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Design and Development of an Interactive Programmable Digital Control Simulator for Engineering Education

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ABSTRACT

By incorporating simulation technologies into engineering education, students can gain hands-on experience with programmable digital control without depending exclusively on actual lab equipment. The design and development of an interactive programmable digital control simulator intended to aid in the teaching and learning of basic digital control concepts is presented in this study. With the help of the developed simulator, users can design, implement, and monitor programmable control operations involving digital inputs and outputs, logic functions, sequencing, and timing in a virtual environment. System architecture design, software development, interface integration, and functional testing were all part of the process. Functionality, usability, accuracy, responsiveness, and instructional suitability were all considered when evaluating the simulator. The evaluation framework was created to ascertain whether the system could simulate simple programmable digital control processes in an interactive and dependable manner. By allowing students to experiment with control logic and watch system responses in a controlled setting, the developed platform provides a useful and possibly economical addition to traditional laboratory instruction. The study shows how interactive simulation can be used as a teaching tool to improve students' conceptual knowledge and practical proficiency with programmable digital control systems.

Keywords: *Programmable Digital Control, Control Simulator, Engineering Education, Interactive Simulation, Digital Systems, Instructional Technology*

INTRODUCTION

Quezon City University offer programs related to technology understand the value of giving students opportunities for hands-on, experiential learning. The incorporation of on-the-job training (OJT) and industry-based learning into academic curricula, frequently as a prerequisite for program completion, reflects this emphasis on practical experience.

Similar to this, laboratory exercises are crucial to major technology and engineering courses because they reinforce the theoretical ideas covered in lectures through hands-on experimentation. By enabling students to apply theoretical concepts in real-world or simulated scenarios, these exercises can promote deeper comprehension, skill development, and knowledge retention. Students and practitioners can also develop technical competencies and make connections between classroom knowledge and practical applications by learning through practice in academic labs and industry settings. In this sense, experiential learning highlights how the learner actively engages with and reflects on experience to develop meaningful knowledge. In order to deliver high-quality, practical instruction, educational institutions and businesses that offer technology-related programs need sufficient training tools and teaching resources. However, these resources are now more costly due to growing expenses and the Philippine peso's diminishing purchasing power. Institutions find it difficult to provide enough

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laboratory resources for efficient technical training because of the increased acquisition and maintenance costs associated with the reliance on imported training materials and equipment.

Training materials for digital electronics education are frequently imported and can be expensive despite their comparatively basic features. Since many of these units are made for particular lessons or subjects, educational institutions must purchase a variety of equipment to cover the course's wider scope. To accommodate more students, technicians, and business professionals, more units might be required, which would raise the cost of purchase and upkeep even more. Specialized training systems can occasionally cost millions of pesos, making it difficult for educational institutions to supply enough equipment for thorough and easily accessible instruction in digital electronics, the primary issue. Training equipment is expensive and difficult to obtain, which is the main issue in digital electronics education.

A lot of training materials are costly, imported, and made for particular courses or uses. As a result, educational institutions must buy a variety of equipment types and sets in order to accommodate a wider range of subjects and more students. Influence. Due to the high cost of training equipment, there may be fewer laboratory resources available and fewer opportunities for students to obtain adequate practical experience. Additionally, it might make it more difficult for educational institutions to provide regular hands-on training and increase their financial burden. These drawbacks underscore the need for a more adaptable, affordable, and accessible digital electronics training program that can accommodate numerous lessons and students.

Because they give students the chance to test circuits, conduct experiments, and hone practical skills, training units are crucial to the teaching of electronics. However, because replacement parts aren't always easily accessible, maintenance can be challenging and expensive, and these units are susceptible to wear and damage. Protective devices can lower the chance of damage, but they are unable to totally stop deterioration brought on by repeated use. These restrictions may result in lower equipment availability and higher maintenance costs for laboratory operations.

