*Journal of Engineering Education Transformations ,*
*Volume 38 , No. 2 , October 2024 , ISSN 2349-2473, eISSN 2394-1707*

*10.16920/jeet/2024/v38i2/24190*

# GUI-Driven Real-Time PID Control Tool for Educational Virtual Systems

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**Abstract:**This research presents a pioneering approach in virtual control systems, focusing on developing a highly intuitive Graphical User Interface (GUI) for real-time PID control of LED brightness using Arduino IDE. By embracing a robust pedagogical framework, the study meticulously outlines specific learning objectives that adhere to the SMART criteria, ensuring precise educational outcomes. The key to this research is the tailored design of the GUI, which considers diverse audience needs, prior knowledge, and learning styles. The interfaces are meticulously crafted for optimal user experience, ensuring seamless navigation and engagement. Interactive elements, encompassing simulations, virtual experiments, problem-solving scenarios, and quizzes, foster active participation and hands-on learning. Multimedia elements, such as text, images, videos, animations, and audio, are thoughtfully integrated to cater to varied learning preferences. This paper underscores the critical role of collaborative learning facilitated through discussion forums, chat functionalities, and collaborative virtual environments. The study emphasizes continuous improvement through regular assessments and detailed user feedback analysis. Notably, the research highlights the significant educational impact of the designed GUI. By offering a practical platform where students can dynamically adjust PID parameters and observe immediate effects on LED brightness, the GUI enhances the learning experience in classroom settings. This approach equips students with a tangible understanding of complex PID principles, preparing them for real-world applications. In summary, this research showcases the creation of engaging, practical virtual control system tools, fostering profound and meaningful learning experiences for users within educational contexts.

**Keywords :** control systems, pedagogy, facilitation

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## 1. Introduction

. In recent years, the rapid advancement of technology has paved the way for innovative approaches in education, including the development of virtual control systems tools. These tools provide an interactive and immersive environment for learning and practicing control systems concepts (Yogesh K. Dwivedi et al. 2022). However, the effectiveness of such tools depends on the design and development process, which requires a pedagogical framework that promotes effective learning and engagement. This paper aims to identify specific learning objectives that virtual control systems tools should strive to achieve, tailor the tools to the target audience, create intuitive user interfaces, incorporate interactive elements, offer various multimedia formats, provide opportunities for collaborative learning, and regularly assess and improve the tools (Muhammad Mujtaba Asad et al. 2021).

1. Importance of Virtual Control Systems Tools

Control systems are crucial in various fields, including engineering, manufacturing, and automation. Understanding control systems principles and gaining proficiency in their application is essential for professionals in these domains. Traditional methods of teaching control systems often rely on theoretical lectures and limited practical experiences. Virtual control systems tools offer a unique opportunity to bridge this gap by providing learners with a hands-on and immersive learning experience (Qian Zhang, 2022). By integrating these tools into the educational process, learners can better understand control systems concepts, improve problem-solving skills, and develop critical thinking abilities (Kamińska D et al. 2019)..

2. Identifying SMART Learning Objectives

It is crucial to establish clear and measurable learning objectives to guide the design and development of virtual control systems tools. These objectives should be specific, measurable, attainable, relevant, and time-bound (SMART). By defining SMART learning objectives, developers can effectively align the tool's features and functionalities to meet the desired learning outcomes (May Britt Bjerke et al. 2017). Identifying learning objectives should consider the characteristics and needs of the target audience, including their prior knowledge, technical proficiency, and preferred learning styles. By tailoring the tools to the specific audience, the learning experience can be enhanced, leading to improved engagement and knowledge retention (Zhu et al. 2016).

3. Designing Intuitive User Interfaces

User interfaces are fundamental to virtual control systems tools (Li-Hao Chenet al. 2017). It is essential to create user interfaces that are intuitive, visually appealing, and easy to navigate to ensure optimal user experience. Users should be able to access and interact with the tools without confusion or frustration. Clear instructions, logical workflows, and responsive design should be incorporated to guide users through the learning process. By designing user interfaces (Islam et al. 2023) that are visually engaging and easy to understand, learners are more likely to stay motivated and actively participate in learning activities (Yiyi Zhao, 2022).

