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Display Development and Simulation of an ESP32-Controlled Automatic Tissue Processor with Touchscreen Time Settings

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ABSTRACT Cancer is one of the leading causes of death worldwide, with the number of patients continuously increasing. Accurate detection and diagnosis through histopathological examination are crucial for effective treatment. One of the processes in histopathology involves the use of an automatic tissue processing machine, which functions to process cancer tissue from its raw state into a mature form, ready for further examination in subsequent histopathological stages. The working principle of this device involves immersing tissue samples in each container (fixation, dehydration, clearing, paraffin infiltration). To achieve optimal results in tissue processing, accuracy in both time and temperature used in the paraffin infiltration container is essential. This device is designed with four containers, with movement controlled by two servo motors that transfer samples from one container to the next. It also uses heating elements to heat the fourth container and a DS18B20 temperature sensor, a 3.2" Nextion LCD touchscreen to display information about the ongoing process, and a buzzer as a signal that the device has completed its operation. An ESP32 microcontroller controls all components. To ensure the device's performance, time measurements were taken for each stage (fixation, dehydration, clearing, and paraffin infiltration) five times, as were temperature measurements. The test results showed that the average accuracy of time measurements was 99.67% for fixation, 99.12% for dehydration, 98.99% for clearing, and 98.93% for infiltration, with error values of 0.33% for fixation, 0.88% for dehydration, 1.01% for clearing, and 1.07% for infiltration. The temperature accuracy was 98.57%, with an error of 1.43%. These results indicate that this automatic tissue processing simulation device has a high level of accuracy in controlling time and temperature at each stage of the process.

INDEX TERMS Automatic Tissue Processing, ESP32, Nextion 3.2' touch screen LCD, Accuracy

1) INTRODUCTION

Cancer is one of the deadliest diseases worldwide [1]. According to the World Health Organization (WHO), cancer is the uncontrolled growth and spread of cells that can metastasize to surrounding tissues, causing abnormal growth in body cells that can ultimately become malignant [2]. These cells can continue to grow, develop, and spread to other parts of the body, potentially leading to death [3]. According to WHO data, cancer is the leading cause of death worldwide, with cancer being the second leading cause of death globally, accounting for 13%, after cardiovascular diseases. Every year, 12 million people worldwide suffer from cancer, and 7.6 million of them die. It is estimated that by 2030, this number could reach up to 26 million people, with 17 million of them dying from cancer, especially in low and middle-income countries where the incidence is rising more rapidly [4]. To detect and diagnose cancer, supporting examinations in an anatomical pathology laboratory are needed, specifically histopathological examination.

Histopathology is a branch of pathology that examines tissue changes resulting from disease. This technique involves examining biopsy or surgical tissue samples that have been cut and stained with special dyes under a microscope. Histopathology can provide valuable information about the diagnosis, prognosis, and treatment of a disease [5].

The tissue processing in histopathology involves a series of steps that prepare the tissue sample for microscopic examination. These steps include fixation, sectioning, dehydration, clearing, paraffin infiltration, embedding, sectioning, and staining [5].

Advances in medical science, including in the field of pathology, require increasingly sophisticated tools and methods to support the diagnostic process. Histopathological examination is a crucial procedure in diagnosing various types of diseases, particularly cancer. The manual tissue preparation process in histopathology is time-consuming and prone to human error. These manual steps can affect the waiting time for test results and the quality of the examination, which in turn impacts the diagnosis and treatment of patients.

One tool that can help in the effective and efficient processing of tissue in the fixation, dehydration, clearing, and paraffin infiltration stages is Automatic Tissue Processing. With the use of Automatic Tissue Processing, the tissue preparation process can be done automatically and continuously, improving laboratory work efficiency. Additionally, this tool can minimize human errors and standardize the tissue preparation process.

Previous research [6] used an Arduino Mega2560, a DS18B20 Sensor, and a 16x2 LCD. A study [7] used an Arduino Nano, DS18B20 Sensor, and a 16x2 LCD in its design. Both of these studies utilized a Liquid Crystal Display (LCD) 16x2 for their user interface.

