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DIGITAL CONSOLE CONTROL SIMULATOR BASED ON NEXTION FOR MOBILE X-RAY CONDENSATOR DISCHARGE

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ABSTRACT As a safe and radiation-free educational tool, this study presents the development of a Nextion-based digital control console simulator for mobile X-ray systems operating on the capacitor-discharge principle. The simulator is designed to replicate capacitor charging and discharging processes while allowing interactive adjustment of key exposure parameters, including tube voltage (kV) and exposure time (mAs). A literature review was conducted to establish the theoretical foundation, referencing textbooks, research articles, Standard Operating Procedures (SOPs), and national and international journals. System testing was performed using 26 imaging protocols representing four anatomical groups: (1) thoracic region, (2) cranium and spine, (3) upper extremities, and (4) lower extremities. Experimental results show that the simulator achieves high measurement accuracy, with a mean voltage error of 1.05 V (1.46% error) and an overall voltage accuracy of 98.57%. The average exposure time measurement deviation was ±0.01 s, corresponding to an accuracy of 99.08%. The system incorporates a user-friendly Nextion interface, enabling configuration of tube voltage within 30–200 kV and exposure settings from 2–30 mAs. These findings demonstrate that the developed simulator is suitable for radiology education, offering a safe, accurate, and accessible platform for practice-based learning without radiation exposure.

KEYWORDS X-ray simulator, capacitor-discharge system, digital control console, radiology education, exposure parameter control, mobile X-ray

I. INTRODUCTION

Portable X-ray systems have become an essential tool in modern medical diagnostics, particularly in emergency and intensive care units where rapid scanning is required without moving the patient[1]These portable units offer flexibility and speed, enabling radiographic examinations at the patient's bedside, which can be critical in life-threatening situation [2]However, operating these systems requires a thorough understanding of exposure parameters, particularly kilovolts (kV) and milliampere-seconds (mAs) as improper configuration can result in poor image quality or excessive radiation exposure[For students, mastering these technical aspects is challenging, especially when access to real equipment is limited or involves safety risks [3].

Historically, the dangers of radiation were often overlooked, as demonstrated by the case of Clarence Dally, Thomas Edison's assistant, who died in 1904 as a result of prolonged exposure to X-rays. This incident highlights the importance of radiation safety and the need for adequate training before handling radiological equipment.

To address this issue, simulation-based learning has become a safer alternative, allowing trainees to practise technical procedures without the risks associated with ionising radiation. Simulators not only reduce the risk of exposure but also provide a flexible and repeatable learning environment that can be integrated into classrooms and laboratories.

Several previous studies have attempted to develop simulators for mobile X-ray systems using the principle of capacitor discharge. However, many of them are limited in scope—focusing on a single anatomical region, fixed exposure parameters, or lacking real-time interactivity [4], [5].

This study introduces a digital console control simulator that integrates a Nextion touchscreen interface with an Arduino-based control system to mimic the behaviour of a mobile X-ray unit using capacitor discharge [6]This simulator allows users to interactively adjust and monitor kV and mAs values, simulating the capacitor charging and discharging cycle with visual indicators and real-time feedback [7]

This system was tested on 26 radiography protocols covering four anatomical regions and demonstrated high accuracy. The main objective was to provide a safe, effective, and educational tool to enhance radiology training by combining technical precision and operational realism—preparing students for clinical practice without compromising safety.

II. RESEARCH METHODS

This study proposes the development of a digital console control simulator that combines hardware and software to mimic the operation of a mobile X-ray system using the principle of capacitor discharge. The main processing unit is an Arduino microcontroller that handles real-time communication with the touch screen interface from Nextion. Users can change the kilovolt (kV) and milliampere-second (mAs) values for 26 different radiography protocols, which are similar to the exposure settings used for scanning the chest, abdomen, extremities, and head. The system is also equipped with an LED light to indicate the capacitor charging status, so users know when it is ready for exposure.

This system is equipped with programmed logic and visual feedback mechanisms that mimic the capacitor discharge cycle of the original mobile X-ray unit, ensuring safe and accurate simulation[8]. The touch screen allows users to select body parts and change exposure settings. Arduino processes this input and activates the appropriate output. The simulator is designed to operate without emitting ionising radiation, so it can be used in classrooms and for practical training without endangering anyone's health. The addition of digital components ensures that all data is accurate, repeatable, and easily modifiable for future educational improvements[[9], [10], [11], [12], [13]

The development process follows a specific sequence: first, literature review and needs assessment; then, hardware design, software programming, and repeated testing. Each radiography protocol is developed using standard clinical methods and reviewed by experts to ensure its functionality[9], [14] [15]Functional testing is conducted to ensure the simulated kV values are accurate.

