International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Check for updates

Design and practical implementation of a ball on plate system with two PD controllers

Mehmet Karahan *

Department of Electrical and Electronics Engineering, Faculty of Engineering, TOBB University of Economics and Technology, Ankara, Turkey.

International Journal of Science and Research Archive, 2025, 16(01), 1575-1583

Publication history: Received on 11 June 2025; revised on 19 July 2025; accepted on 21 July 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.16.1.2169

Abstract

Ball stabilization control system is an important control problem in undergraduate and graduate education. Practical applications are carried out in control system laboratories on this subject. Students develop projects with a multidisciplinary approach using their control systems knowledge, software knowledge, design knowledge, and using equipment such as DC motors and microprocessors. The problem of keeping the ball balanced is a control problem that is handled in two different ways. The ball and beam and the ball on plate systems stand out in this regard. However, in many studies, the ball on beam system is preferred because it is easier. In these systems, the ball is controlled only on the vertical axis. In these systems, a single PID controller and a single servo motor are preferred. In the ball on plate control system proposed in this study, the ball's movement in both the x and y axes is controlled. The system is both designed using MATLAB software and its practical application is carried out. 2 PD controllers and two servo motors are used to provide more precise and faster control of the ball. In addition, an LCD screen is used to show the instantaneous position of the ball on the x and y axes. Thus, a better design is obtained than standard ball on beam systems.

Keywords: Ball on plate; Kinematic; Modeling; PD control; Servo motor

1. Introduction

In control systems education, inverted pendulum control, two tank system control, and ball on beam control are important practical control problem applications [1]-[3]. Thus, students have the opportunity to reinforce their theoretical knowledge with experiments and practical applications. In addition, while performing these practical applications, they perform a multidisciplinary study by using their theoretical control systems knowledge together with Arduino programming, servo motor and battery usage, and design skills [4]-[7].

The ball and beam is a widely applied system both theoretically and practically. In this system, control of the ball on the beam in the vertical axis is carried out. In general, practical application is carried out with a single PID controller and a single servo motor. The ball and beam is a single-degree-of-freedom system and is cost-effective.

Ahmad et al. designed a cost-effective ball and beam with one PID controller, a servo motor, an ultrasonic distance sensor, and an Arduino microcontroller [8]. Maalini et al. developed a ball and beam, and they controlled the beam angle with one servo motor. They selected the PID controller parameters with the PID tuner algorithm of MATLAB [9]. Yao et al. used a visual sensor and an LQR controller to stabilize the ball and beam. They also created a practical implementation and designed some experiments [10]. Srivastava et al. used a PID controller to stabilize the position of the ball and beam angle. They tested different PID tuning algorithms and compared their mean square error values to obtain the best results [11]. Zaare et al. developed a state disturbance observer-based adaptive sliding mode controller to control the position of the ball under uncertainties [12]. Blake et al. designed a 3D printed ball and beam and used a PID controller to control beam angle and position and speed of the ball. They used reinforcement learning to tune the

* Corresponding author: Mehmet Karahan.

gains of the PID controller [13]. Zafar et al. proposed two different control strategies for a ball and beam system. Their first control strategy used a PIDD2-PI controller, and their second control strategy used a tilt integral derivative with a filter. They tested these strategies with the MATLAB program and compared the obtained results [14]. Chaturvedi et al. proposed a cascade PID control method for the ball and beam system. They used a teaching–learning–based optimization method to control the position of the ball [15]. Some researchers have designed a ball on plate system using a small plate and a single controller. Bang et al. designed a system with a smaller plate and controlled by a single sliding mode controller to control the ball on plate [16]. Kumar et al. designed a ball on plate system using a single servo motor and 2 PID controllers. Due to the use of a single servo motor, this system showed a high oscillation, and it took a long time for the ball to reach the balance point [17].

In this study, modeling and experimentation of a ball on plate system were carried out. The aim of the developed ball on plate system is to control the ball in the x and y axes. In this research, more sensitive and faster control was achieved by using two PD controllers. Modeling of the system was carried out with MATLAB software. In addition, a practical application was carried out. Unlike studies using plastic and wooden plates, the current position of the ball was tracked much more precisely by using a resistive touch panel, and it was ensured that it reached the balance point more quickly. Arduino microprocessor, resistive panel, battery, servo motors, and LCD screen with Bluetooth module were used in the practical application. With the Bluetooth module of the LCD screen, the position of the ball in the x and y axes is taken instantly and shown on the screen.

