Propeller Pendulum Control by Matlab Simulink

Omar Salem, Ameen Hasan, Neal zain Edden, Saif Zedan, Muhammad Dradi, Samer Alsadi, Tareq Foqha, and Ayman Amer

Abstract In this project, A PID controller is proposed to control the angle of simple pendulum based on brushless motor propeller. MATLAB Simulink with Arduino hardware package is used to control the pendulum angle via Arduino Mega development board. This Arduino used to control the pendulum angle by controlling the speed of dc brushless motor. The result is reached, which is to maintain equilibrium on definite angle regardless of the external forces affecting the motor speed. A certain value of the angle is entered through the MATLAB simulink software, which is shown on the real model with the greatest accuracy through the rotation of the motor at a certain speed.

Keywords PID controller · Pendulum control · Matlab

1 Introduction

The pendulum is a well-known control problem that remains relevant today in various practical applications. Its purpose is to stabilize a machine's base using a pendulum system, which is relatively easy to understand, analyze and design through mathematical modeling and appropriate controller design. This project aims to investigate the properties of an "aeropendulum," which is a simplified version of a pendulum

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consisting of a brushless DC motor with a propeller attached to the end of a string. The aeropendulum differs from a traditional pendulum in that it has a motorized propeller at the end that can raise the pendulum to a certain angle [1].

Also, the equilibrium in the pendulum when the pendulum moves in a vertical position, its stability requires the use of a powerful control technology that is able to deal with the rapid dynamics of the system based on the desired angle, through the angle the motor will work at a certain speed to maintain balance.

The motor takes orders from the controller based on the angle, and it works at some speed to get the desired angle, and regardless of the external forces, the motor will continue to rotate at a constant speed, which leads to the stability of the angle unless the required angle is changed. In this study, the Matlab software is used to control the pendulum motion. By doing this, it is easier to understand the control system. A pendulum motion is a kind of second-degree ordinary differential equation.

The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

$$F = \frac{m}{a} \tag{1}$$

The law states that unbalanced forces cause objects to accelerate with an acceleration that is directly proportional to the net force and inversely proportional to the mass [2].

$$\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} + \frac{b}{m}\frac{(\mathrm{d}\theta)}{\mathrm{d}t} + \frac{g}{L}\sin\theta = 0 \tag{2}$$

The purpose of the simple pendulum system is to provide an illustration of how to create a model for a rotational mechanical system. This involves discussing the relevant theory of modeling and identifying the appropriate simplifying assumptions for this particular system. In addition, an experiment is conducted to showcase how various aspects of the physical system can be identified and to demonstrate the precision of the resulting model.

Author in [2], used the PID controller with optimal calculation to obtain the parameters. The block diagram shown in Fig. 1 illustrate the basic PID formula, $u(t)$ and $e(t)$ represent the control signal and error signal and K_p, K_i, and K_d are the proportional gain, integral gain, and derivative gain, respectively. By entering parameters K_p, K_i, and K_d, the control signal is calculated and then sent to the controlling module; the controlled object is driven. If the controller is designed properly, the control signal will make the output error converge to a small neighborhood of the origin to achieve the control requirement. Therefore, the optimization objective of the PID controller is to obtain an optimal set of parameters (K_p, K_i, K_d), which will minimize the performance function by searching the given controller parameters space.

The PID controller first compares the system's output with a user-defined set point and generates an error signal, through Feedback loops is controlled of the system's

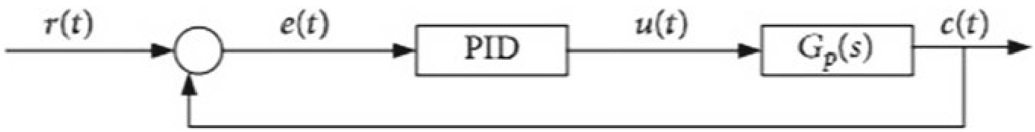

Fig. 1 Block diagram of PID controller

and calculating the error. By utilizing closed-loop operation, it is feasible to expedite transient processes, diminish the impact of disturbances on the system, and adjust its steady-state behavior. The feedback signal can be obtained as an analog output and can also be directly implemented to the output of an internal frequency generator to regulate its amplitude, frequency, offset, and phase [3].