In Fig. 1, the flowchart shows a systematic framework for carrying out an engineering or scientific research project. The project begins with reading the literature as a conceptual foundation and studying the basic theory, the latest technology, and previous research that supports the development of the tool or system to be designed.

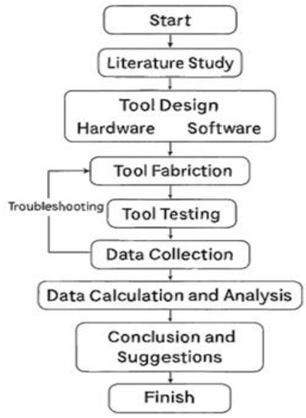

FIGURE 1. **Research stages**

Literature studies serve as scientific references and references for determining the appropriate design parameters and methodology. The tool design process is the next step, which includes the integration of software and hardware. Functionality, efficiency, and safety must be considered when designing this tool, especially if it is intended for medical purposes such as radiology simulators.

Once the design is complete, the project proceeds to the fabrication stage, where the physical and digital components of the tool are created. Material selection, component assembly, and control system programming are all part of this process. Next, a testing phase is conducted to evaluate the overall performance of the tool. The flowchart offers a problem-solving path that returns to the fabrication stage in the event of incompatibility or malfunction. This cycle demonstrates the principle of iterative engineering, whereby repeated improvements and evaluations are made until the tool meets the desired operational standards. This method is particularly important for the creation of technology-based educational tools as it ensures that the final product is not only useful but also safe to use during learning.

Once the tool has been declared fit for purpose, the process continues with the collection of data using the tool in the designed scenario. To evaluate the accuracy, efficiency, and contribution of the tool to the research objectives, the collected data is analysed qualitatively and quantitatively. The results of this analysis are used as a basis for drawing conclusions and making recommendations. These recommendations summarise key findings and offer a way forward. The project will produce academically accountable scientific work and useful practical tools. This structure is well suited to radiology simulator projects or other technical research that requires structured documentation, iterative evaluation, and high precision during each stage of development.

A. BLOCK DIAGRAM

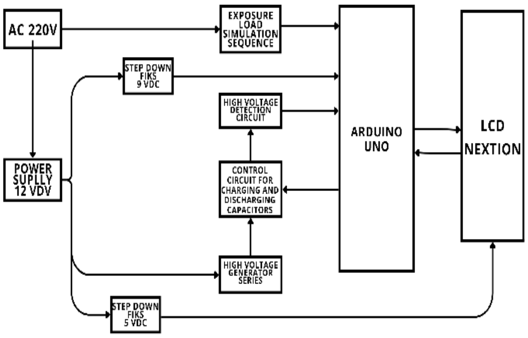

FIGURE 2. **Block Diagram**

In Fig. 2, this system uses a 220V AC supply that is converted to 12V DC, then stepped down to power the Arduino Uno and Nextion LCD. The Arduino controls capacitor charging, reads the voltage through a divider, and controls the load simulation and user interface. The Nextion LCD displays the system status, radiography protocol options, and kV and mAs settings.

The capacitor charging circuit operates automatically based on the voltage value set by the user. The Arduino monitors the voltage via the ADC and stops charging when the limit is reached. The actual voltage is displayed on the LCD to ensure accuracy and control during the process.

Exposure simulation using LEDs as visual indicators instead of X-ray tubes. When the button is pressed, the LEDs light up brightly, indicating the exposure process. This system is safe for training because it does not produce radiation, but still provides a realistic technical experience[16], [17], [18], [19], [20].

B. FLOW CHART

As shown in Fig. 3, the system starts by initialising the Nextion LCD when the device is activated. It displays data such as the student's name, student ID number, and supervising lecturer. After the user presses the "OK" button, the system will enter a page that fills in information about the patient. This page displays the patient number, name, date of birth, and the body part to be examined. If the data is correct, the system returns to the main page, where the kV and mAs parameters, as well as the selected body part, are displayed.