Furthermore, students' capacity to apply theoretical knowledge to practical applications—particularly in circuit troubleshooting, testing, and design—may be hampered by a reliance on graphical simulations or representations rather than real electronic devices. Students' chances to experiment and investigate different circuit configurations may also be limited by restricted access to components. Furthermore, current training units may become outdated due to the rapid development of digital technology, and it may be difficult or expensive to adapt older equipment to new technologies. These difficulties underscore the necessity of adaptable, long-lasting, and updateable training systems that can offer real-world learning opportunities while keeping up with evolving digital electronics technologies. Science and engineering in application. Applied science is the practical use of scientific ideas to solve problems and create novel solutions. These ideas are used in engineering disciplines like computer, electrical, mechanical, and electronics to create systems, gadgets, and technologies that meet real-world needs. Gadgets. Technology develops tools, systems, and procedures that enhance human activities and support a variety of applications by utilizing scientific and engineering knowledge. Programmable control systems are widely used for automation, monitoring, and system operation in the fields of digital electronics and computer technology.

The Programmable Digital Control Simulator is suggested as a teaching aid for engineering education in this context. Programmable logic, digital inputs and outputs, sequencing, and control operations are just a few of the digital control concepts that students can learn and practice in this interactive environment. By offering a versatile and user-friendly platform for honing practical skills in digital electronics and programmable control systems, the simulator seeks to supplement laboratory instruction.

Aiming For the Study the Overall Goal

This study's main goal is to create an interactive programmable digital control simulator for engineering education that offers a useful and approachable platform for understanding and using basic digital control concepts. Particular Objectives, in particular, the study seeks to: One. Create and program a digital control system based on microcontrollers using PIC integrated circuits (ICs); Two. Create a training program that integrates

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hardware and computer software for programmable digital control; and three. Test and assess the developed Programmable Digital Control Simulator for usability, functionality, and suitability as a teaching tool

Scope ang Limitation

The design, development, and construction of an inexpensive interactive programmable digital control simulator for engineering education is the main focus of this project. Programs for PIC microcontroller-based applications can be programmed, uploaded, and downloaded using the simulator. Sequential lighting, small appliance control, LCD displays, alarm systems, stepper motor operation, and other fundamental industrial control applications are among the digital control activities it covers. The study is restricted to the chosen features and applications included in the simulator that was created. It does not address sophisticated industrial automation systems, large-scale control applications, or other microcontroller platforms outside of the designated PIC-based system; instead, it concentrates on its use as a teaching and training tool for digital control concepts.

Significance of the Study

The goal of the Design and Development of an Interactive Programmable Digital Control Simulator for Engineering Education is to offer a useful and affordable training environment for understanding and utilizing programmable digital control principles. By offering a locally constructible tool for programming, modifying, uploading, and downloading programs to PIC microcontrollers, the developed system may help the electronics and computer industries, technical shops, educational institutions, and universities. Building, maintaining, and modifying the simulator is made easier by using locally accessible parts. Current-limiting resistors, LEDs, seven-segment displays for visual indication, integrated circuits for control functions, and a computer interface for programming and system operation are among the system's fundamental electronic components. A 12-volt input supply powers the simulator, and the proper circuit components receive regulated 5-volt output levels.

METHODS

The study, entitled **"**Design and Development of an Interactive Programmable Digital Control Simulator for Engineering Education," evaluates the developed simulator based on expert assessment of its acceptability as an instructional and training device. The evaluation focuses on the following criteria:

- *Safety and Usability***:** The simulator is safe to operate and easy to use during laboratory and training activities.
- *Portability and Functionality***:** The simulator is designed to be portable and capable of supporting practical digital control training activities.
- *Cost-Effectiveness***:** The design emphasizes the use of locally available materials to reduce development and production costs.
- *Durability***:** The simulator is assessed based on the quality of its materials, construction, and ability to withstand regular use.
- *Overall Acceptability:* Expert ratings are used to determine the simulator's suitability as a practical instructional tool for engineering education.

The descriptive procedure of the PCB assembly noting the following precautions:

1. Use soldering iron rated 30 watts or less for the PCB assembly.
2. Never remove the protective wrapping unless it is to be inserted in to its socket.