According to y. soni The PID controller is designed using ISE, IAE, ITAE, and MAE standards for a linear stable static system, in addition to finding Parameter: K_{i}, K_{d}, K_{p} to be applied to the PID controller system [4], in the 2013 A. Kiruthika She said Mathematical modeling and speed control of a censored brushless DC motor using intelligent controller Brushless DC motor are rapidly gaining popularity due to its high efficiency and accurate control characteristics [5], like he said 2015 Mila Mary Job She designed the modeling and control of a pendulum is important because it allows the motion of the pendulum to be controlled by controlling the voltage applied to the actuator [6], make Elisa Sara Varghese suggest that Optimal control of inverted pendulum system using PID controller, LQR and MPC, The inverted pendulum is a highly non-linear system, we suggest the control technology to control the inverted pendulum trolley, when the trolley reaches the desired position, the inverted pendulum continues in the existing position, so the PID controller and LQR regulator are used to control the system, and the MPC predictive controller is used to calculate events future and implement the necessary control measures. In [7], the goals are to achieve minimal over-shoot in steady-state response and lower stability time. Several other tuning methods have been used classified into classical and meta-heuristic optimization methods for the purposes of PID tuning.

The main objective of this project is to design and implement an angle controller for simple propeller pendulum with different feedback sensors.

The Sub objective are:

- Implement a Simulink PID controller to control the pendulum angle by potentiometer as a feedback sensor.
- Implement a Simulink PID controller to control the pendulum angle by camera as a feedback sensor.
- Comparison between the two techniques.

2 Methodology

The methodology and scope followed to control the pendulum angle is shown in Fig. 2.