On the main page, users can choose to perform automatic settings or manually adjust the kV and mA values. If there are no changes, press the OK button to start the capacitor charging process. The incoming voltage will be displayed on the screen in real time. When the voltage reaches the specified value, the system status changes to "Charging", and the system is ready to perform exposure simulation.

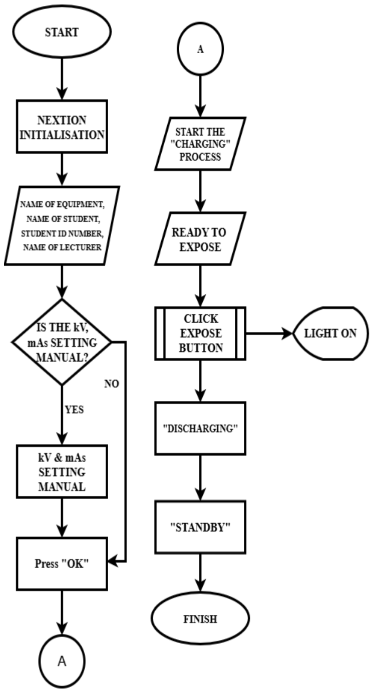

FIGURE 3. **Block Diagram**

After pressing the exposure button, the LED indicator lights up as if it were an active X-ray tube. Next, the system enters the "Discharge" phase, which is the process of discharging the capacitor. The Arduino voltage will be monitored until it drops to a safe value (±0.9V)[[16]After that, the system status will change to "Standby", indicating that the device is ready to be used again or turned off. All of these steps are designed to provide a safe, realistic, and educational simulation experience without radiation.

C. HARDWARE DESIGN

D. The structure shown in Fig. 4 is a compact, vertically oriented radiography simulator, and the front panel has an exposure indicator, Nextion LCD, and control buttons. The cooling fan is located on the side. At the bottom, the 220V AC port and MCB serve as current protection. The internal system consists of a fixed voltage regulator, voltage divider, capacitor charging circuit, AC to 12V DC regulator, and AC to DC power converter. Through the LCD, Arduino regulates the process based on user input. Then, through the ADC, it monitors the voltage and stops charging when the limit is reached. The system flowchart shows the sequence of operations from power supply, parameter setting, capacitor charging, to exposure simulation. This supports safe and interactive technical learning and can be further developed with additional features such as temperature sensors, data storage, or wireless connectivity. When the button is pressed, the LED lights up as an exposure simulation, displaying the status and parameters in real-time on the LCD.

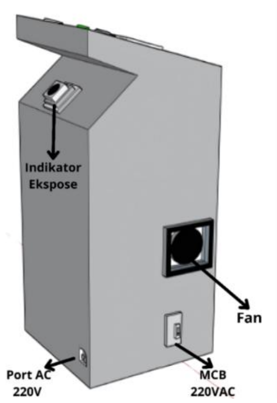

FIGURE 4. Module Corner Design

FIGURE 5. Front Module Design

As shown in Fig. 5, this device has a compact vertical design, and at the top there is a control panel consisting of three buttons in black, green and yellow that serve as power and system status controls. Modular components that can be removed. The bottom has a width of 50 cm, which means that this device can be easily placed in a practice room. On the other hand, the front has an access door for inspection or component replacement. This device is suitable for technical simulations or training due to its ergonomic structure and easy-to-understand controls. In addition, a digital interface and additional features can be added to improve functionality and operational safety.

E. SOFTWARE DESIGN

The software, designed to interactively and educationally replicate radiology workflows, is developed for a Nextion-based digital console control simulator. Academic identities such as student names, student ID numbers, and supervising lecturer names are displayed on the system's home page, which serves as formal documentation and academic validation. To provide clear context for users, this display also shows the developer institution and tool title. The simulator can be used in this way as a technical aid and as a professionally designed learning tool.

