SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Semarak International Journal of STEM Education

Journal homepage:
https://semarakilmu.my/index.php/sijste/index
ISSN: 3030-5152

Development of An Educational Pid Controller Kit for Airflow Control using Arduino Controller

Norlaili Abdul Rahman @ Abdul Rahim[1,*], Siti Hajar Ismail[2]

[1] Department of Mechanical Engineering, Politeknik Sultan Abdul Halim Mu'adzam Shah, 06000 Jitra, Kedah, Malaysia
[2] Department of Mechanical Engineering, Politeknik Tuanku Sultanah Bahiyah, 09000 Kulim, Kedah, Malaysia

ARTICLE INFO

Article history:
Received 23 October 2025
Received in revised form 25 December 2025
Accepted 23 January 2026
Available online 18 February 2026

Keywords:

Proportional-Integral-Derivative (PID) controller; Arduino Uno; airflow control; control systems education; mechatronics training kit

ABSTRACT

This research presents the design and development of an educational training kit focused on airflow control using a Proportional-Integral-Derivative (PID) controller implemented through Arduino Uno technology. The aim is to provide students, educators, and automation enthusiasts with an affordable, accessible, and practical platform to learn the core concepts of control systems through real-world application. Control theory, especially PID control, is a foundational element in mechatronics, automation, and process engineering. However, the theoretical nature of PID tuning and dynamic response analysis can be difficult to grasp without physical interaction. This project addresses that gap by integrating sensor-based airflow control and real-time system feedback into a compact and user-friendly educational tool. The kit utilizes an Arduino Uno microcontroller, which offers a programmable and open-source environment suitable for beginners and advanced users alike. Airflow is controlled through a DC fan or blower, and monitored using airflow or analogue voltage sensors. The PID algorithm is programmed to maintain desired airflow setpoints, with tuneable parameters allowing users to observe how changes in the proportional (P), integral (I), and derivative (D) gains affect system behaviour, such as stability, overshoot, and settling time. Key hardware components include the Arduino Uno board, airflow sensor, DC fan, display interface (e.g., LCD or serial monitor), push buttons or potentiometers for input, and a power supply unit. Software is developed using the Arduino IDE, with PID libraries for ease of implementation and experimentation. This kit not only supports active learning through parameter tuning and data observation but also encourages students to engage in system modelling, real-time troubleshooting, and programming fundamentals. It is modular and can be adapted or expanded to include wireless communication, graphical data logging, or integration with other control systems.

1. Introduction

Feedback control systems are pervasive across engineering domains from process industry loops to motor drives and robotics. Among feedback strategies, the proportional integral derivative (PID)

* *Corresponding author.*
E-mail address: norlaili@polimas.edu.my

controller remains the industry workhorse due to its simplicity, interpretability and robustness for a wide range of linear-like processes. Control systems courses therefore represent critical components of undergraduate and diploma-level engineering curriculum. However, studying control theory students often struggle to connect the mathematical derivation of PID laws with observable physical phenomena such as overshoot, oscillation and steady-state error. Experimental, hands-on exercises are essential to bridge this gap and to develop practical intuition for controller design, tuning and hardware constraints.

Low-cost, compact laboratory demonstrators that visualize closed-loop phenomena are particularly valuable in resource-constrained teaching environments. Airflow ball levitation systems (also called air levitation or levitating-ball trainers) are ideally suited for this purpose because it:

i. provide immediate, continuous visual feedback (the levitating ball) that directly maps to control performance;
ii. exhibit fast dynamics amenable to classroom demonstrations; and
iii. can be implemented with inexpensive components (fans/blowers, Arduino microcontrollers, acrylic tubes, simple sensing).