4. Incorporating Interactive Elements

Virtual control systems tools should offer interactive elements to promote active learning and engagement. These elements may include simulations, virtual experiments (Campos et al. 2020), problem-solving scenarios, and quizzes. These interactive elements foster critical thinking and more profound understanding by providing hands-on experiences and opportunities for learners to apply theoretical knowledge. Learners can actively explore concepts, experiment with different parameters, and observe the real-time effects of their actions. Additionally, incorporating interactive elements (Abid Haleem et al. 2022) encourages learners to take ownership of their learning journey, as they can test hypotheses, make decisions, and analyze outcomes.

5. Utilizing Multimedia Formats

Recognizing that learners have diverse preferences in processing information, virtual control systems tools should incorporate various multimedia elements such as text, images, videos, animations, and audio. Developers can cater to different learning styles by presenting information in multiple formats and enhancing comprehension. Text-based content can provide detailed explanations, while visual elements like images, videos, and animations can illustrate complex concepts and facilitate visualization. Including audio components can further engage learners and provide alternative ways of absorbing information. Offering multiple pathways for content delivery allows users to customize their learning experience based on their preferences, promoting personalized and practical learning (Haritha et al. 2024, Chavan et al. 2024).

6. Facilitating Collaborative Learning

Virtual control systems tools should provide opportunities for collaborative learning, acknowledging that interaction and knowledge sharing among peers can deepen understanding and foster a sense of community. Features like discussion forums, chat functionalities, or collaborative virtual environments can enable learners to interact with peers, discuss concepts, and solve problems together. By facilitating collaboration, virtual control systems tools create an environment where learners can benefit from collective intelligence, exchange ideas, and learn from different perspectives. Collaborative learning enhances communication skills, teamwork, cooperation, and valuable professional competencies (Sharma et al. 2024, Vaghela et al. 2024).

7. Regular Assessment and Improvement

Assessing their effectiveness and gathering regular user feedback is essential to continuously enhancing virtual control systems tools. Analyzing data on user engagement, learning outcomes, and usability provides valuable insights into areas that require improvement. User feedback should be actively sought and considered during the design iteration process. By incorporating user suggestions and addressing identified areas for improvement, developers can refine the tools and optimize the overall learning experience. Continuous assessment and improvement guarantee that virtual control systems tools remain effective, up-to-date, and aligned with the evolving needs of learners (Sreejana et al. 2024, Prince et al. 2024).

## 2. Pedagogical Framework To Design Virtual Control Systems Toolbox

Designing a pedagogical framework for a virtual control systems toolbox involves creating a structured approach for teaching and learning about control systems in a virtual or digital environment.

2.1Virtual Control Systems Toolbox Design
2.1.1.learning Objectives

Clearly define the learning objectives that the toolbox aims to achieve. For example, understanding control system concepts, designing controllers, analyzing system responses, etc.

2.1.2 User Interface And Interaction

- Design an intuitive and user-friendly interface that allows users to interact with the toolbox easily.
- Consider including visual representations of control system components, such as block diagrams, graphs, and real-time system responses.
- Provide options for users to input system parameters, select control algorithms, and visualize the results.

2.1.3 Simulation And Modeling Capabilities

- Incorporate simulation and modeling capabilities to allow users to simulate different control system scenarios.
- Provide tools for users to create or import system models, specify system dynamics, and define inputs and disturbances.
- Implement numerical solvers to simulate system responses and visualize the results in real-time.

2.1.4 Control Algorithms And Tuning

- Include a variety of control algorithms such as PID, state-space, adaptive control, or fuzzy logic control.
- Allow users to select and implement different control algorithms to observe their effects on system behavior.
- Provide options for users to tune control parameters manually or use automated tuning methods, such as Ziegler-Nichols or optimization techniques.

2.1.5 Analysis And Visualization Tools

- Incorporate tools for analyzing system responses, such as step response, frequency response, stability analysis, and root locus plots.
- Include features to visualize and compare the effects of different control strategies on system behavior.
- Provide tools for observing and analyzing control performance metrics, including rise time, settling time, and overshoot.

2.1.6 Educational Resources

- Include instructional materials, such as tutorials, documentation, and examples, to guide users through different control system concepts and applications.