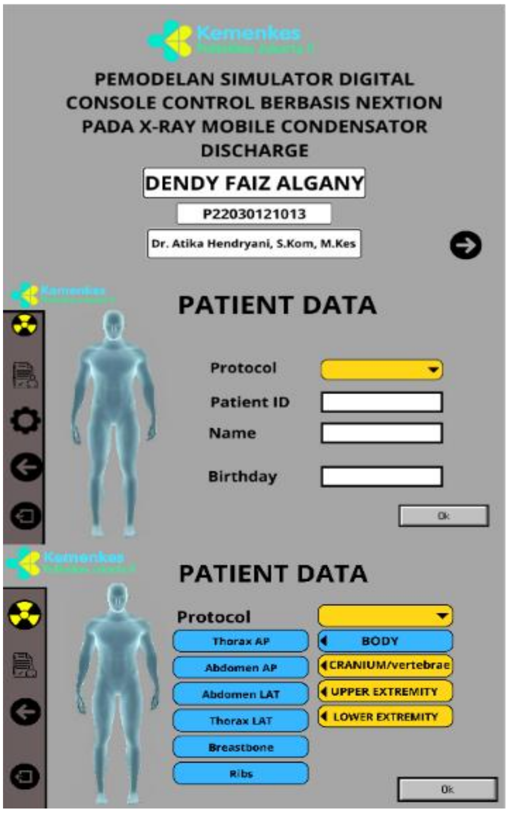

FIGURE 6. Display Design When the Tool is Turned On

As shown in Fig. 6, the initial screen prompts the user to enter important data such as name, date of birth, ID, and examination protocol on the patient data input page. This data is used to simulate the patient identification process prior to radiology procedures, as occurs in the real world. The system will display exposure parameters such as kV and mAs, as well as the status of the device, which changes according to the simulation stage after the data is entered. This software not only teaches technical skills, but also provides users with procedural medical documentation.

The capacitor discharge-based mobile X-ray system simulator relies heavily on the user interface design using Nextion modules. The purpose of this design is to support students and medical personnel in learning techniques for using radiography equipment.

The Nextion Editor platform is used for development, enabling the design of visually effective graphical interfaces. The interface structure consists of several interactive pages. The first is a page for identifying tools and developers. The next page enters patient data, which includes identity, name, and date of birth. In addition, there is a page for selecting examination protocols based on anatomical region (body, cranium/vertebrae, upper and lower extremities). Exposure parameter values, such as kV and mAs, are programmed and can be adjusted by the user manually or automatically.

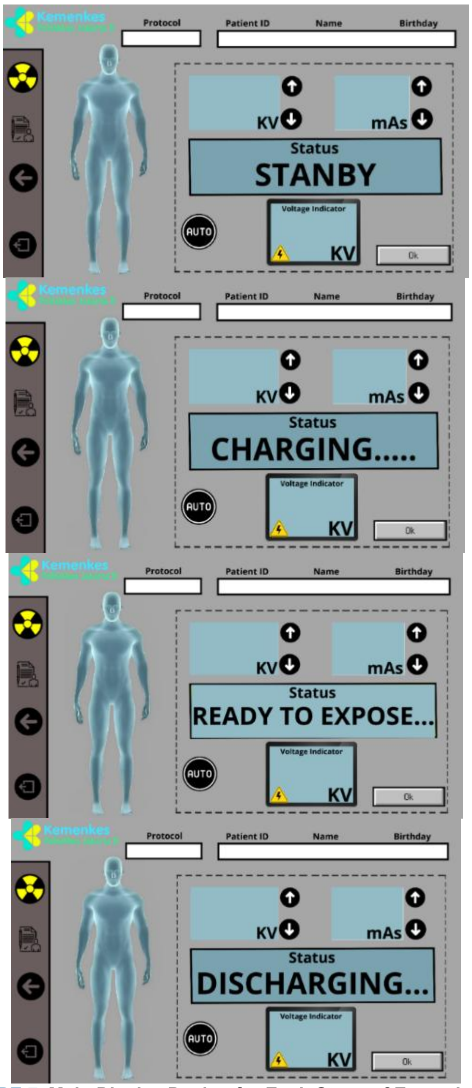

FIGURE 7. Main Display Design for Each Stage of Execution

The main page displays in Fig. 7 showed the changing operational status of the device, including indicators such as "STANDBY", "CHARGING", "READY TO EXPOSE", "DISCHARGING", and others. These statuses are updated in real time via serial communication between the Arduino microcontroller and the Nextion display using the UART protocol. In addition, digital indicators display the actual capacitor voltage values, allowing users to view the charging and discharging processes.

In addition, this design has an easy-to-understand navigation system based on touch buttons and features to control exposure parameters manually and automatically. By using text buffers and callback functions in Arduino programming, the interface receives user input quickly and accurately. Overall, this Nextion-based HMI design helps develop a digital technology-based radiology simulator and makes the workflow of mobile X-ray equipment safe and educational.