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3. Note carefully the orientation of all polarization components (electrolytic capacitors, LED's,
4. diodes, transistors, IC's), make sure they are correctly mounted.
5. The LEDs should be mounted with sufficient height from the PCB or board surface (>20mm from led top to PCB surface) to allow them to protrude on the front panel after cabinet mounting. See the project

This study employed a descriptive research design. The creation of a programmable digital circuit board for Peripheral Interface Controller (PIC) microcontroller programming and simulation was the main goal of the project. The developed unit has LED indicators, seven-segment displays, IC sockets, push-button switches, toggle switches, and other essential accessories. Its dimensions are roughly 9.5 × 6.5 × 3.0 inches (L × W × H). A PIC microcontroller is used by the programmable digital circuit board to simulate simple control-system applications. The four-sided enclosure is made of fiberglass, and the panels are composed of acrylic and stainless steel. These materials support the intended use of the simulator as a training tool and give the components a suitable structure. The prevailing conditions and the respondents' opinions of the developed system were evaluated using the descriptive method. A survey questionnaire was used to collect data, which was then corroborated by observations and other suitable evaluation techniques.

The researchers were able to ascertain the respondents' opinions about the developed programmable digital control simulator's functionality, usability, and acceptability by using this method. 240 technical support staff members and engineering faculty members made up the study population. To choose respondents with relevant experience and knowledge of the developed system, purposeful sampling was used. The sample comprised 22 engineering faculty members and 10 technical support staff, for a total of 32 responders. This chapter covers bills of materials, tools and equipment, design, flow charting, diagramming, operation sample programs, and the preparation and acquisition of the chosen samples for experimentation. A. The project's development: The Programmable Digital Control Simulator was created by the researcher. through reading the most recent books, journals, and magazines online. interviewing advisors, friends, and coworkers to confirm the project's availability and prevent duplication or copying. Where the materials and components required for the project in question were available Building Procedure: The programmable digital control simulator was built using the following steps: Get all the parts and supplies needed for the project ready. Create the schematic diagram and give each component and connection the correct label. In accordance with the schematic design, lay out the PCB foil pattern.

Solder the electronic components firmly after inserting them into the PCB's designated locations. Using extra wires, attach the eight LED indicators to the appropriate terminals on the board, making sure to solder the connections correctly. Attach the seven-segment LED display to the board's appropriate terminals. To make it easier to test, insert, and program the programmable integrated circuit, install an IC socket on the board. Attach the toggle switch to the board's designated terminals. To guaranty correct identification of the test connections, use a black wire for the negative probe and a red wire for the positive probe. • Operation: easy to install, exciting to operate, accuracy and functionality, learn knowledge in programming. PIC microcontroller burner.



Figure No.1 *The interactive programmable digital control simulator prototype aims to enhance engineering education and laboratory training.*

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Figure 1 illustrates that includes a large breadboard, input switches, LED indicators, seven-segment displays for output monitoring, and IC sockets for programming and testing. The compact design provides a safe and organized environment for students to construct, program, test, and troubleshoot digital circuits.

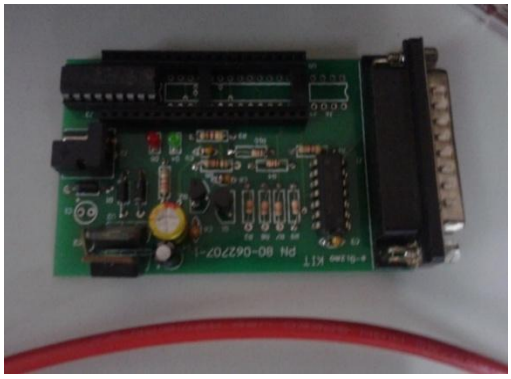

Figure No.2 *A programmable microcontroller interface/control board used in a digital control simulator.*

Figure no. 2 shows the electronic parts, indicator LEDs, input/output terminals, a microcontroller/IC socket, and a DB-type communication connector for connecting to computers or other devices are all included. Users can load programs, process control signals, and connect the microcontroller to various digital circuits and training applications using this board, which serves as the main control and programming interface.