- Offer explanations of control theory principles, step-by-step walkthroughs, and interactive exercises to reinforce learning.

- Provide access to reference materials, textbooks, or online resources for further study (Karn, A. et al 2023, Masek, A. et al 2022).

2.1.7 Customization And Expansion

- Design the toolbox modular and extensible, allowing for future additions or customization.

- Provide options for users to modify or add controlalgorithms, import their system models, or integrate additional analysis tools.

2.1.8 Assessment And Feedback

- Incorporate assessment tools, quizzes, or interactive challenges to evaluate users' understanding and progress.

- Offer immediate feedback and explanations to help users understand their mistakes and improve their learning.

2.1.9 User Support And Community

- Include user support mechanisms, such as FAQs, user forums, or chat support, to assist users in navigating the toolbox and addressing their questions or concerns.

- Encourage forming a community around the toolbox, where users can share their experiences, collaborate, and provide feedback for continuous improvement (Kittur, J. et al 2020, Kulkarni, N. N. et al 2018).

2.1.10Iterative Development And User Feedback

- Continuously iterate and improve the toolbox based on user feedback and evaluation data.

- Regularly update the toolbox with new features, bug fixes, and enhancements based on user needs and emerging control system trends.

By considering these aspects, design a Pedagogical framework for a Virtual control systems toolbox that provides a practical and interactive learning experience for learners interested in control

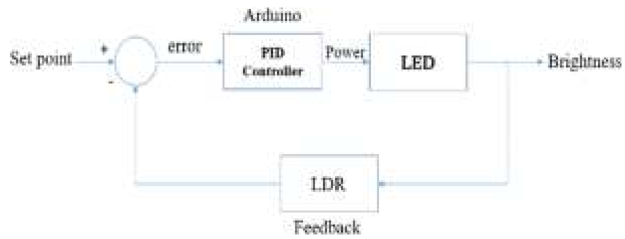


**Fig.1 : Design of PID Control of Led Brightness Based on LDR Using Arduino Uno Processor**

systems. The design of a pedagogical framework for a virtual control systems toolbox should be flexible, considering the evolving nature of technology and educational needs. Regularly assess the effectiveness of the framework and update it accordingly.

2.2 Implementation Of Proportional Integral

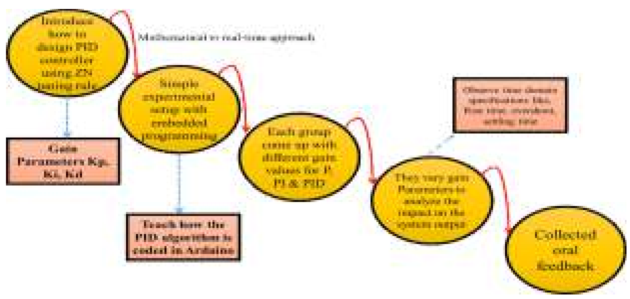


**Fig. 2 : Pedagogical Framework**

Derivative (pid) Controller Of Led Brightness

Figure 1 shows the PID Controller hardware setup to control the brightness of the LED based on a light-dependent resistor using an Arduino Uno Processor. Connect the LED to one of the pulse-width modulated pins on pin 9 of the Arduino Uno Processor. LDR is connected to one of the analog input pins on the Arduino Uno Processor.

Figure 2 shows the Pedagogical framework to facilitate the PID Controller. Ziegler-Nichols (ZN) method offers three different tuning rules: ZN P, ZN PI, and ZN PID. Each rule corresponds to a different combination of proportional, integral, and derivative terms. Implement a PID controller in an embedded system, such as a microcontroller, initialize PID parameters, and calculate the control signal. Repeat the PID Control loop and update the values.

2.3 Collaborative Problem-solving In Control Systems

Imagine a scenario where a team of control system engineers is tasked with optimizing the performance of a complex manufacturing process. They use a collaborative control system tool with the features mentioned above.

1. Real-Time Monitoring and Simulation: The team accesses the control system tool, which provides real-time data on the manufacturing process. They simultaneously simulate different control strategies to identify areas for improvement.

2. Shared Control System Models: Engineers collaboratively design control system models and configurations within the tool. They can share these models, solicit feedback, and collectively fine-tune the control algorithms.