F. DATA COLLECTION TECHNIQUES

To support the evaluation process of the Nextion-based digital console control simulator on a mobile X-ray system with a capacitor discharge principle, the data collection method in this study was designed to support the system evaluation process. A series of trials and direct observations of system performance ensured that the data complied with the established radiography protocol.

1) Capacitor Voltage Measurement

were performed using an AVO meter connected to the circuit test point. The measurement results were compared with the voltage values displayed on the Nextion screen to assess the accuracy of the simulation system.

2) Exposure Time Measurement (mAs)

The exposure time is simulated by the LED light as an indicator. A stopwatch is used to record the duration of the light, which is then compared to the mAs value set via the digital interface.

3) Charging Time Testing

Capacitor The charging time is recorded using a stopwatch until the voltage reaches the specified value. The test is conducted at several voltage levels to evaluate charging efficiency.

4) Status Observation

Status systems such as "Charging," "Ready to Expose," "Exposing," and "Discharging" are observed during the process. The aim is to ensure that status transitions proceed according to programming logic.

5) Radiography Protocol Validation

The simulator was tested using 26 radiography protocols from various anatomical categories. Each protocol was examined to ensure that the kV and mAs values complied with clinical exposure standards.

III. RESULTS AND DISCUSSION

At this stage, after the module has been developed, several measurements have been carried out. The author will present the data obtained from these measurements.

A. PHYSICAL FORM OF THE DEVICE

There is a cooling fan that functions to maintain air circulation in the device as shown in Fig. 8, thereby preventing overheating of the internal components. At the top, there is a port for the expose button, which allows for certain operations or settings on the device. In addition, there is a handle on the side of the device that makes it easier for users to move the device more practically, providing convenience in the process of transporting or arranging the device as needed.

FIGURE 8. **Physical Appearance of the Device Side View**

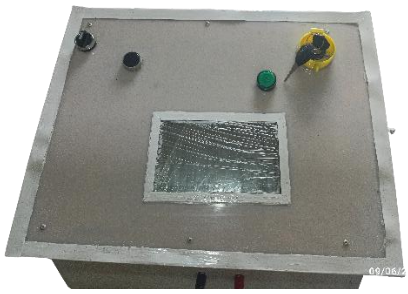

FIGURE 9. **Physical Appearance of the Device ( ) Top View**

Fig. 9 shows a top view of a control device used by the operator. On the front panel, there are several indicators that show the status of the device. At the top left, there is a selector that allows the device to be set to " ", while in the centre there is an input voltage indicator that shows the power supply condition. Next to it, there is a green indicator that indicates that the device is ready for exposure, or in "Ready" mode. In addition, there is a yellow contact key that serves to activate or deactivate the device.

B. INTERFACE *SCREEN*

As shown in Fig. 10, the interface of contemporary digital radiography systems is designed to improve the accuracy and efficiency of medical imaging processes. Patient identity, exposure parameters, and system status are displayed in two screen configurations of the X-ray device with automatic mode (AUTO) active. On the first screen, the system displays the patient ID , with kV 80, mAs 12, and actual voltage 80.40 kV. On the second screen, it displays the patient ID with kV 73, mAs 6, and actual voltage 73.05 kV. Both screens show the status "ready for exposure", indicating that the system is ready for exposure. The operator can view the human anatomy with the imaging area indicator, represented by a red box.