Prior open designs (for example Float Shield and other lab stands) explicitly targeted replicability, low cost and Arduino compatibility to promote broad adoption in control laboratories.

i. This work develops a compact, portable PID controller training kit using Arduino Uno, designed primarily for diploma/undergraduate control laboratories. The kit's aims are to:

ii. Provide a low-cost, robust hardware demonstrator of closed-loop PID control for airflow or levitation experiments.

iii. Offer students immediate visualization of transient and steady-state responses while providing manual access to PID gains and setpoint changes.

iv. Expose practical elements of control implementation (PWM actuation, motor-driver thermal limits, sensor noise and parameter sensitivity).

v. Enable simple laboratory experiments and worksheets for instructors to assess conceptual learning.

The paper contributes a full implementation report (mechanical, electronic, and software design), experimental evaluation (motor-driver thermal behavior, PID parameter trends, ball height response), and an educational discussion to guide instructors who wish to deploy the kit in teaching labs. Additionally, we situate the kit relative to recent developments (2020–2024) in open-source educational levitation devices, model identification procedures, and novel control strategies applied to such plants.

1.1 Problem Statement

Although PID controllers are extensively used in industrial automation, many engineering students lack practical competency in implementing and tuning PID control systems. Traditional instructional methods often emphasize mathematical derivations and software simulations while providing limited exposure to real physical systems. Existing laboratory equipment is frequently expensive, bulky, or insufficient in quantity, restricting student access to hands-on experimentation. As a result, students may graduate without adequate confidence or intuition when applying PID control in real-world engineering scenarios.

1.2 Objectives

The objectives of this research are as follows:

1. To design and develop a low-cost, portable educational PID controller kit for airflow control.
2. To implement a PID control algorithm using an Arduino Uno microcontroller.
3. To experimentally evaluate the control performance and stability of the developed system.
4. To assess the suitability of the system as a teaching and learning tool for control systems education.

1.3 Scope of Study

This study focuses on the development of an educational airflow control system based on a ball levitation mechanism. The scope includes mechanical design, electronic hardware integration, software development, PID parameter tuning, and experimental validation. The system is intended for laboratory-scale educational use and does not address industrial-scale airflow systems or advanced adaptive and intelligent control strategies.

2. Methodology

2.1 Overall System Architecture

The developed educational PID controller kit is designed around a closed-loop airflow control system employing a ball levitation mechanism. The system architecture consists of four primary subsystems: (i) mechanical structure, (ii) sensing and actuation subsystem, (iii) control and processing unit, and (iv) user interaction and display interface. Figure references from the original project documentation illustrate the integration of these subsystems into a compact and portable educational platform.

The mechanical subsystem provides a transparent airflow column that enables direct visualization of system dynamics. A lightweight ping-pong ball is suspended within the vertical acrylic tube by regulating the airflow generated from a DC blower fan located at the base of the system. The levitation height of the ball serves as the controlled variable, while the fan speed acts as the manipulated variable.

The sensing subsystem in the current prototype relies on manual observation of the ball position to emphasize conceptual understanding during initial learning stages. This design decision was made intentionally to allow students to visually associate PID parameter changes with system response. However, the architecture allows for future expansion through the integration of ultrasonic or infrared distance sensors.

The actuation subsystem comprises a DC blower fan driven by an L298N H-bridge motor driver. The fan speed is controlled using pulse-width modulation (PWM) signals generated by the Arduino Uno microcontroller. The control and processing subsystem execute the PID algorithm in real time, adjusting the PWM duty cycle based on the tuned control parameters.

Finally, the user interaction subsystem includes an LCD display module that presents real-time PID parameters (Kp, Ki, and Kd) and system status information. This interface enhances usability and supports instructional activities in laboratory environments.

2.2 Mechanical Design and Fabrication

The mechanical design of the training kit prioritizes portability, durability, transparency, and safety. Acrylic material with a thickness of 3 mm was selected for the structural components due to its lightweight nature, mechanical strength, and transparency, which allows clear visualization of airflow behavior and ball movement.

