zanini, A. Shehri, K. Kotsovos, and I. Gereige, “Automated, robotic dry-cleaning of solar panels in Thuwal, Saudi Arabia using a silicone rubber brush,” *Sol. Energy*, vol. 171, pp. 526–533, 2018, doi: 10.1016/j.solener.2018.06.104.

[12] S. Mousavi and G. Farahani, “Introducing a new method of automatic cleaning of the PV array surface using a suction robot,” *Mechatronics*, vol. 85, no. May, p. 102845, 2022, doi: 10.1016/j.mechatronics.2022.102845.

[13] S. Fan, W. Liang, G. Wang, Y. Zhang, and S. Cao, “A novel water-free cleaning robot for dust removal from distributed photovoltaic (PV) in water-scarce areas,” *Sol. Energy*, vol. 241, no. February, pp. 553–563, 2022, doi: 10.1016/j.solener.2022.06.024.

[14] M. G. Antonelli, P. Beomonte Zobel, A. De Marcellis, and E. Palange, “Autonomous robot for cleaning photovoltaic panels in desert zones,” *Mechatronics*, vol. 68, Feb. 2020, doi: 10.1016/j.mechatronics.2020.102372.

[15] N. E. Budiyanta, L. Wijayanti, W. W. Basuki, H. Tanudjaja, and V. Budi Kartadinata, “The development of healthcare mobile robot for helping medical personnel in dealing with COVID-19 patients,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 22, no. 3, pp. 1379–1388, 2021, doi: 10.11591/ijeecs.v22.i3.pp1379-1388.

[16] Y.-H. Han and B.-K. Cho, “Slope walking of humanoid robot without IMU sensor on an unknown slope,” *Rob. Auton. Syst.*, vol. 155, Sep. 2022, doi: 10.1016/j.robot.2022.104163.

[17] J. G. Victores, S. Martínez, A. Jardón, and C. Balaguer, “Robot-aided tunnel inspection and maintenance system by vision and proximity sensor integration,” *Autom. Constr.*, vol. 20, no. 5, pp. 629–636, 2011, doi: 10.1016/j.autcon.2010.12.005.

[18] R. T. Yunardi, D. Arifianto, F. Bachtiar, and J. I. Prananingrum, “Holonomic Implementation of Three Wheels Omnidirectional Mobile Robot using DC Motors,” *J. Robot. Control*, vol. 2, no. 2, 2021, doi: 10.18196/jrc.2254.

[19] P. Megantoro, H. Setiadi, and B. A. Pramudita, “All-terrain mobile robot disinfectant sprayer to decrease the spread of COVID-19

in open area," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 3, pp. 2090–2100, 2021, doi: 10.11591/ijece.v11i3.pp2090-2100.
[20] A. Hassan *et al.*, "A Wirelessly Controlled Robot-based Smart Irrigation System by Exploiting Arduino," *J. Robot. Control*, vol. 2, no. 1, pp. 29–34, 2020, doi: 10.18196/jrc.2148.
[21] A. Murad, O. Bayat, and H. M. Marhoon, "Implementation of rover tank firefighting robot for closed areas based on arduino microcontroller," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 21, no. 1, pp. 56–63, 2021, doi: 10.11591/ijeecs.v21.i1.pp56-63.
[22] K. Kunal, A. Z. Arfianto, J. E. Poetro, F. Waseel, and R. A. Atmoko, "Accelerometer Implementation as Feedback on 5 Degree of Freedom Arm Robot," *J. Robot. Control*, vol. 1, no. 1, pp. 31–34, 2020, doi: 10.18196/jrc.1107.
[23] B. R. Yenugula and M. Zia-ur-Rahman, "Stability control structure of hovercraft prototype utilising PID controller," *Bulletin of Electrical Engineering and Informatics*, vol. 6, no. 4, pp. 348–350, 2017, doi: 10.11591/eei.v6i4.864.
[24] Lasmadi, A. Cahyadi, S. Herdjunanto, and R. Hidayat, "Inertial navigation for quadrotor using kalman filter with drift compensation," *International Journal of Electrical and Computer Engineering*, vol. 7, no. 5, pp. 2596–2604, 2017, doi: 10.11591/ijece.v7i5.pp2596-2604.
[25] B. A. Tawfeeq, M. Y. Salloom, and A. Alkamachi, "A self-balancing platform on a mobile car," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 6, pp. 5911–5922, 2022, doi: 10.11591/ijece.v12i6.pp5911-5922.
[26] G. H. Merabet *et al.*, "Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques," *Renew. Sustain. Energy Rev.*, vol. 144, no. March, p. 110969, 2021, doi: 10.1016/j.rser.2021.110969.
[27] B. Dahmane, B. Lejdel, E. Clementini, F. Harrats, S. Nassar, and L. H. Abderrahmane, "Controlling the degree of observability in GPS/INS integration land-vehicle navigation based on extended kalman filter," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 2, pp. 702–712, 2022, doi: 10.11591/eei.v11i2.3695.