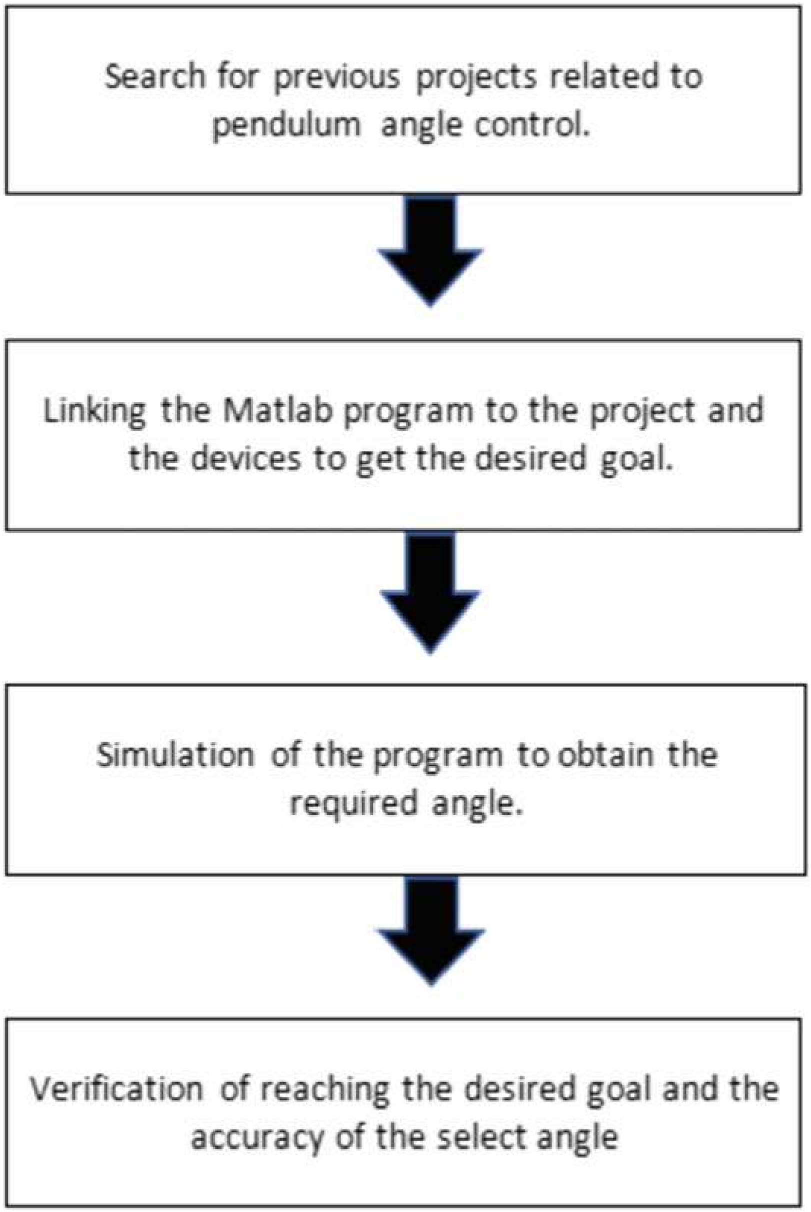

Fig. 2 Flowchart of the methodology

This study involved modeling and analyzing a pendulum system. A possible next step would be to create and implement a control system that can maintain the pendulum angle at a specified level. One approach to accomplish this is by attaching a motor directly to the pendulum via a gear or pulley system. Alternatively, a motor equipped with propellers could be attached to one end of the pendulum system, with the end mass serving as a counterweight to reduce the demand on the motor. The speed of the motor would be adjusted to generate lift and change the orientation of the pendulum assembly. An example of this setup is shown in Fig. 3, which illustrates

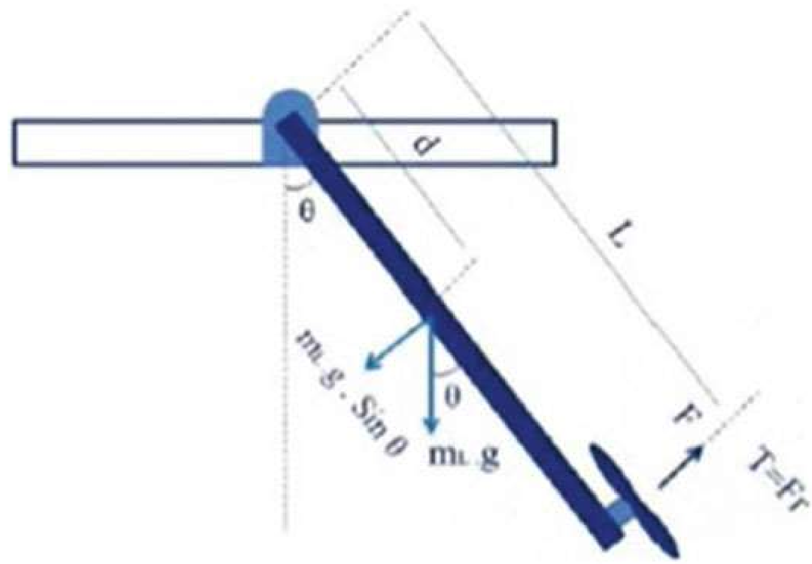

Fig. 3 Analysis net magnitude and direction force

the forces acting on the rod and how they can be analyzed, as well as the direction of each force.

The brushless DC motor possesses several features, such as high efficiency, high starting torque, high torque output, and low electrical noise, making it a popular choice in various industrial applications [8]. To regulate the system, a motor speed controller is utilized, which enables the adjustment of the DC voltage. The required DC supply value is dependent on the motor speed (in RPM) and its capacity. Furthermore, a controller is necessary for this system, and a PID (proportional-integral-derivative) controller is typically implemented to manage the output voltage [9].