3. Collaborative Data Analysis: The team uses the tool to analyze historical data from the control system. They spot anomalies and patterns that might indicate inefficiencies and discuss their findings through the integrated chat feature.

4. Real-Time Chat and Discussion: While adjusting the control system parameters, the team members use the chat feature to discuss their rationale, share relevant research articles, and seek advice from one another.

5. Version Control and System History: The tool keeps a detailed log of all changes and decisions made during optimization. This history proves invaluable when the team encounters unexpected issues, allowing them to backtrack to identify the root causes.

Through these collaborative features, the control system engineers work together more effectively, combining their expertise and knowledge to solve complex control system problems, improve efficiency, and enhance the overall performance of the manufacturing process.

## 2.4 Instructional Design Methodology

2.4.1 Analysis Stage:

- Identification of Learning Objectives: A pedagogical framework helps clearly define the learning objectives the control system should achieve. It involves understanding what knowledge and skills the learners need to acquire.

- Learner Analysis: Determine the target audience's characteristics, preferences, and prior knowledge. This information helps tailor the control system to the specific needs of the users.

2.4.2 Design Stage:

- Content Selection: Based on the defined learning objectives, select the content and topics to be included in the control system. It ensures that the content is both relevant and educational.

- Instructional Strategies: Design instructional strategies and methods that align with the learning objectives. It might involve using simulations, interactive elements, or feedback mechanisms to enhance the learning experience.

- User Interface Design: Design the control system's user interface to promote user engagement, comprehension, and usability. Consider principles of user-centered design.

2.4.3 Development Stage:

- Content Creation: Create informative, engaging, and pedagogically sound content. It could include written materials, multimedia elements, or interactive components.

- Prototyping: Develop prototypes or pilot versions of the control system to test its functionality and instructional effectiveness. User feedback is valuable at this stage.

- Integration of Educational Features: Embed educational features within the control system, such as tutorials, quizzes, and progress tracking, to support the learning process.

2.4.4 Evaluation Stage:

- Formative Evaluation:

Throughout the developmental phase, formative evaluation assumes a central role in shaping and refining the virtual control system. A continuous assessment process is systematically implemented, diligently identifying and rectifying potential design or pedagogical issues. Integral to this evaluation is collecting user feedback through surveys, feedback forms, and open-ended questions. Incorporating user suggestions and testing outcomes into the development process enables a responsive approach to address concerns effectively. The formative evaluation process facilitates ongoing improvements to operate within an iterative framework. Changes are thoughtfully implemented based on the continuous feedback loop, specifically addressing usability concerns. This iterative and user-centric approach ensures that the final product aligns precisely with educational objectives, providing an optimal learning experience for users.

- Summative Evaluation: The summative evaluation phase represents a conclusive assessment conducted upon the finalization of the virtual control system. This thorough evaluation seeks to determine the extent to which learning objectives have been achieved. It involves meticulously assessing the system's effectiveness in imparting user knowledge and skills validating its alignment with educational goals. Through a detailed analysis of both quantitative and qualitative data collected during the developmental and testing phases, the overall performance of the virtual control system is comprehensively gauged. Adopting a data-driven approach enables a profound understanding of the system's strengths and areas for improvement. Subsequently, based on the summative assessment results, final refinements are made to optimize the virtual control system for its intended educational purpose. It ensures it meets the highest effectiveness standards and aligns seamlessly with academic objectives.

2.4.5 Implementation and Maintenance Stage:

- Training for Users:

Provide comprehensive training for users on effectively utilizing the virtual control system. This training should encompass technical aspects, such as navigating the Graphical User Interface (GUI) and adjusting PID parameters using Arduino IDE, as well as pedagogical elements to enhance the learning experience. Users will be guided on leveraging the interactive and multimedia features, participating in virtual experiments, and engaging with problem-solving scenarios and quizzes. Emphasis will be placed on collaborative learning through discussion forums, chat functionalities, and collaborative virtual environments.