BIOGRAPHIES OF AUTHORS

Prisma Megantoro is a lecturer in Electrical Engineering, at the Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga since 2020. He received his bachelor degree and master's degree from Universitas Gadjah Mada, Yogyakarta, Indonesia in 2014 and 2018. His current research is focused on solar photovoltaic technology, embedded system, and the internet of things. He can be contacted at email: prisma.megantoro@ftmm.unair.ac.id.

Abdul Abror was born in 10 october 2002. After graduating from high school, he choosed to continued his studied at Airlangga University majoring In Electrical Engineering in 2020. Now he is active in the robotics community of the soccer robot division, mikrotik networking community, cisco networking community and also, he is active in the instrumentation research group. He can be contacted at email: abdul.abror-2020@ftmm.unair.ac.id.

Muhammad Akbar Syahbani was born in Nusa Tenggara Barat, Indonesia in 2001, after graduating from high school, he continued his studies in Electrical Engineering at the Universitas Airlangga in 2020. Now he is actively researching renewable energy at Universitas Airlangga Research Community. He can be contacted at email: muhammad.akbar.syahbani-2020@ftmm.unair.ac.id.

Antik Widi Anugrah was born in Madiun, Indonesia in 2002, after graduating from high school, her continued studies in electrical engineering at the Universitas Airlangga in 2021. Now she is actively researching renewable energy at Universitas Airlangga Research Community. She can be contacted at email: antik.widi.anugrah-2021@ftmm.unair.ac.id.

Sigit Dani Perkasa is a sixth semester undergraduate student majoring in electrical engineering at Universitas Airlangga. He is active in the research of renewable energy, instrumentation, and microcontroller system as a part of Universitas Airlangga's Research Centre for New and Renewable Energy Engineering (RCNREE). He can be contacted at email: sigit.dani.perkasa-2020@ftmm.unair.ac.id.

Herlambang Setiadi is a lecturer in Universitas Airlangga since 2019. He received a bachelor's degree in Electrical Engineering from the Institute Teknologi Sepuluh Nopember, Surabaya, Indonesia. A master's degree from Liverpool University, United Kingdom, and a doctoral degree from the University of Queensland, Australia. His research interest includes small signal stability in power systems, renewable energy integration, control system engineering, and metaheuristic algorithm. He can be contacted at email: h.setiadi@ftmm.unair.ac.id.

Lilik Jamilatul Awalin was born in East Java, Indonesia, in 1977. She received the Bachelor of Engineering degree in Electrical Engineering in 1999 from the University of Widya Gama, Master of Engineering. degree in 2004 from the Institut Teknologi Sepuluh Nopember, Indonesia and Ph.D. degree in 2014 from University of Malaya. She was a senior lecturer in International College of UKL, Malaysia from 2015 to 2020. Currently, she is head of section in Airlangga University, Indonesia. She can be contacted at email: lilik.j.a@ftmm.unair.ac.id.

Pandi Vigneshwaran has obtained his doctoral degree in Anna University Chennai during 2016 and Master of Engineering under Anna University Chennai during June 2005. He is having 18.4 years of experience and specialization in cybersecurity. Presently, he is working as Associate Professor in SRM Institute of Science and Technology, Chennai. His area of interest includes security, routing, and intelligent data analysis. He can be contacted at email: vigenesp@srmist.edu.in.