The overall system is shown in Fig. 4.

As shown in Fig. 5, this mechanical model was designed based on the desired goal, which is the rotation of the motor to move the arm at the required angle, as everything that affects the movement of the arm was taken into account, such as the use of wood in addition to reducing friction, and the size of the model is suitable for the movement of the fan so that the fan does not hit the body and the limbs.

The Arduino board is only used in this project as a communication board. For this reason, all software part is done on the MATLAB Simulink. The feedback angle is measured by Arduino board and then sends to the Matlab Simulink as an input for the control system. After that the decision of duty cycle is sent back from Simulink to motor drive via Arduino. The motor runs at certain speed and rotates the propeller, which raises the arm with a required angle. Figures 6 and 7 show the block diagram of control system that was built to reach the desired goal.

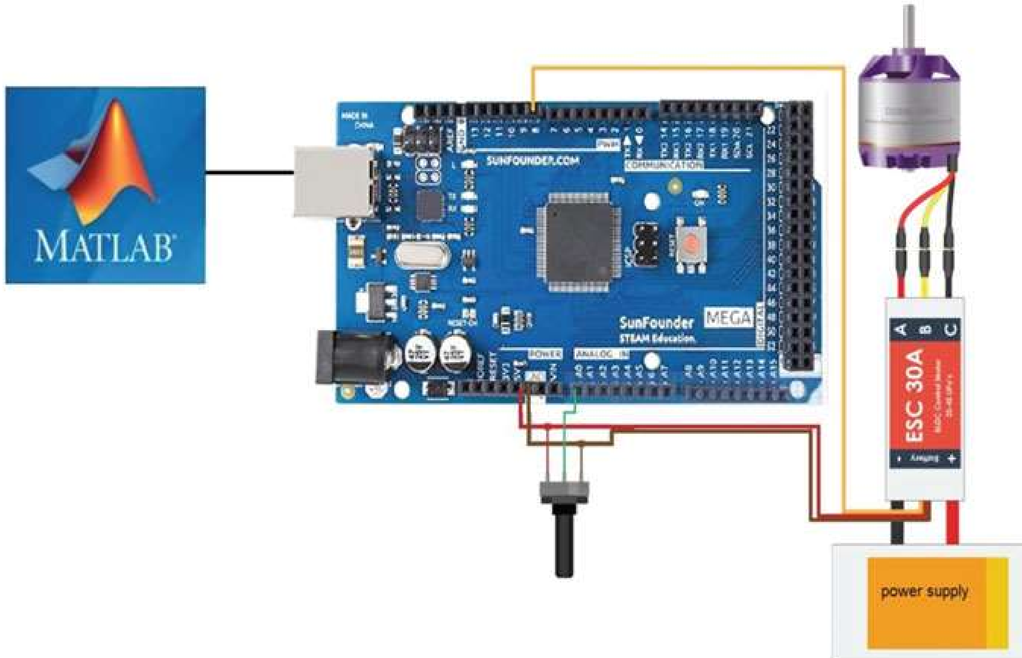

Fig. 4 Electrical overall project circuit

3 Results

In this project mainly two scenarios are conducted, the first one is to use the potentiometer to provide the pendulum angle, while the other use the camera and raspberry pi to provide the angle contactless to avoid any problems due to potentiometer.

3.1 Scenario 1

Using variable resistance to feedback the required angle as mentioned previously in the hardware. When the Simulink starts, the angle is already set to 90° and this angle continues to 60 s. After that, the user change the reference angle to 70° then the pendulum follows this angle with very small time and without large swing. Then the user also decreases the reference angle to 45°. The values of the constants used in the system for Fig. 8: ($K_P = 0.1$, $K_I = 0.05$, $K_D = 0.05$).