- Ongoing Updates:

Regularly maintain and update the virtual control system to reflect changes in content or technology. Continuously improve the pedagogical elements based on feedback and evolving educational practices. This iterative approach ensures that the system remains engaging, effective, and aligned with

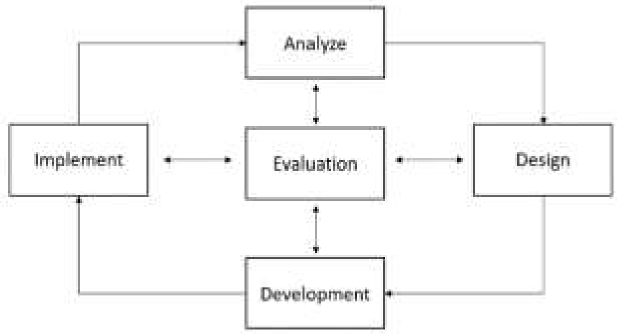


**Fig. 3 : Flow of instructional design methodology**

the educational objectives outlined in the study.

By adhering to a pedagogical framework in the training process, users will acquire technical proficiency in using the GUI and benefit from an enhanced and meaningful learning experience within educational contexts. The flow of instructional design methodology is shown in Figure 3.

## 3. Results And Discussion

3. Experimental Results:

In this section, the outcomes of the experimental PID control system are facilitated through the developed Graphical User Interface (GUI) in Arduino IDE and are comprehensively detailed. The GUI allowed users to dynamically adjust Proportional-Integral-Derivative (PID) parameters, set points, and view real-time data, providing an interactive platform for LED brightness control based on ambient light levels. The experimental setup is shown in Figure 5.

3.1Set-point Variations: Several experiments were conducted to analyze the system's response to changes in the set-point values. The graphical representation displayed the LED's reaction to different set point values ranging from 0 to 1024, shown in Figure 4. Notably, the LED's brightness levels demonstrated a rapid adjustment in correspondence with the alterations in the set-point values, indicating the system's high responsiveness.

3.2PID Controller Performance: The PID control system's performance was evaluated in relation to the characteristic oscillations observed in the LED brightness control. These oscillations, typical of controlled systems, were effectively managed by the PID controller, ensuring stable and precise brightness regulation. Graphical data illustrated the control output's adaptation, showcasing the PID controller's ability to maintain stability under varying environmental conditions. The performance is shown in Figure 6 as a servo response. Blue indicates the reference input, and red means the system response.

3.3 System Adaptability and User Interaction:

Users could modify PID constants (Kp, Ki, Kd) and observe their real-time effects on LED brightness through the GUI. The interactive nature of the interface enabled users to intuitively grasp the impact of PID parameter adjustments on the system's behavior. The GUI's toggling functions also allowed seamless transitions between automatic and manual modes, providing users with flexible control options. The parameter ranges available in the GUI are outlined in Table 1, facilitating users in making adjustments within specified limits for optimal performance.

**Table 1 : GUI Parameter Ranges**

| Parameter | Minimum | Maximum |
|---|---|---|
| Set-point | 0 | 1023 |
| Proportional (Kp) | 0.0 | 10.0 |
| Integral (Ki) | 0.0 | 1.0 |
| Derivative (Kd) | 0.0 | 1.0 |

3.4System Stability and Robustness: The PID control system exhibited remarkable stability throughout the experiments. Despite sudden changes in set point values, the system efficiently adapted to maintain the LED's brightness within the desired range. It is termed a regulator response, which is shown in Figure 7. The system's robustness was evident, indicating its suitability for real-world applications where stable brightness control is essential. The set point tracking of the system response is shown in Figure 8.

3.5 Educational Impact and Quantification:

In evaluating the educational impact of the developed GUI for real-time PID control of LED brightness, it is crucial to acknowledge the significance of empirical measurement. The GUI, designed to aid students in grasping the complex concept of PID control, offers an interactive platform for dynamic parameter adjustment, providing immediate visibility into LED brightness changes. This hands-on learning experience, illustrated in Figure 9, highlights the practical understanding fostered by the GUI. Figure 9 captures Professor Dr. G. Prabhakar implementing experiential learning with students.

However, we recognize the need for explicit quantitative measures to substantiate the claim of an enhanced learning experience. The Course Exit Survey is a valuable tool for capturing student perspectives on various facets of the course. Our initial emphasis on the GUI's role in aiding comprehension of PID control concepts can be reinforced by integrating specific metrics from the survey. The survey covers essential aspects such as course relevance, appropriateness of content, and alignment with cognitive outcomes, each assessed on a scale from "Excellent" to "Poor." Integrating quantitative data from the survey, particularly in categories like course relevance (46.15% Excellent), appropriateness of content (47.69% Excellent), and alignment with cognitive outcomes (43.08% Excellent), provides tangible evidence of the GUI's effectiveness in enhancing the learning experience.