2. Method

The purpose of the ball on plate system is to bring a ball placed at a random location on the plate to the center point. In this section, mathematical equations related to the system are given. The parameters of the proposed system are given in Table 1.

Table 1 The parameters of the system

Variable	Definition	Value
m_b	mass of the ball	33 g
g	gravity	9.81 m/s^2
r_b	radius of the ball	20 mm
J_b	inertial moment	1.32x10^{-5}
r_{arm}	radius of the servo arm	0.025 m
L_{plate}	length of the plate	386 mm
T_s	sampling period	10 s

The nonlinear motion equation of the system is presented in (1).

$$\ddot{x}(t) = \frac{m_b g sin\alpha(t) r_b^2}{m_b r_b^2 + J_b} \qquad (1)$$

In cases where θ angle is small, sin (θ) = θ can be accepted [18]-[19]. When (1) is linearized with the small angle approximation, (2) is obtained.

$$\ddot{x}(t) = \frac{2 m_b g r_{arm} r_b^2}{L_{plate}(m_b r_b^2 + J_b)} \theta_l(t) \qquad (2)$$

After applying the Laplace transform to (2), (3) is obtained.

$$\frac{x(s)}{\theta(s)} = \frac{2 m_b g r_{arm} r_b^2}{L_{plate}(m_b r_b^2 + J_b) s^2} \qquad (3)$$

Damping ratio is given in (4). OS represents overshoot.

$$\zeta = \frac{-\ln(\%\frac{OS}{100})}{(\pi^2+ln^2(\frac{OS}{100}))^{1/2}} \quad (4)$$

Natural frequency equation is represented in (5).

$$w_n = \frac{4}{\zeta T_s} \quad (5)$$

In many studies, PID controller is preferred due to its easy adjustment, simple structure and its widespread use [20]-[25]. In this study, PD controller is used. With the above equations, the k_p and k_d gains of the PD controller can be calculated. These gains are shown in (6) and (7), respectively.

$$k_p = w_n^2 \frac{L_{plate}(m_b+r_b^2+J_b)}{m_b g r_{arm} r_b^2} \quad (6)$$

$$k_d = \zeta w_n \frac{L_{plate}(m_b+r_b^2+J_b)}{m_b g r_{arm} r_b^2} \quad (7)$$

The values of the PD controllers used in the simulations are given in Table 2. The same values were used for both controllers. The values of the PD controllers were determined manually by trial and error.

Table 2 PD Control Parameters

K_p	K_d
1	1

The schematic representation of the employed ball on plate from the top and side is as in Figure 1.

(a) (b)

Figure 1 Schematic representations of ball on plate (a) top view of the ball on plate system and (b) side view of the ball on plate system

3. Results and discussion

The results obtained in this research are examined under two subheadings. The simulations section includes simulations made using MATLAB software. The practical application section includes the practical application of the ball on plate.

3.1. Simulations

Simulations were performed using MATLAB. The simulations show how long it takes for a ball released at any point on the plate to reach the equilibrium point (0, 0). The goal in the simulations is to bring the ball to the (0, 0) point in less than 10 seconds. In addition, the ball's trajectory on the x and y axes is shown in simulations. In simulations, x and y lengths are in meters, and time is in seconds. The ball was released from x = 0.09 m and y = 0.05 m in the first simulation. PD controllers were able to bring the ball to the equilibrium point in a short time. Figure 1 shows how long it takes for a ball released from a certain x and y point to reach the equilibrium point.