Figure No. 3 *PICkit 3, an In-Circuit Debugger and In-Circuit Serial Programmer (ICSP) developed by Microchip Technology for programming and debugging PIC microcontrollers*

The green POWER LED is illuminated, signifying that the USB connection is providing power to the PICkit 3. During flashing and debugging, ACTIVE/STATUS LEDs are used to display error/status states or activity (data transfer, read/write operations). The device is connected to a host PC running the MPLAB IDE via the USB cable (right).6-Pin ICSP Header Cable (Left): Transfers firmware or debug code by connecting directly to the target board or microcontroller pins.

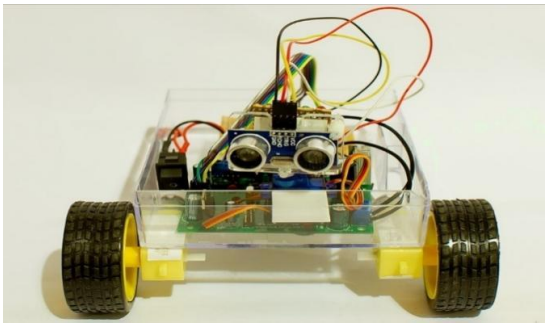

Figure No. *4 a small obstacle-avoiding robot car built on a 2-wheel drive (2WD) smart chassis*

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Mounted prominently at the front, the Ultrasonic Distance Sensor (HC-SR04) functions as the robot's "eyes" to measure the distance to obstacles by sending and receiving ultrasonic waves. The Micro servo Motor (SG90), which rotates the ultrasonic sensor left and right to scan its surroundings, is situated directly beneath it. Microcontroller & Motor Driver Board: To process sensor input and regulate wheel direction, an Arduino Uno and an L298N or L293D motor driver shield are probably housed inside the clear acrylic chassis. DC Gear Motors & Wheels: For movement, two yellow drive wheels are attached to DC motors.Power Switch: To turn on or off the main power circuit, this switch is visible on the left side of the chassis.



Figure No. 5 *A top-down view of a 2-wheel drive (2WD) robotic chassis configured as an obstacle-avoiding robot*

Mounted on the front bracket (left side of the picture), the Ultrasonic Distance Sensor (HC-SR04) detects obstacles in front.Servo Motor: Located directly behind the ultrasonic sensor, this motor rotates it for scanning and panning. Battery Pack: Provides power to the motors and microcontroller by holding AA batteries in the middle.The IC chip, power supply, and motors are connected by wiring on the control board and motor driver circuit, which is located on the right side of the chassis.The microcontroller board is connected to a computer via a USB cable so that firmware can be programd or debugged.

Drive Wheels and Motors: Positioned for mobility and differential steering on either side of the transparent acrylic base.

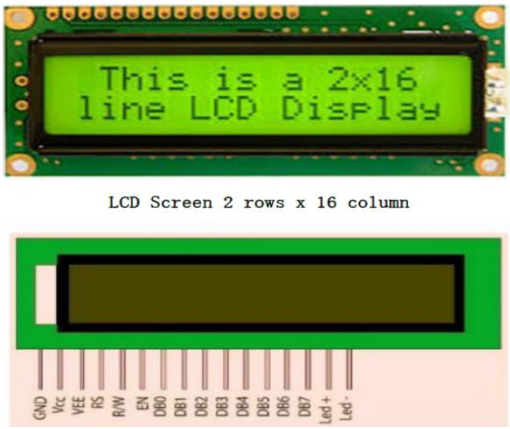

Figure No. 6 *standard 16x2 Character LCD Display module (commonly based on the HD44780 controller) used in embedded systems and electronics projects*