3.2 Scenario 2

The Raspberry Pi and the camera are used to take the value of the angle on the wooden object through the stick and show it on the display screen. The Raspberry Pi

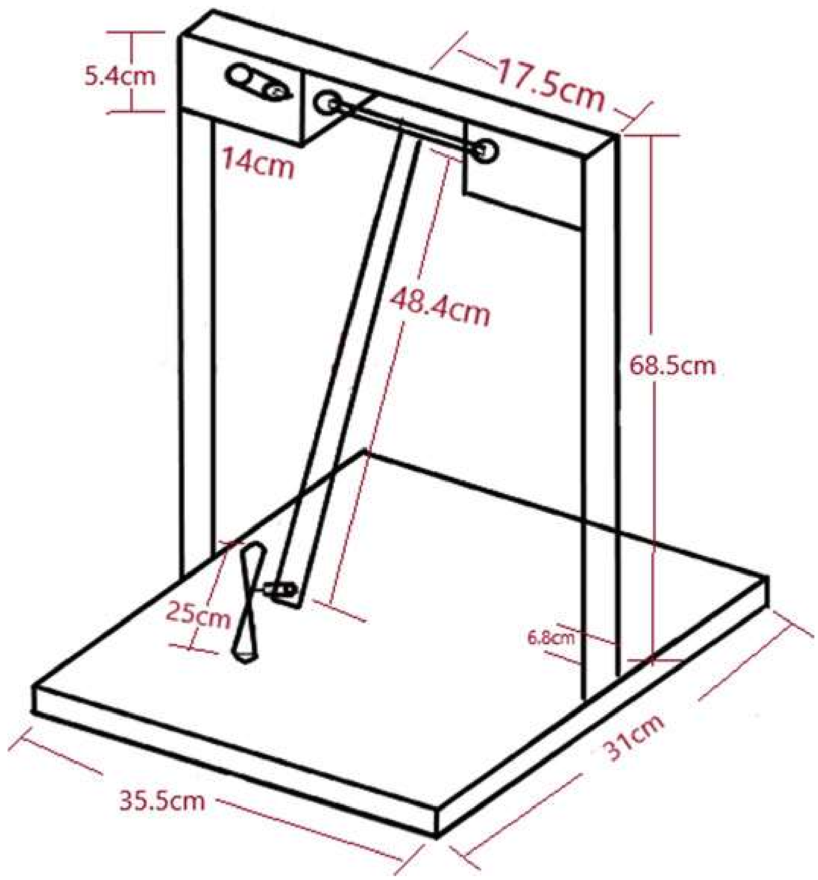

Fig. 5 Mechanical design

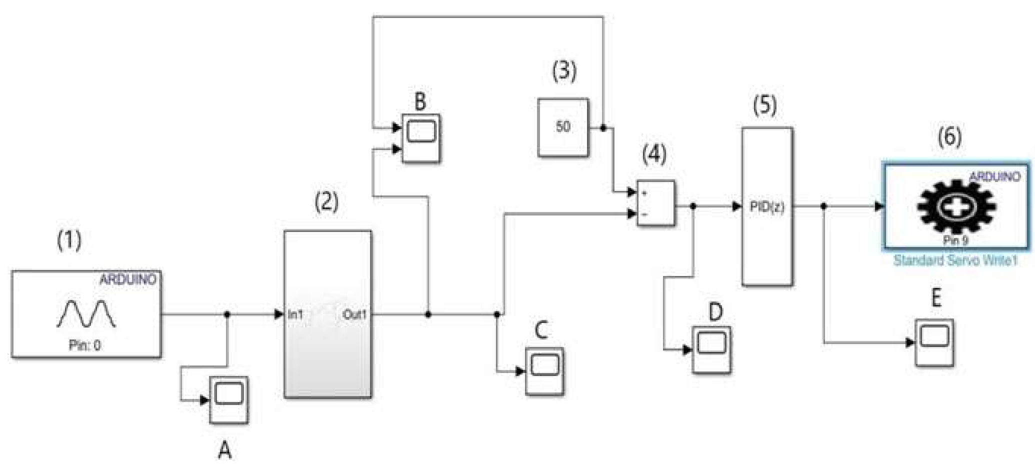

Fig. 6 Block diagram of pendulum control system

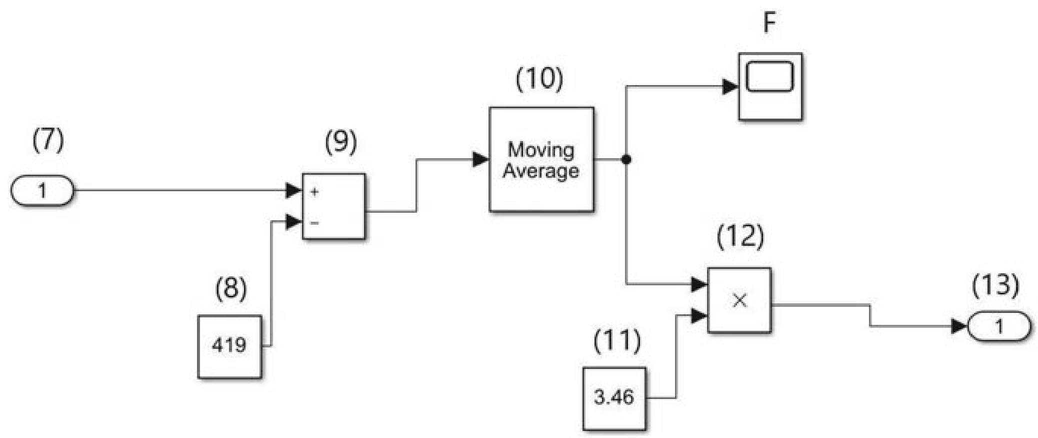

Fig. 7 Block diagram for scaling the output of the potentiometer in range (0–90)

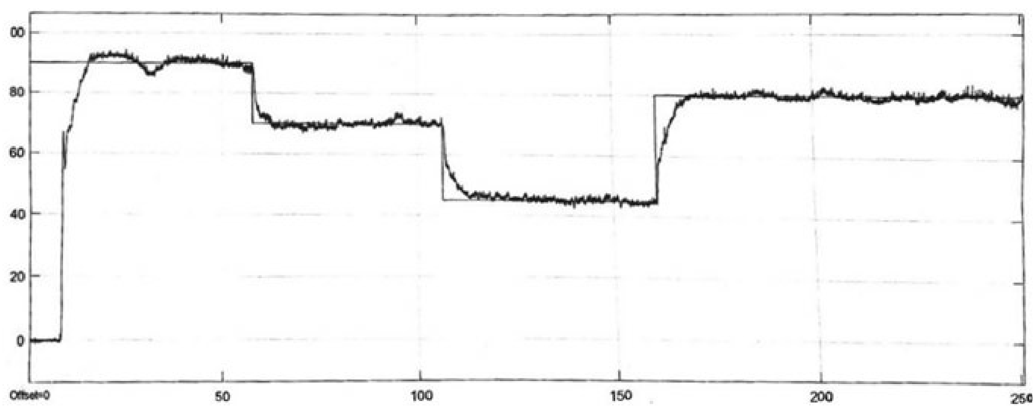

Fig. 8 The curve of how the value of the angle shown on the solid behaves

is programmed in the Python programming language to reach the target. The camera takes pictures and detects two points to show the angle value. This scenario is not considered due to the inability to measure the angle continuously. The following images are part of the work that was done and an attempt was made to reach a result, but a satisfactory result was not obtained. Figure 9 shows how two points were taken and the camera visualized those two points to show the corner of the display screen.