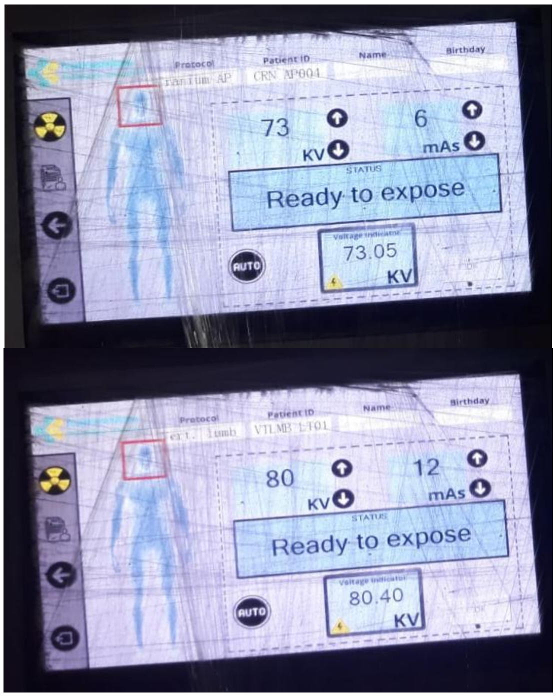

FIGURE 10. **Physical Display of the Device Screen**

The navigation icons and protocol presets on the side of the screen are additional features that support a structured workflow and reduce manual input errors. The system can change exposure parameters according to predetermined protocols in automatic mode, which improves patient safety and consistency of diagnostic results. Designed to support efficiency and safety-based radiology practices, this interface combines digital technology and radioprotection principles.

C. STANDARD OPERATING PROCEDURES (SOP)

The following are the steps for the proper and correct use of the Mobile X-Ray Console control device:

- Ensure that the X-Ray Mobile console control device is ready for use and that all components are properly connected.
- Connect the power cable to a 220V AC mains power source to supply electricity to the device.
- Activate the Miniature Circuit Breaker (MCB) to supply electricity to the device.
- Turn the ignition key to the active position to activate the device system.
- Turn the rotary switch to the active position to start the device preparation process.
- Enter the patient's details and the body part to be examined, then press the OK button to continue.
- Adjust the kV and mAs settings as needed for the examination, if necessary.
- Press the OK button until the "charging" indicator appears on the screen, indicating that the device is charging.

- If the device status has changed to "Ready to display", press the display button once to start the display process. Once the display process is complete, the device will automatically discharge. Wait until the device status changes to "Standby" before proceeding to the next step or turning off the device.

D. VOLTAGE MEASUREMENT TESTING

Testing was conducted to evaluate the accuracy and efficiency of the simulator system in simulating radiographic exposure parameters, specifically voltage (kV) and exposure time (mAs). The testing process involved 26 radiology examination protocols covering four anatomical regions: Body, Cranium/Vertebrae, Upper Extremity, and Lower Extremity. Each protocol was tested with kV values ranging from 30 to 200 kV and mAs values ranging from 2 to 30 mAs. The capacitor voltage was measured using two methods: digital reading via the Nextion screen and manual measurement using an AVO meter. The measurement results showed that the average voltage error was 1.05 volts with a percentage error of 1.46% ( ), resulting in a system accuracy of 98.57%. Meanwhile, exposure duration testing showed an error of ±0.01 seconds with an accuracy of 99.08%, indicating the stability of the system in regulating exposure time with precision.

Data analysis was performed using a descriptive statistical approach, employing average calculations and percentage deviations to assess the consistency between the set values and the actual readings. Each protocol showed consistent measurement patterns, with deviations within technical tolerance limits. In addition, the capacitor charging time was tested based on voltage variations, showing a duration of between 3 and 19 seconds, with an average charging time of 10.9 seconds. This pattern shows that the system is capable of efficiently adjusting the energy charging process according to exposure requirements. These results reinforce the validity of the simulator as an educational tool capable of realistically and safely replicating the working characteristics of capacitor discharge-based X-ray equipment.

Overall, the digital console control simulator demonstrates superior performance in measurement accuracy, capacitor charging efficiency, and exposure control stability. The responsive Nextion interface allows for real-time parameter setting and monitoring, supported by LED indicators that simulate X-ray tubes. With its modular design and high accuracy, this tool is highly suitable for use in radiology education as a safe, effective, and practical learning medium that supports the improvement of electromedical students' competencies.

1) Voltage Accuracy Test

The voltage accuracy test in Fig. 11 on the digital console control simulator was carried out by comparing the voltage values displayed on the Nextion screen with the manual measurement results using an AVO meter, covering 26 radiography protocols with a range of 30–200 kV. The test results showed an average error of 1.05 volts or 1.46%, meaning that the system's accuracy reached 98.57%. Statistical analysis showed that the measurement deviation was within technical tolerance limits, with stable and consistent voltage readings in various scenarios. The tests were conducted repeatedly to ensure the reliability of the system in displaying actual values in real time, reinforcing the simulator's validity as a precise and safe educational tool for radiology training. With high accuracy and a microcontroller-based monitoring system, this simulator provides a realistic technical experience without the risk of radiation exposure and supports practice-based learning in the field of electromedicine.