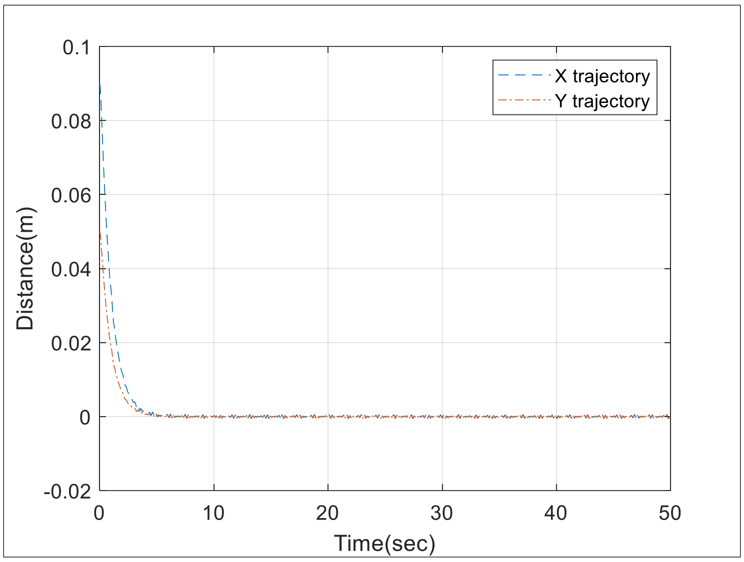

Figure 2 Position with time simulation for x = 0.09m, y = 0.05 m

Figure 3 shows the distance traveled on the x-axis and y-axis until the ball reaches the balance point.

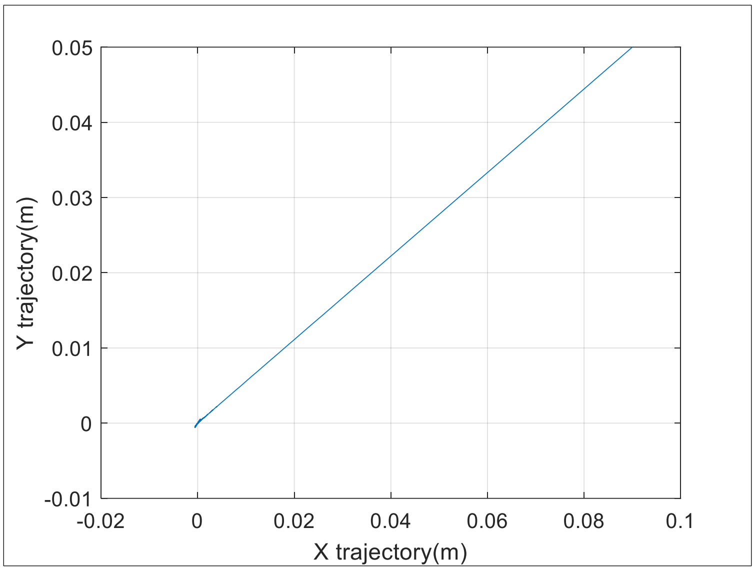

Figure 3 Trajectory graph for x = 0.09, y = 0.05 values

As seen from the simulation results, the ball dropped on the resistive panel reaches the balance point in less than 5 seconds.

Secondly, the ball was placed at x = 0.15 m, y = 0.08 m. The ball on plate system again managed to bring the ball to the balance point in less than 5 seconds. Figure 4 shows how many seconds it took for the ball placed at x = 0.15 m, y = 0.08 m to reach the balance point of (0, 0).

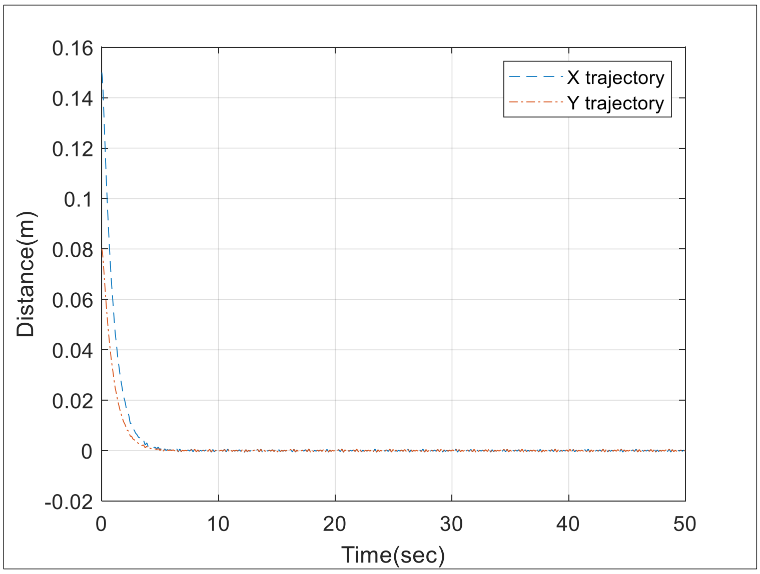

Figure 4 Position with time simulation for x = 0.15 m, y = 0.08 m

Figure 5 shows the trajectory of the ball released from x= 0.15 m, y= 0.08 m on the x and y axes until it reaches the balance point.