Text Displayed: The top image shows the active text output that reads "This is a 2x16 line LCD Display." Pinout Configuration (16-Pin Header): The bottom diagram shows the standard pin interface for interacting with microcontrollers: GND (Pin 1): Ground connection; Vcc (Pin 2): Positive power supply (usually +5V); VEE (Pin 3): Contrast adjustment pin (connected to a potentiometer); Control Lines: RS (Read/Write, Pin 5): Selects either Read (1) or Write (0) mode; EN (Enable, Pin 6): Latching pin that initiates the data read/write operation; and LED+ / Anode (Pin 15): Positive supply. Transmitter Ultrasonic sensor/Input device/that detect an object within

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10 feet) it emits an ultrasonic sound or waves that transmits and receives. As shown in figure. This device use US sensor as the front sensor and two IR sensor for the left and right respectively. The robot will move forward when there is no object present before it. So, robot will move forward until the Ultrasonic (US) sensor detects any object

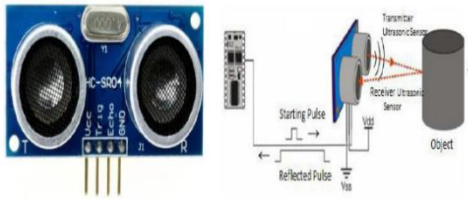

Figure No.7 *The physical module and working principle of an HC-SR04 ultrasonic distance sensor*

Two cylinders, T (transmitter) and R (receiver), as well as four interface pins—Vcc (power), Trig (trigger signal input), Echo (echo signal output), and GND (ground)—make up the HC-SR04 sensor. In order for the Transmitter to produce ultrasonic sound waves, a microcontroller must send a trigger pulse to the Trig pin. These waves reflect off an obstacle and are detected by the Receiver, resulting in a "Reflected Pulse" output on the Echo pin. The pulse duration indicates the time taken for the sound wave to travel to the object and back, allowing the microcontroller to calculate the distance based on the known speed of sound.

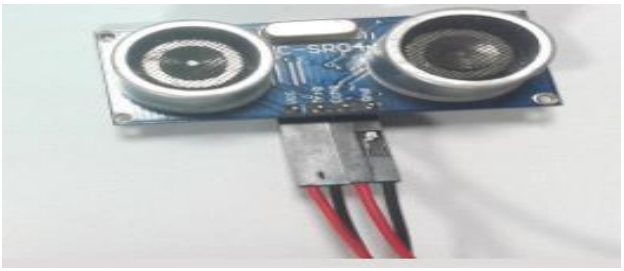

Figure No. 8 *This clearly indicates the design/development, simulation function, and intended educational application.*

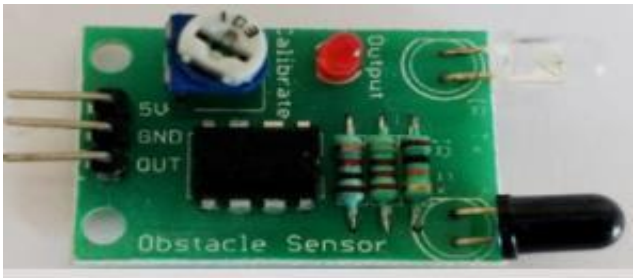

Figure No. 9 *IR (Infrared) Obstacle Avoidance Sensor Module*

R Transmitter & Receiver is made up of a black component (photodiode/phototransistor) that detects reflected infrared light when an obstruction is present, and a clear LED that emits an infrared signal. The "Calibrate" potentiometer enables the sensitivity and range of detection to be adjusted. The analog signal from the receiver is processed by the 8-pin comparator IC (typically an LM393), which then compares it to the threshold established by the potentiometer. Obstacle detection is indicated by a "Output" LED. Pin headers also offer connections for GND, 5V (VCC), and a microcontroller's digital output signal.