FIGURE 11. Voltage Testing

TABLE I
STRESS TESTING ON MODULES AND MEASURING INSTRUMENTS

Voltage Setting (KV)	Measurable Voltage Test		Error	Error Percentage	Accuracy
	Modul	Avo			
50	51.6	52.6	1.00	1.90%	98.10%
52	52.41	53.5	1.09	2.04%	97.96%
54	54.39	55.3	0.91	1.65%	98.35%
56	56.35	57.03	0.68	1.19%	98.81%
58	58.86	59	0.14	0.24%	99.76%
60	60.35	61.3	0.95	1.55%	98.45%
62	62.13	63.2	1.07	1.69%	98.31%
64	64.52	65.6	1.08	1.65%	98.35%
68	68.49	69.5	1.01	1.45%	98.55%
70	70.27	71.3	1.03	1.44%	98.56%
Mean	59.94	60.83	0.90	1.48%	98.52%

In Table I, the results of module voltage testing with Avo have an error value of 0.90, an error percentage of 1.48% and an accuracy level of 98.52%.

2) Ready to Expose Indicator Test

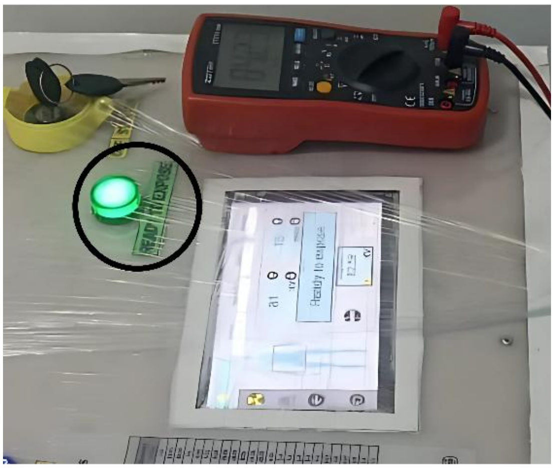

FIGURE 12. Testing the Ready to Expose Indicator

Fig. 12 showed the digital console control simulator, the "Ready to Expose" indicator serves as a visual marker that the system has reached the capacitor voltage according to the preset value and is ready to perform the exposure process. When this indicator is active, it is usually displayed in the form of a green LED light. This indicates that the capacitor charging is complete and the system is in the best condition for the shooting simulation. This feature is particularly important for educational purposes as it provides immediate feedback to the user and ensures that exposure is only performed when the system is truly ready, enhancing operational safety and simulation accuracy.

3) Exposure Indicator Test

FIGURE 13. Exposure Indicator Test

Fig. 13 showe the exposure indicator test shown in Figure 13 was conducted by simulating the irradiation duration using an LED as a substitute for an X-ray tube, where the LED's duration of illumination represented the preset mAs value. This test aimed to assess the system's accuracy in regulating the exposure duration according to the mAs parameters programmed through the Nextion interface. Each mAs value was converted to a time unit (seconds) and compared with the measurement results using a digital stopwatch. The test results showed that the system had an average time error of ±0.01 seconds and an accuracy of 99.08%.

This simulation not only provides clear visual feedback to users, but also allows for technical evaluation of the stability and reliability of the exposure time control system. With this approach, students or operators can understand the relationship between mAs values and exposure duration in a practical manner, without the risk of radiation exposure.

The LED-based exposure indicator test is an important part of validating the simulator as an educational tool, as it is able to represent the exposure process safely, accurately, and in accordance with the working standards of capacitor discharge-based mobile X-ray systems.

IV. CONCLUSION.

The Nextion-based digital console control simulator on the mobile X-Ray system with the capacitor discharge principle successfully represents the radiography device's working process accurately and safely. This system interactively displays exposure parameters such as voltage (kV) and time (mAs), and regulates capacitor charging and discharging with high accuracy, as demonstrated by an average voltage error of only 1.05 volts and a time error of ±0.01 seconds. With an average charging efficiency of 10.9 seconds and system accuracy reaching 98.57%, this simulator is suitable for use as a technical learning medium in the fields of electromedicine and radiology. The modular design, visual indicators, and interface that resemble real clinical conditions make this tool effective, safe, and interactive for improving student competence without the risk of radiation exposure, and it has the potential to be further developed with additional features to support practice-based learning.

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