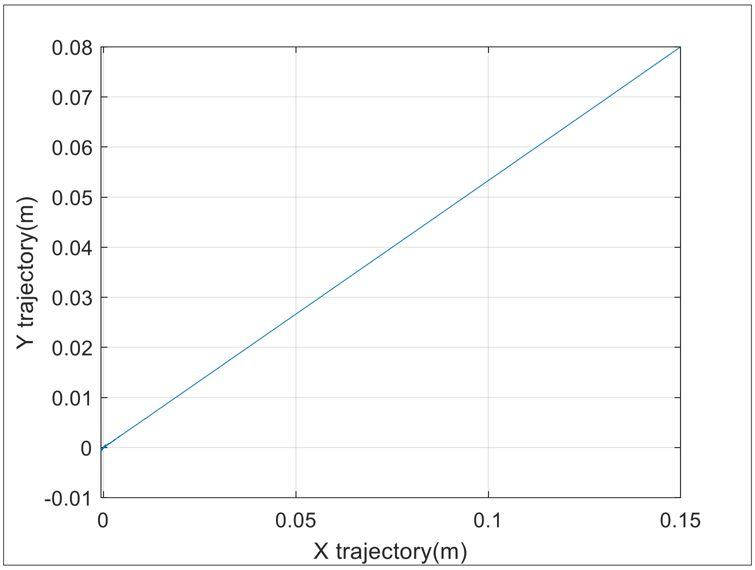

Figure 5 Trajectory graph for x = 0.15, y = 0.08 values

The simulation results show that even if the ball is released from different points, the system can reach the balance point in less than 5 seconds. In this case, the target of reaching the balance point before 10 seconds, as determined in the study, was successfully achieved.

3.2. Practical Implementation

In this section, the practical application of the ball on plate was carried out. The findings obtained from simulation results were confirmed with the experimental results. The list of materials used in the development of the practical application is shown in Table 3.

Table 3 The materials of the project

Material	Specification	Quantity
Resistive panel	GreenTouch 19-inch panel	1
Controller	Arduino uno	2
Servo motor	MG 995 180°	2
Bluetooth module	HC-06 Receiver, HC-05 Transmitter	2
LCD screen	16x2 character LCD	1
Power supply	9 V Li-ion Battery	1
Ball	AISI 52100 steel ball	1

A resistive touch panel was used to accurately detect the instantaneous position of the ball [26]. The MG995 servo motor was preferred due to its ability to rotate 180 degrees, operate continuously, and be cost-effective [27]. HC-06 Receiver and HC-05 Transmitter Bluetooth modules were preferred due to their compatibility with Arduino [28]. The appearance of the assembled system is given in Figure 6.

(a) (b)

Figure 6 The appearance of the assembled system (a) ball on plate (b) resistive panel

The LCD screen that instantly shows the x, y position of the ball is presented in Figure 7.

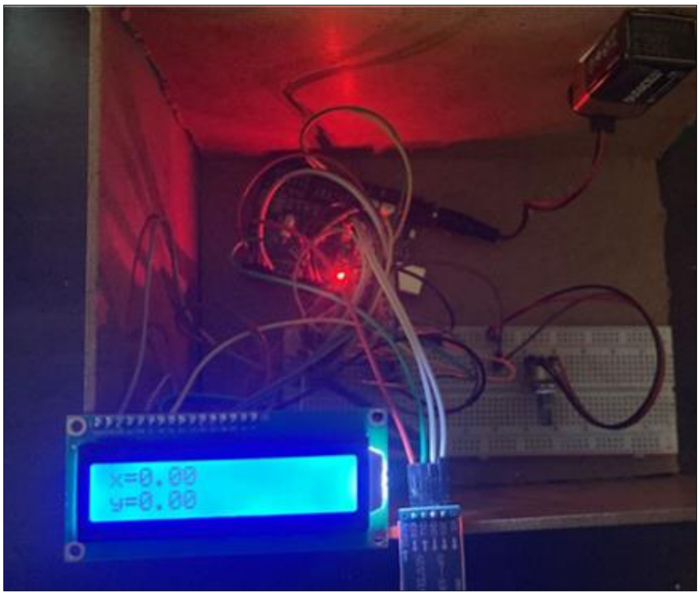

Figure 7 LCD screen

4. Conclusion

In this study, a ball on plate system controlled by 2 PD controllers was modeled, simulations were made using MATLAB and a practical application was carried out. Simulations were performed by placing the ball at different points on the x-axis and the axes. The ball dropped on the resistive panel was able to reach the (0, 0) point, which is the balance point, in less than 10 seconds. The results obtained with the simulations were verified in the practical application. The instantaneous position of the ball was shown on the LCD screen. The platform with 2 servo motors, 2 PD controllers, and a resistive panel showed very good performance. In future studies, experiments will be carried out using different types of controllers.