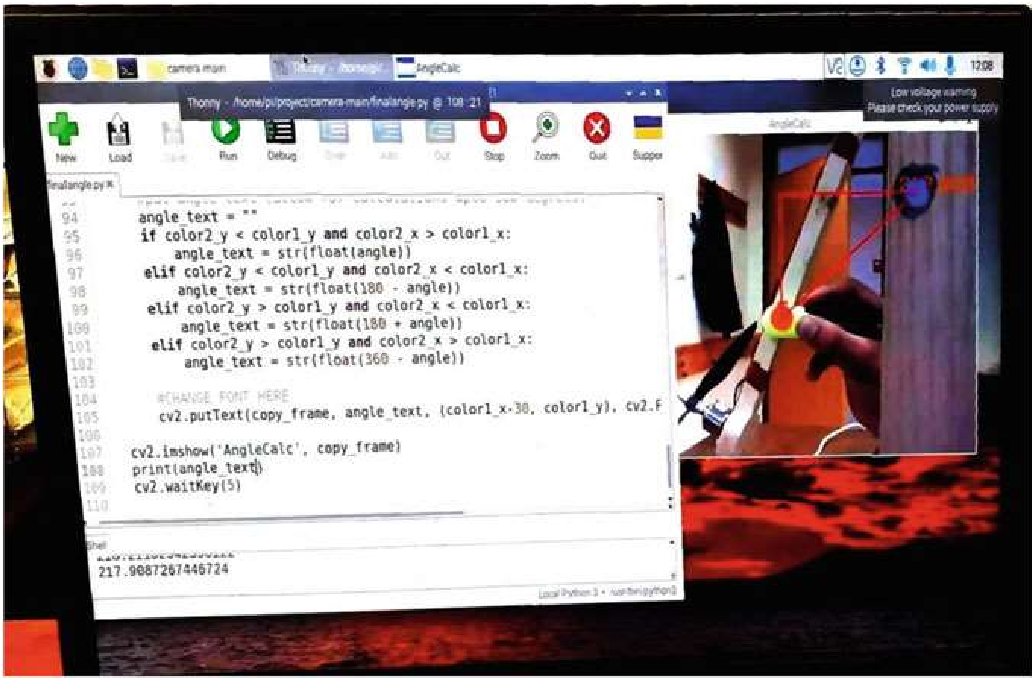

Fig. 9 Using raspberry pi and camera to detect the pendulum angle

4 Conclusion

By using MATLAB Simulink software, an angle is entered by user, so that the model will react and follow the required angle. A good response has been achieved in producing the required angle, the motor rotate the propeller and raise the arm fast and smoothly. The ability to stabilize when influenced by an external force. When a force is applied to the rod, then it returned to the desired angle. This indicates that the system is stable due to external force.

5 Problems and Solutions

When the user set the angle less than 45°, the brushless motor is turn off since the pulse duration will be around 750 ms. This is occurred because the DC brushless motor is working in pulse duration between (1–2 ms). Figure 10 illustrates this problem; the user set the angle to 40° which makes the motor to turn off and turn on and the pendulum is swings.

When entering the value of large angles, the motor will draw a high current because it needs more power, and this will affect the drive and its temperature will rise, and this leads to a reduction in its life span.