The base platform of the system measures approximately 30.48 cm × 20.32 cm × 7 cm and houses the Arduino Uno, motor driver, power supply, and wiring components. Ventilation openings were incorporated into the base design to ensure adequate airflow for fan operation and thermal dissipation. The airflow column is a vertical acrylic tube with a height of approximately 62 cm and a square cross-section of 10 cm × 10 cm. This configuration provides sufficient space for stable ball levitation while minimizing lateral oscillations.

Fabrication was carried out using a combination of laser cutting, manual cutting, grinding, and adhesive bonding techniques. Laser cutting ensured dimensional accuracy for the acrylic components, while grinding processes improved surface finish and reduced sharp edges to enhance safety. Chloroform adhesive and mechanical fasteners were used to assemble the structure securely. The final assembled unit is lightweight and compact, making it suitable for classroom demonstrations, laboratory exercises, and mobile instructional use.

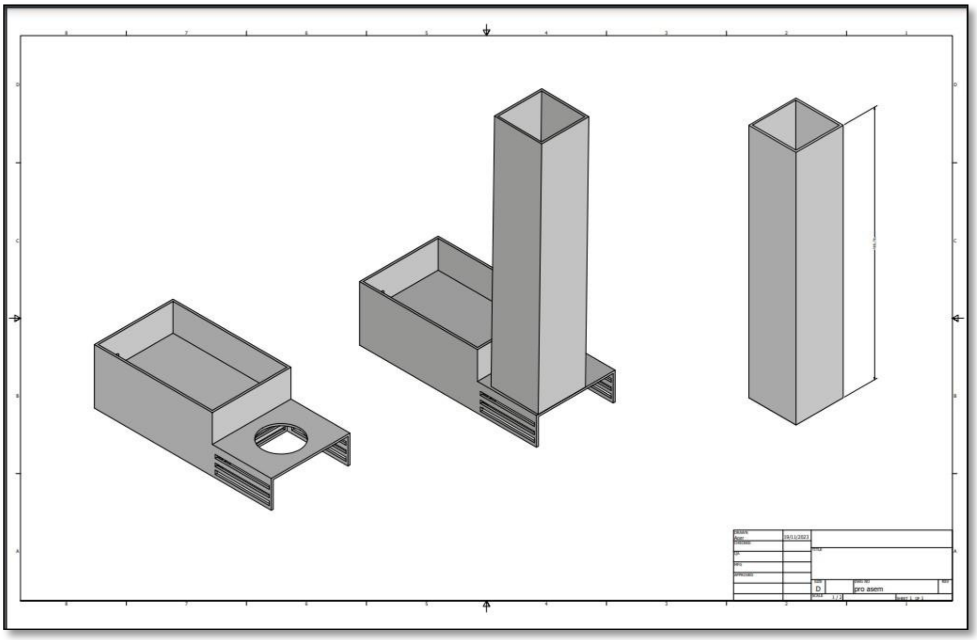

Fig. 1. CAD drawing in 3D view

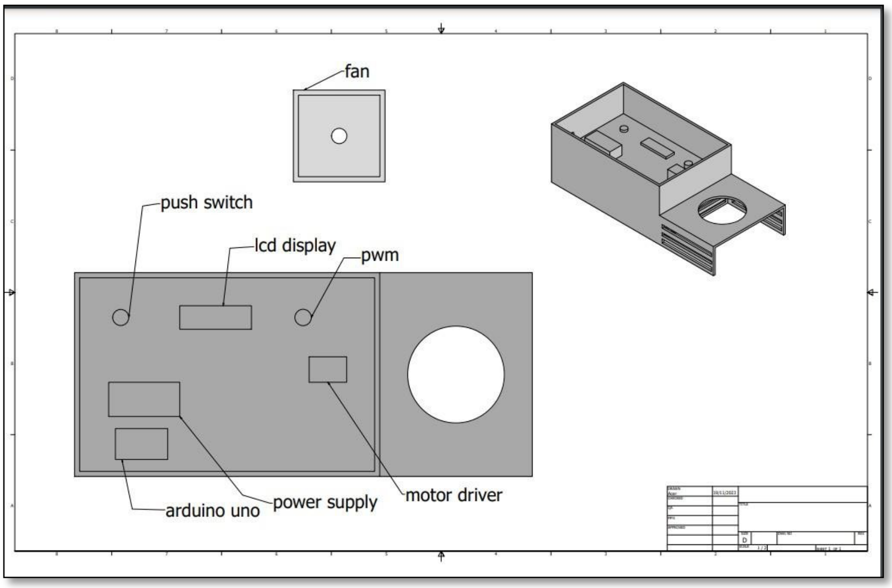

Fig. 2. CAD drawing in top view

Figure 1 show the upper part of the project while Figure 2 show the top view of the project. This design is drawn using Autocad software.

2.3 Electronic Hardware Design

The electronic hardware design emphasizes simplicity, reliability, and ease of replication. The Arduino Uno microcontroller serves as the core processing unit due to its widespread adoption in educational contexts, extensive community support, and compatibility with numerous open-source libraries.

A 12 V DC power supply is used to drive the blower fan, while the Arduino Uno operates at 5 V. Voltage regulation and proper grounding were implemented to ensure electrical safety and system stability. The L298N motor driver module enables bidirectional control and speed modulation of the DC fan using PWM signals from the Arduino.