Compliance with ethical standards

Disclosure of conflict of interest

Author states no conflict of interest.

Funding information

Author states no funding involved.

References

[1] İ. Şahin and C. Ulu, "Control of Inverted Pendulum System with Single Input Interval Type-2 Fuzzy PD Controllers," 2023 Innovations in Intelligent Systems and Applications Conference (ASYU), Sivas, Turkiye, 2023, pp. 1-5, doi: 10.1109/ASYU58738.2023.10296815.

[2] T. T. Huong et al., "Federated Learning-Based Explainable Anomaly Detection for Industrial Control Systems," in IEEE Access, vol. 10, pp. 53854-53872, 2022, doi: 10.1109/ACCESS.2022.3173288.

[3] N. Vreman, C. Mandrioli and A. Cervin, "Deadline-Miss-Adaptive Controller Implementation for Real-Time Control Systems," 2022 IEEE 28th Real-Time and Embedded Technology and Applications Symposium (RTAS), Milano, Italy, 2022, pp. 13-26, doi: 10.1109/RTAS54340.2022.00010.

[4] Y. Ueyama, T. Sago, T. Kurihara and M. Harada, "An Inexpensive Autonomous Mobile Robot for Undergraduate Education: Integration of Arduino and Hokuyo Laser Range Finders," in IEEE Access, vol. 10, pp. 79029-79040, 2022, doi: 10.1109/ACCESS.2022.3194162.

[5] D. Loukatos, M. Kondoyanni, I.-V. Kyrtopoulos and K.G. Arvanitis, "Enhanced Robots as Tools for Assisting Agricultural Engineering Students' Development," Electronics, vol. 11, pp. 755, 2022.

[6] [6] M. Rossi et al., Introduction to Microcontroller Programming for Power Electronics Control Applications: Coding with MATLAB® and Simulink®, CRC Press, 2021.

[7] M. C. Rodriguez-Sanchez, A. Torrado-Carvajal, J. Vaquero, S. Borromeo and J. A. Hernandez-Tamames, "An Embedded Systems Course for Engineering Students Using Open-Source Platforms in Wireless Scenarios," in IEEE Transactions on Education, vol. 59, no. 4, pp. 248-254, Nov. 2016, doi: 10.1109/TE.2016.2526676

[8] B. Ahmad and I. Hussain, "Design and hardware implementation of ball and beam setup," 2017 Fifth International Conference on Aerospace Science and Engineering (ICASE), Islamabad, Pakistan, 2017, pp. 1-6, doi: 10.1109/ICASE.2017.8374271.

[9] P. V. M. Maalini, G. Prabhakar and S. Selvaperumal, "Modelling and control of ball and beam system using PID controller," 2016 International Conference on Advanced Communication Control and Computing Technologies (ICACCCT), Ramanathapuram, India, 2016, pp. 322-326, doi: 10.1109/ICACCCT.2016.7831655.

[10] S. Yao, X. Liu, Y. Zhang and Z. Cui, "Research on solving nonlinear problem of ball and beam system by introducing detail-reward function," Symmetry, vol. 14, no. 9, pp. 1883, Sep. 2022

[11] V. Srivastava, S. Srivastava, H. Malik, G. Chaudhary and S. Srivastava, "Hybrid optimization based PID control of ball and beam system," J. Intell. Fuzzy Syst., vol. 42, no. 2, pp. 919-928, Jan. 2022.

[12] S. Zaare and M. R. Soltanpour, "The position control of the ball and beam system using state-disturbance observe-based adaptive fuzzy sliding mode control in presence of matched and mismatched uncertainties," Mech. Syst. Signal Process., vol. 150, Mar. 2021.