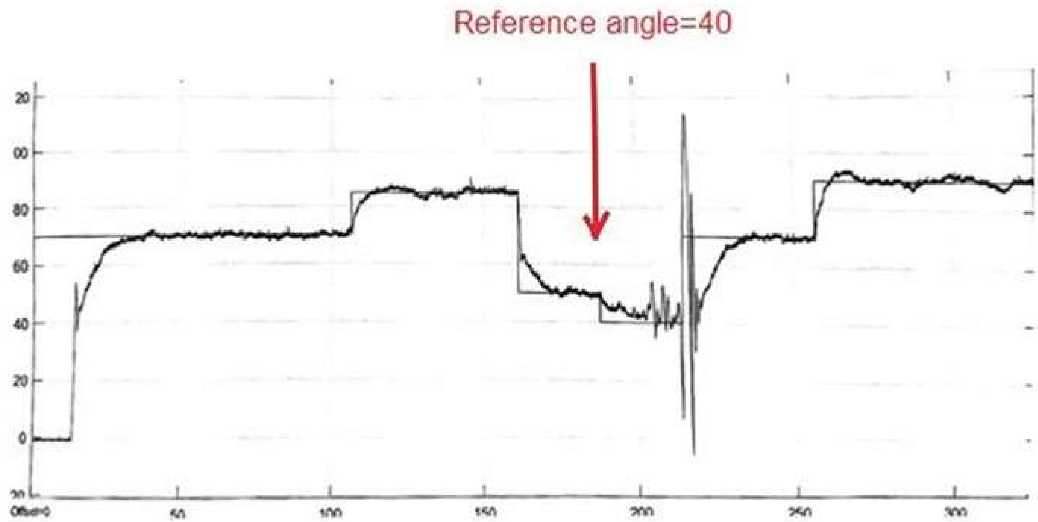

Fig. 10 The output curve of angle

6 Recommendations

- To control the pendulum for small angle less than 45°, three solutions can be followed: the first solution is conducted by adding weight on the rod. The second solution is to change the propeller by small one so the lift force will be less. The final solution is to change the brushless motor with DC motor which works on small period.
- To solve the problem of high temperature, a small fan is used that is placed above the motor drive.

7 Cost Analysis

The cost of each component of the project is presented in Table 1.

Table 1 Cost analysis of the project

Equipment	Price (NIS)
Arduino	120
Brushless motor	100
Drive motor	30
Fan	20
Wooden hologram	100
Potentiometer	5
Raspberry pi and camera (optional)	300
Total	375 or 670

References

1. Job, M.M., Jose, P.S.H.: Modeling and control of mechatronic aeropendulum. In: 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), 2015, pp. 1–5
2. Zhang, Y., Zhang, L., Dong, Z.: An MEA-tuning method for design of the PID controller. Math. Prob. Eng. **2019**, 1378783 (2019). https://doi.org/10.1155/2019/1378783
3. Astrom, K.J.: PID controllers: theory, design, and tuning. Int. Soc. Meas. Control (1995)
4. Kiruthika, A., Rajan, A.A., Rajalakshmi, P.: Mathematical modelling and speed control of a sensored brushless DC motor using intelligent controller. In: 2013 IEEE International Conference on Emerging Trends in Computing, Communication and Nanotechnology (ICECCN), 2013, pp. 211–216
5. Soni, Y.K., Bhatt, R.: BF-PSO optimized PID controller design using ISE, IAE, IATE and MSE error criteria. Int. J. Adv. Res. Comput. Eng. Technol. **2**(7), 2333–2336 (2013)
6. Varghese, E.S., Vincent, A.K., Bagyaveereswaran, V.: Optimal control of inverted pendulum system using PID controller, LQR and MPC. IOP Conf. Ser.: Mater. Sci. Eng. **263**(5), 52007 (2017)
7. Joseph, S.B., Dada, E.G., Abidemi, A., Oyewola, D.O., Khammas, B.M.: Metaheuristic algorithms for PID controller parameters tuning: review, approaches and open problems. Heliyon, p. e09399 (2022)
8. Hameed, H.S.: Brushless DC motor controller design using MATLAB applications. In: 2018 1st International Scientific Conference of Engineering Sciences-3rd Scientific Conference of Engineering Science (ISCES), 2018, pp. 44–49
9. Mahmud, M., Islam, M.R., Motakabber, S.M.A., Satter, M.D.A., Afroz, K.E., Habib, A.K.M.A.: Control speed of BLDC motor using PID. In: 2022 IEEE 18th International Colloquium on Signal Processing & Applications (CSPA), 2022, pp. 150–154