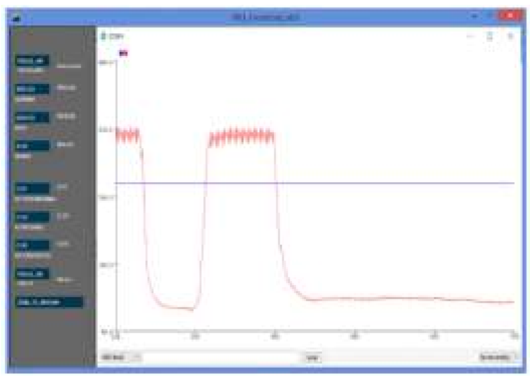

**Fig. 4 : Graphical User Interface For Real-time Pid Control**

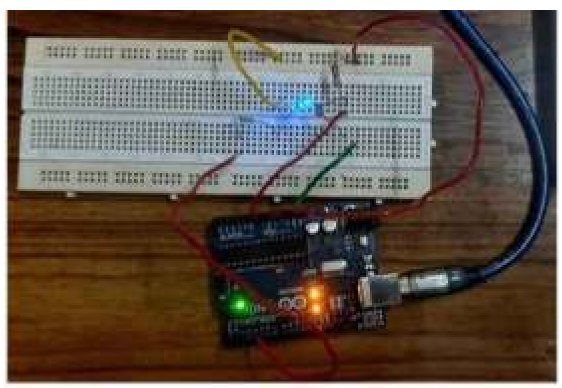

**Fig. 5 : Experimental Setup**

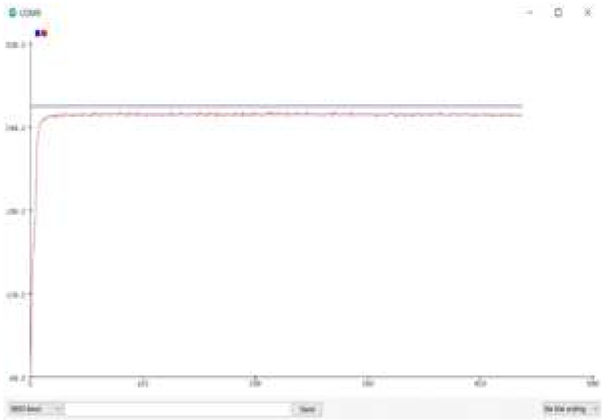

**Fig. 6 : Servo Response Of Pid Control**

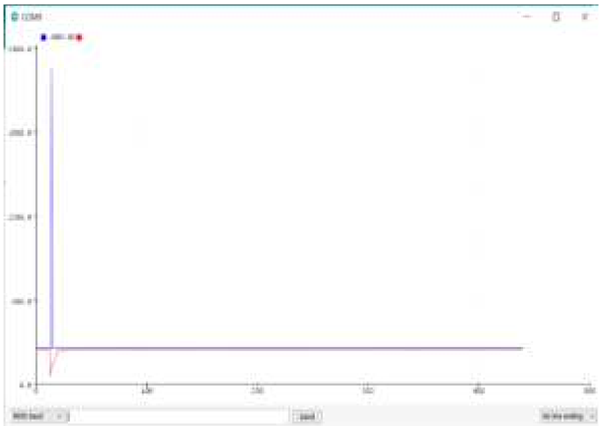

**Fig. 7 : Regulator Response Of Pid Control**

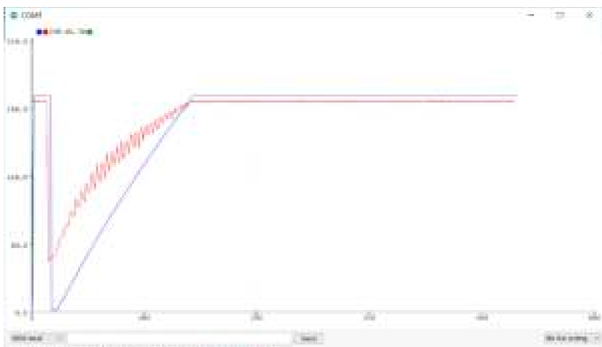

**Fig: 8 : Set Point Tracking**

**Fig. 9 : Experiential Learning Using Gui-based Real-time Pid Control**

**Table 2: Course Exit Survey**

| Total count: 65, Response count: 65 | | | | |
|---|---|---|---|---|
| **Course Exit Survey Questions / Rating level** | Excellent % | Very Good % | Good % | Poor % |
| **Course (Overall score: 78.77%)** | | | | |
| 1. Relevance to the programme | 46.15 | 23.08 | 30.77 | 0 |
| 2. Appropriateness of the course content | 47.69 | 21.54 | 30.77 | 0 |
| 3. Appropriateness of the course content with the cognitive level of Course outcomes | 43.08 | 24.62 | 32.31 | 0 |
| 4. Assessment Pattern for CAT and terminal examination | 50.77 | 18.46 | 30.77 | 0 |
| 5. Course plan and reading materials | 43.08 | 26.15 | 30.77 | 0 |
| **Course Outcome (Overall score: 76.67 %)** | | | | |
| 6. Rate your level of attainment of CO1 | 43.08 | 23.08 | 32.31 | 1.54 |
| 7. Rate your level of attainment of CO2 | 43.08 | 23.08 | 32.31 | 1.54 |
| 8. Rate your level of attainment of CO3 | 41.54 | 24.62 | 30.77 | 3.08 |
| 9. Rate your level of attainment of CO4 | 41.54 | 24.62 | 30.77 | 3.08 |
| 10. Rate your level of attainment of CO5 | 44.62 | 20 | 32.31 | 3.08 |
| 11. Rate your level of attainment of CO6 | 46.15 | 20 | 30.77 | 3.08 |
| **Content Delivery (Overall score: 78.21 %)** | | | | |
| 12. Availability for clarifying doubts/mentoring | 46.15 | 21.54 | 30.77 | 1.54 |
| 13. Syllabus coverage as per course plan | 46.15 | 26.15 | 26.15 | 1.54 |
| 14. Utilizing the class hours effectively with complete preparation for the class | 46.15 | 24.62 | 26.15 | 3.08 |
| 15. Use of blackboard and active learning methods | 44.62 | 24.62 | 29.23 | 1.54 |