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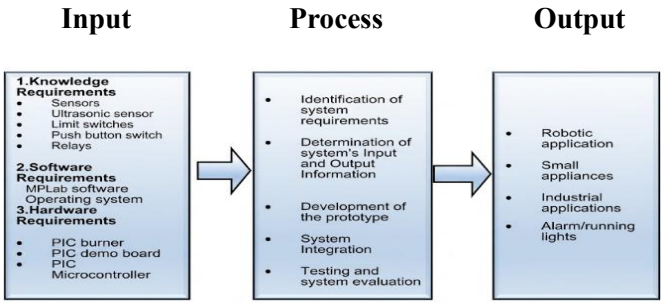

Figure 10. *This figure depicts an Input-Process-Output (IPO) Conceptual Framework for embedded system design and prototyping*

In addition to software tools like MPLab and hardware for microcontroller programming, such as a PIC burner and demo board, the document describes the system requirements for a project involving ultrasonic sensors, limit switches, push buttons, and relays as knowledge requirements. Identifying system requirements, defining I/O parameters, constructing a physical prototype, integrating hardware and software, and carrying out final testing are the sequential development stages that make up the engineering methodology. Robotic applications, small appliances, industrial automation, and alarm or running light systems are among the intended uses for the developed system.

Simulation

- Software Application

Programming technique/lookup table and code for PIC programming.

Table 1. Number Segments & Hexadecimal Equivalent

Number	Segments	Hex
0	1100 0000	$C0
1	1111 1001	$F9
2	1010 0100	$A4
3	1011 0000	$B0
4	1001 1001	$99
5	1001 0010	$92
6	1000 0010	$82
7	1111 1000	$F8
8	1000 0000	$80
9	1001 1000	$98

Table 2. The Lookup Table with basic program approach

```
movlw 1          ; Display a 1
call bin2seg     ; Convert number in W to the segment value
movwf PORTB      ; Send value returned in W to the segments bin2seg
addwf PCL, F     ; Jump into the lookup table
retlw H'C0'      ; Return segment code for 0
retlw H'F9'      ; Return segment code for 1
retlw H'A4'      ; Return segment code for 2
retlw H'B0'      ; Return segment code for 3
retlw H'99'      ; Return segment code for 4
retlw H'92'      ; Return segment code for 5
retlw H'82'      ; Return segment code for 6
retlw H'F8'      ; Return segment code for 7
retlw H'80'      ; Return segment code for 8
retlw H'98'      ; Return
```

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Table No. 1

Number	Segments	Hex
0	1100 0000	$C0
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4	1001 1001	$99
5	1001 0010	$92
6	1000 0010	$82
7	1111 1000	$F8
8	1000 0000	$80
9	1001 1000	$98

Table No. 2

Instruction	Code / Operand	Comment
movlw	1	; Display a 1
call	bin2seg	; Convert number in W to the segment value
movwf	PORTB	; Send value returned in W to the segments bin2seg
addwf	PCL, F	; Jump into the lookup table
retlw	H'C0'	; Return segment code for 0
retlw	H'F9'	; Return segment code for 1
retlw	H'A4'	; Return segment code for 2
retlw	H'B0'	; Return segment code for 3
retlw	H'99'	; Return segment code for 4
retlw	H'92'	; Return segment code for 5
retlw	H'82'	; Return segment code for 6
retlw	H'F8'	; Return segment code for 7
retlw	H'80'	; Return segment code for 8
retlw	H'98'	; Return
Sources		

This study has the following specific objectives:

1. To program micro-controller PIC ICs.
2. To create training package for computer software and hardware application.
3. To test and evaluate the acceptability of the Programmable Digital Control Simulator.

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RESULTS AND DISCUSSION

In order to test and program PIC (Peripheral Interface Controller) ICs with input and output devices, the researcher planned to create a full microcontroller-based digital programmable chip board, complete with a driver or demonstration board. The effectiveness of the current procedures was rated as "Fairly Effective," and the status of the Engineering Department's office was evaluated as "Satisfactory" based on the opinions of the two respondent groups—technical support staff and engineering faculty. The loss of employee records, time-consuming record retrieval, erroneous attendance monitoring, applicant record loss, appointment paper processing delays, and the time needed for wage and salary analysis are just a few of the operational issues that the respondents noted. The suggested remedies included setting up an orderly computerized file-maintenance system, keeping backup copies of employee records, and putting in place computerized attendance monitoring and testing-result systems.