[13] X. J. Blake and N. Aphiratsakun, "Reinforcement Learning for PID Gain Tuning in Ball-and-Beam Systems: A Comparative Study," 2024 1st International Conference on Robotics, Engineering, Science, and Technology (RESTCON), Pattaya, Thailand, 2024, pp. 187-190, doi: 10.1109/RESTCON60981.2024.10463594.

[14] F. Zafar, S. A. Malik, T. Ali, A. Daraz, A. R. Afzal, F. Bhatti, I. A. Khan, "Stabilization and tracking control of underactuated ball and beam system using metaheuristic optimization based TID-F and PIDD2–PI control schemes," Plos One vol. 19, no. 2, e0298624 2024.

[15] S.Chaturvedi, N. Kumar, R. Kumar, "Two feedback PID controllers tuned with teaching–learning-based optimization algorithm for ball and beam system," IETE J. Res. vol. 70, no. 7, pp. 6340-6349, 2023. doi: 10.1080/03772063.2023.2284955

[16] H. Bang and Y. S. Lee, "Implementation of a Ball and Plate Control System Using Sliding Mode Control," in IEEE Access, vol. 6, pp. 32401-32408, 2018, doi: 10.1109/ACCESS.2018.2838544.

[17] G. J. R. Kumar, N. Showme, M. Aravind and R. Akshay, "Design and control of ball on plate system," Int. J. Control Theory Appl., vol. 9, no. 34, pp. 765-778, 2016.

[18] M. Karahan, "Nonlinear Modelling and Robust Backstepping Control of a Quadcopter in Aggressive Maneuvering", Studies in Informatics and Control, vol. 33(3), pp. 29-38, 2024. https://doi.org/10.24846/v33i3y202403

[19] M. Karahan, C. Kasnakoglu, A. N. Akay, "Robust Backstepping Control of a Quadrotor UAV Under Pink Noise and Sinusoidal Disturbance", Studies in Informatics and Control, vol. 32(2), pp. 15-24, 2023. https://doi.org/10.24846/v32i2y202302

[20] V Dubey, H Goud and P C. Sharma, "Role of PID control techniques in process control system: a review," Data Engineering for Smart Systems: Proceedings of SSIC 2021, pp. 659-670, 2022.

[21] J. D. Rojas, O. Arrieta and R. Vilanova, Industrial PID Controller Tuning: With a Multiobjective Framework Using MATLAB (R), Cham, Switzerland:Springer, 2022.

[22] U. M. Nath, C. Dey and R. K. Mudi, "Review on IMC-based PID controller design approach with experimental validations," IETE J. Res., vol. 69, no. 3, pp. 1640-1660, Apr. 2023.

[23] M. Karahan and C. Kasnakoglu, "Stability Analysis and Optimum Controller Design for an Inverted Pendulum on Cart System," 2022 International Conference on Smart Information Systems and Technologies (SIST), Nur-Sultan, Kazakhstan, 2022, pp. 1-4, doi: 10.1109/SIST54437.2022.9945731.

[24] M. Karahan, "Reinforcement Learning and PD Control Based Trajectory Tracking for a Quadcopter UAV," Journal of Computer Science and Technology Studies, 6(4), pp. 131-141, 2024. doi:10.32996/jcsts.2024.6.4.15.

[25] M. Karahan, "Modeling of a DC Motor and Position Angle Control Using Optimized PID Controller," 2024 11th International Conference on Electrical and Electronics Engineering (ICEEE), Marmaris, Turkiye, 2024, pp. 107-110, doi: 10.1109/ICEEE62185.2024.10779219.

[26] M. M. Kopichev, A. V. Putov and A. N. Pashenko, "Ball on the plate balancing control system", IOP Conf. Ser. Mater. Sci. Eng., vol. 638, no. 1, 2019.

[27] T. H. Nasution, Fahmi and M. R. Syahputra, "Design of Automatic Doors for Ultraviolet Sterile Box," 2022 6th International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM), Medan, Indonesia, 2022, pp. 190-195, doi: 10.1109/ELTICOM57747.2022.10038025.

[28] R. Thomas, J. George, A. S, K. S. Sarathkumar and S. Prasad, "Spyonian 300 6WD-the dark spy worker voice-controlled robot using arduino," International Conference on Communication, Embedded-VLSI Systems for Electric Vehicle (ICCEVE 2023), Hybrid Conference, Kottayam, India, 2023, pp. 79-82, doi: 10.1049/icp.2023.1424.