| 16. Communicate effectively | 47.69 | 20 | 30.77 | 1.54 |
| 17. Relevance to the cognitive level of course outcomes | 40 | 29.23 | 29.23 | 1.54 |
| **Assessment (Overall score: 77.38 %)** | | | | |
| 18. Following assessment pattern in CATs | 41.54 | 23.08 | 33.85 | 1.54 |
| 19. Correlation of questions in CATs /assignments with cognitive levels of Course Outcomes | 44.62 | 23.08 | 29.23 | 3.08 |
| 20. Promptness in evaluating answer scripts | 43.08 | 24.62 | 30.77 | 1.54 |
| 21. Effectiveness of Assignments / mini projects / other activities in attaining course outcomes | 44.62 | 24.62 | 29.23 | 1.54 |
| 22. Unbiased and fairness in treatment and assessment | 47.69 | 20 | 29.23 | 3.08 |

Moreover, the experimental section detailing the

**Fig .10: Multimodal Learning**

PID control system's performance is a foundational overview, highlighting adaptability, stability, and user-friendly interaction. Future iterations could incorporate specific learning outcome assessments and comparisons with traditional teaching methods to quantify the educational impact further. It would offer a more comprehensive understanding of the effectiveness of the academic framework.

3.6 Multimodal Learning

Multimodal learning is integral to crafting an effective Graphical User Interface (GUI) for real-time PID control of LED brightness using Arduino IDE. Figure 10 illustrates a group discussion to determine the optimal PID gain values. The GUI accommodates varied learning styles by blending visual elements, interactive simulations, and diverse multimedia. Learners engage with hands-on simulations, access well-structured textual content, and tackle problem-solving scenarios with interactive quizzes. This approach provides immediate feedback and fosters a comprehensive understanding of PID control principles. Collaborative features like discussion forums and real-time chat enhance the interactive learning experience. In essence, multimodal learning within the GUI ensures a dynamic, inclusive, and effective educational environment for mastering real-time PID control concepts.