A 20 × 4 LCD display with an I2C interface was integrated to minimize wiring complexity and reduce the number of required input/output pins. The display provides real-time feedback on PID parameters and system status, allowing students to observe how tuning adjustments influence system behavior.

All electronic components were interconnected using insulated wiring and soldered joints to ensure reliable electrical connections. Careful cable management was implemented to improve system aesthetics and reduce the risk of short circuits. Figure 3 show the schematic circuit used to develop this project which is construct using Proteus software.

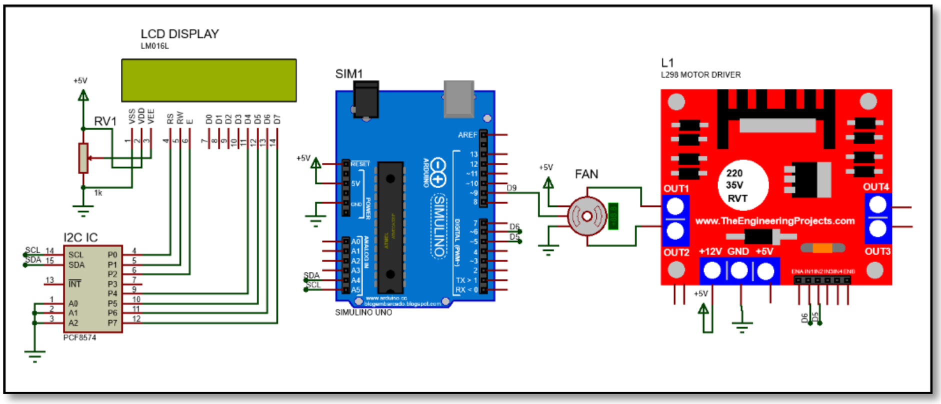

Fig. 3: Schematic circuit of PID controller training kit to control the air flow

2.4 PID Control Algorithm Implementation

The PID control algorithm was implemented using the Arduino Integrated Development Environment (IDE). The control law follows the standard PID formulation in Equation 1:

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

where u(t) represents the control signal (PWM duty cycle), e(t) is the error between the desired and actual system output, and Kp, Ki, and Kd are the proportional, integral, and derivative gains, respectively. In the educational context of this training kit, the error signal is indirectly interpreted through ball height variation. Students manually adjust PID parameters and observe the resulting system response, enabling intuitive understanding of control concepts such as overshoot, steady-state error, oscillation, and damping. The Arduino executes the PID algorithm at a fixed sampling interval, ensuring consistent control behavior. PWM output values are constrained within safe operating limits to prevent excessive fan speeds that could damage the motor driver or mechanical structure.