Development of the Programmable Digital Control Simulator

The developed Interactive Programmable Digital Control Simulator provides an interactive platform for teaching and learning basic programmable digital control concepts. The system integrates hardware and software components to allow users to program, upload, and download PIC microcontroller applications. The simulator supports fundamental applications such as sequential lighting, small-appliance control, LCD displays, alarm systems, and stepper-motor operationThe simulator incorporates locally available electronic components, including current-limiting resistors, LEDs, seven-segment displays, integrated circuits, and a computer interface. A 12-V input supply is regulated to provide a 5-V output to the appropriate circuit components. This configuration provides a practical platform for students to observe the relationship between programmed instructions and physical digital outputs.

Programming and Simulation Functionality

The results demonstrate that the simulator can support basic PIC microcontroller programming and digital-output operations. The seven-segment display uses a lookup table that converts numerical values into corresponding segment codes. For example, the hexadecimal codes for the numbers 0 to 9 are provided in the manuscript, demonstrating how programmed data can be converted into visual output through the display.The programming example further demonstrates the use of instructions such as movlw, call, movwf, addwf, and retlw to process and display numerical values. This feature allows students to observe how programming instructions control electronic outputs, thereby strengthening their understanding of the relationship between software commands and hardware operation.

Usability and Functionality

The simulator was designed to be easy to install and operate while providing opportunities for students to develop programming knowledge. The evaluation criteria specifically included safety, usability, portability, functionality, cost-effectiveness, durability, and overall acceptability. The integration of hardware and software makes the simulator suitable for practical training. Students can experiment with control logic and observe the resulting system responses without relying exclusively on conventional laboratory equipment. This supports the study's objective of providing an accessible training platform for basic digital control concepts.

Cost-Effectiveness and Portability

The use of locally available materials contributes to the potential cost-effectiveness of the developed simulator. The manuscript identifies the high acquisition and maintenance costs of imported digital electronics training equipment as a major concern. In response, the developed system emphasizes locally obtainable components and a design that can be built, maintained, and modified more easily. The simulator is also intended to be portable, allowing it to support practical training activities in different instructional settings. Its relatively

compact and integrated design can provide students with access to programmable digital control exercises without requiring multiple specialized laboratory units.

Educational Application

The developed simulator provides an opportunity for students to connect theoretical programming concepts with practical digital control applications. Through programming and simulation activities, students can examine digital inputs and outputs, control logic, sequencing, timing, and microcontroller-based operations. Overall, the results indicate that the simulator has the functional features required to serve as a supplementary instructional tool for engineering education. However, because the manuscript does not present the actual numerical results of the expert evaluation, conclusions regarding the degree of acceptability, usability, or effectiveness should be supported by the completed evaluation data before making quantitative claims.

Recommendations

The study's conclusions lead to the following suggestions being put forth One. Develop, build, and run the Universal Programmable Digital Control Simulator through a series of workshops involving students, instructors, and technicians in Electronic and Computer Engineering. Industries, technical shops, retail establishments, and educational institutions may include these workshops in their development plans. Two. For engineering students enrolled in courses on Electronic and Computer Technology and Engineering, make the Programmable Digital Control Simulator a project requirement. Students will gain hands-on experience in programming, circuit design, and digital control applications as a result.Future research and project development will increase the testing and programming of programmable integrated circuits. Applications like stepper motors, alarm systems, programmable lighting systems, and other PIC-based industrial applications should be the subject of additional testing and data gathering.

The Programmable Digital Control Simulator's electrical connections, computer configuration, and related parts should all undergo routine maintenance and inspection. To maintain the simulator's efficacy and efficiency in programming and PIC-based applications, regular testing and appropriate maintenance should be carried out.

Summary and Results

The Interactive Programmable Digital Control Simulator is a portable, easy-to-use, and affordable educational tool that effectively combines PIC microcontroller programming, hardware, software, and simulation. During simple digital control exercises, students can write code and directly observe corresponding hardware outputs thanks to the system, which is built using locally available components. These findings support the simulator as an additional teaching tool, but the Results and Discussion section would be greatly strengthened by adding the quantitative expert-evaluation ratings.

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