## 4. Course Exit Survey

The Course Exit Survey serves as a valuable tool for assessing the overall effectiveness of the educational experience and gaining insights into various facets of the course, ranging from content delivery to course outcomes. This survey is designed to capture the perspectives and feedback of students, providing a comprehensive understanding of their satisfaction and perceptions.

The following Table 2 presents a detailed analysis of the responses obtained from participants. The survey covers aspects such as the relevance and appropriateness of the course content, alignment with course outcomes, content delivery, and the effectiveness of assessment methods. Each category is assessed on a scale ranging from "Excellent" to "Poor," providing a nuanced view of the students' opinions.

This feedback is instrumental in shaping future iterations of the course and facilitating continuous improvement in pedagogical approaches and instructional strategies. The quantitative data

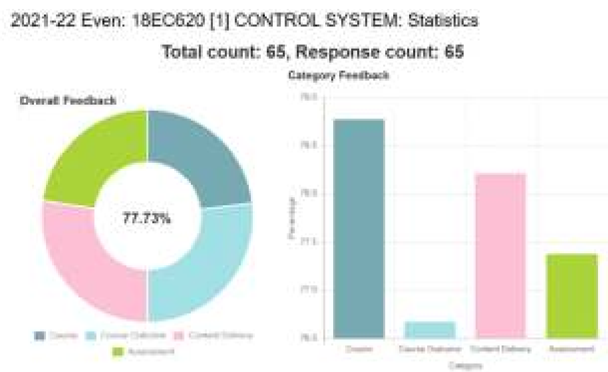


**Fig. 11 : Overall Feedback of Course Exit Survey**

presented in the tables is complemented by qualitative insights gathered through open-ended questions, contributing to a holistic evaluation of the educational experience.

The ensuing analysis delves into specific areas, allowing for a focused examination of strengths and areas for enhancement. The objective is to harness this feedback to refine educational practices, ensuring that the learning objectives are met and surpassed, creating a more enriching academic environment.

Figure 11 shows that collecting and analyzing data on student engagement, learning outcomes, and usability and incorporating this feedback/course exit survey on course control systems into the iterative design process can ensure that the control system remains user-centric, effective, and continuously improved to meet the evolving needs of its learners or students.

## Conclusion

In conclusion, this research pioneers a user-friendly Graphical User Interface (GUI) for real-time PID control of LED brightness using Arduino IDE within virtual control systems. The study strategically defines SMART learning objectives and tailors the GUI design for diverse audiences, which needs to be rooted in a robust pedagogical framework. Interactive elements like simulations and quizzes foster hands-on learning, accommodating varied preferences. Utilizing multimedia elements enriches the learning experience, and collaborative learning through forums remains a cornerstone. Continuous improvement, driven by assessments and user feedback, consistently enhances the effectiveness of educational tools.

Crucially, this study quantifies the significant educational impact of the designed GUI, supported by the insightful Course Exit Survey data from 65 participants. Noteworthy overall scores include the course receiving 78.77%, content delivery achieving 78.21%, and assessment garnering 77.38%. Specific highlights include assessment patterns scoring 50.77% Excellent and content delivery achieving an overall score of 78.21%. These quantitative measures substantiate the claim of enhanced learning experiences.

The study's emphasis on the practical platform provided by the GUI, allowing students to dynamically adjust PID parameters and observe immediate effects on LED brightness, aligns with the survey findings. Exceptional scores in categories such as relevance to the program (46.15% Excellent) and appropriateness of course content (47.69% Excellent) further underline the GUI's effectiveness in enhancing classroom learning experiences.

This research establishes a new standard for interactive virtual control system tools, validated by quantitative measures from student responses. Beyond fostering profound learning experiences, these tools empower users in educational contexts, setting a precedent for immersive learning in control systems education. Integrating quantitative data enhances our understanding, paving the way for continuous improvement and innovation. Looking ahead, exploring adaptive learning algorithms and incorporating real-world application scenarios could further improve the effectiveness and applicability of virtual control system tools in diverse educational settings.

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