2.5 Experimental Procedure

A series of experimental tests were conducted to evaluate the performance, reliability, and safety of the developed PID controller training kit. Each test was repeated on different days to minimize measurement bias and ensure consistency.

Three primary experimental objectives were defined:

1. To evaluate the thermal behavior of the L298N motor driver under varying fan speeds.
2. To observe the variation of PID parameters (Kp, Ki, and Kd) with changes in fan speed.
3. To assess the achievable levitation height of the ball under different operating conditions.

Each experiment was conducted over a duration of 60 minutes to simulate extended classroom usage.

(1)

3. Results and Analysis

One of the main factors in the project objective that forms the basis for the design of the PID CONTROLLER Training Kit to Control Air flow using Arduino UNO is to reduce the burden on the lecturer who teaches the control system subject. Not only that, it can make it easier for students to learn about PID CONTROLLER in class. To avoid error, each series of tests was performed on a different day. Table 4.1 shows the details of the tests that have been carried out.
Among the series of tests held are:

Experiment 1. Observe heat if the Motor driver (H-Bridge L298N)
Experiment 2. Observe Kp, Ki and Kd of PID CONTROLLER
Experiment 3. Observe height of the plastic ball (cm)

3.1 Observe heat of the Motor driver (H-BRIDGE L298N)

Three series of tests were performed to observe the heat of the motor driver (H-Bridge L298N) when the dc fan operated for 60 minutes as stated in Table 1.

Table 1
Result of experiment 1

Test series	Test A	Test B	Test C
Duration operation of DC Cooling Fan	60 Minutes	60 Minutes	60 Minutes
Percentage speed of DC Cooling Fan (%)	50	70	100
Temperature of Motor driver (H- Bridge L298N)	Not Hot	Slightly Hot	Too Hot

3.2 Observe Kp, Ki, and Kd of PID CONTROLLER

Three series of tests were performed to observe the Kp, Ki and Kd of PID CONTROLLER Training Kit with percentage speed of DC Fan as stated in Table 2

Table 2
Result of experiment 2

Percentage speed of Cooling fan (%)	50	60	70	80	90	100
Kp - Proportional Term	0.14	0.22	0.27	0.25	0.30	0.25
Ki - Integral Term	0.14	0.22	0.27	0.26	0.30	0.25
Kd – Derivative Term	1.66	1.02	0.85	0.90	0.76	0.91

3.3 Observe Height of the Plastic Ball (cm)

Three series of tests were performed to observe the heat of the DC 12V fan when the DC fan operated for 60 minutes as stated in Table 3.

Table 3
Result of experiment 3

Series test	A Test	B Test	C Test	D Test	E Test
Percentage speed of DC Cooling Fan (%)	60	70	80	90	100
Duration operation of DC Cooling Fan	60 minutes	60 minutes	60 minutes	60 minutes	60 minutes
Height of the plastic ball (cm)	8	36	27	43	53

4. Conclusions

This paper presented the design, development, and evaluation of an educational PID controller kit for airflow control using an Arduino Uno microcontroller. The system successfully demonstrates closed-loop control principles through a visually intuitive ball levitation mechanism. Experimental results confirm reliable performance, safety under controlled operating conditions, and strong educational value.

The training kit enhances student understanding of PID control by bridging the gap between theoretical concepts and real-world implementation. Its low cost, portability, and ease of use make it a practical addition to engineering education laboratories.

5. Recommendations

Future improvements may include the integration of ultrasonic sensors for automated position feedback, the use of more advanced microcontrollers for expanded functionality, and the development of structured laboratory modules and assessment tools. These enhancements would further strengthen the system's educational impact and research potential.

Acknowledgement
The author thanks the Mechanical Engineering Department workshop staff for fabrication assistance and the students who participated in iterative testing. This research was not funded by any external grant.

References
[1] Coren, Stanley, and Diane F. Halpern. "Left-handedness: a marker for decreased survival fitness." *Psychological bulletin* 109, no. 1 (1991): 90. https://doi.org/10.1037/0033-2909.109.1.90.
[2] De Kovel, Carolien GF, and Clyde Francks. "The molecular genetics of hand preference revisited." *Scientific reports* 9, no. 1 (2019): 5986. https://doi.org/10.1038/s41598-019-42515-0.
[3] Llaurens, Violaine, Michel Raymond, and Charlotte Faurie. "Why are some people left-handed? An evolutionary perspective." *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, no. 1519 (2009): 881-894. https://doi.org/10.1098/rstb.2008.0235.
[4] Geschwind, Norman, and Albert M Galaburda. 2003. "Cerebral Lateralization." Bradford Books.
[5] Annett, Marian, and Diana Kilshaw. "Mathematical ability and lateral asymmetry." *Cortex* 18, no. 4 (1982): 547-568. https://doi.org/10.1016/s0010-9452(82)80053-1.
[6] Papadatou-Pastou, Marietta, Eleni Ntolka, Judith Schmitz, Maryanne Martin, Marcus R. Munafò, Sebastian Ocklenburg, and Silvia Paracchini. "Human handedness: A meta-analysis." *Psychological bulletin* 146, no. 6 (2020): 481. https://doi.org/10.1037/bul0000229.

[7] Somers, Metten, Roel A. Ophoff, Maartje F. Aukes, Rita M. Cantor, Marco P. Boks, Meenakshi Dauwan, Kees L. de Visser, René S. Kahn, and Iris E. Sommer. "Linkage analysis in a Dutch population isolate shows no major gene for left-handedness or atypical language lateralization." *Journal of Neuroscience* 35, no. 23 (2015): 8730-8736. https://doi.org/10.1523/JNEUROSCI.3287-14.2015

[8] Edwards, A. W. F. "Punnett's square." *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 43, no. 1 (2012): 219-224. https://doi.org/10.1016/j.shpsc.2011.11.011.

[9] Sperry, Roger W. "Left-brain, right-brain." *Saturday Review (New York 1975)* 2, no. 23 (1975): 30-3.

[10] Reveal, That'll. 2018. "11 Optical Illusions That'll Reveal Your Personality Type." YouTube. November 26, 2018. https://youtu.be/Dq0gmzTDqaA?si=YrPVFepfe_q6Fao2.

[11] Sha, Zhiqiang, Antonietta Pepe, Dick Schijven, Amaia Carrión-Castillo, James M. Roe, René Westerhausen, Marc Joliot, Simon E. Fisher, Fabrice Crivello, and Clyde Francks. "Handedness and its genetic influences are associated with structural asymmetries of the cerebral cortex in 31,864 individuals." *Proceedings of the National Academy of Sciences* 118, no. 47 (2021): e2113095118. https://doi.org/10.1073/pnas.2113095118.

[12] Ocklenburg, Sebastian, Patrick Friedrich, Onur Güntürkün, and Erhan Genç. "Voxel-wise grey matter asymmetry analysis in left-and right-handers." *Neuroscience letters* 633 (2016): 210-214. https://doi.org/10.1016/j.neulet.2016.09.046.

[13] Corballis, Michael C. "Left brain, right brain: facts and fantasies." *PLoS biology* 12, no. 1 (2014): e1001767. https://doi.org/10.1371/journal.pbio.1001767

[14] Mehrdad, Ali Gholami, and Manouchehr Ahghar. "Learning styles and learning strategies of left-handed EFL students." *Procedia-Social and Behavioral Sciences* 31 (2012): 536-545. https://doi.org/10.1016/j.sbspro.2011.12.100.

[15] Prithishkumar, Ivan J., and Stelin Agnes Michael. "Understanding your student: Using the VARK model." *Journal of postgraduate medicine* 60, no. 2 (2014): 183-186. https://doi.org/10.4103/0022-3859.132337.