A. ANATOMICAL PATHOLOGY

Anatomical Pathology is a discipline that studies diseases by analyzing the anatomy of tissues taken from a patient's body. These tissues are examined in an anatomical pathology laboratory to determine the type of disease the patient is experiencing [8]. The process in the Anatomical Pathology laboratory consists of three stages: the pre-analytical phase, the analytical phase, and the post-analytical phase. The pre-analytical phase is crucial in preparing the routine histopathology and cytology processes performed in the laboratory. The analytical phase begins with tissue sampling from the patient's body, where the identity of the forms and tissues is labeled, followed by tissue fixation procedures, appropriate packaging, and shipment of the tissue to the anatomical pathology laboratory [9].

In general, anatomical pathology is divided into two main categories: histopathology and cytopathology. Histopathology is the examination of entire tissue samples under a microscope, involving the analysis of intact tissue from biopsies or surgeries. This process is supported by special staining techniques and additional tests, such as the use of antibodies to identify various tissue components. Meanwhile, cytopathology is the examination of single cells or small groups of cells obtained from scraping or aspirating fluid or tissue, also conducted under a microscope. Sample collection in cytology is typically done through non-invasive procedures. A typical example of cytology testing is the Pap smear, which is performed on the cervix.

Anatomical pathology tests provide a variety of information related to the identification of various diseases, including cancer, tumors, kidney and liver diseases, autoimmune disorders, and infections.

B. HISTOPATHOLOGY STAGES

The tissue processing for histopathology involves a series of steps to prepare the sample, as follows:

1) Fixation, Dehydration, Clearing, Impregnation (Tissue Processing)
2) Embedding
3) Sectioning
4) Staining
5) Microscopic Examination of the Results

C. TISSUE PROCESSING

Tissue processing is the initial step in preparing tissues for histopathological examination. This process involves several stages, with 12 containers containing reagent solutions. These containers represent four main processes as follows:

1) Fixation is one of the crucial stages aimed at preserving the tissue morphology in its original or physiological state. Fixation is performed immediately after tissue collection by immersing the tissue in a fixative solution. The tissue is soaked for a specified period. The goal of fixation is to preserve the tissue morphology as close as possible to its original state, maintaining its structure and size without any changes [10].

2) Dehydration is the process of removing water from the tissue using alcohol. Dehydration is carried out gradually with increasing concentrations of alcohol, allowing the water in the sample organ to be removed slowly and evenly. If dehydration is performed directly with absolute alcohol (100% concentration), the tissue may harden quickly, potentially leading to damage during the cutting process.

3) Clearing is an essential step in preparing tissue for microscopic examination under a light microscope. The clearing process is done to remove the tissue's water content, making it suitable for embedding in materials such as paraffin.

4) Paraffin Infiltration is aimed at ensuring that the tissue does not get damaged during the cutting process using a microtome. This process is performed by immersing the tissue in liquid paraffin.

D. MICROCONTROLLER

The ESP32 is a microcontroller developed by Espressif Systems as a successor to the ESP8266. The advantages of the ESP32 compared to other microcontrollers lie in its higher number of pins, smaller pin size, and larger memory capacity. The ESP32 is a highly integrated chip that combines processor, storage, and GPIO access [11].

E. SERVO MOTOR

A servo motor is a type of motor that utilizes a closed-loop feedback system to send position information back to the internal control circuit. With control inputs that can be either analog or digital signals, servo motors are commonly used in applications that require precise rotational positioning. The rotation angle of the servo motor is controlled by the pulse width it receives through the signal wire. Typically, servo motors only move within a specific range of angles and do not operate continuously. However, in some situations, a servo motor can be modified to move continuously [12].

A servo motor is controlled by sending a Pulse Width Modulation (PWM) signal through the control wire. The duration of the "pulse" determines the rotational position of the servo motor shaft. The motor shaft will move and remain at the commanded position after receiving the pulse duration. The servo motor will try to maintain that position with its torque, even if there is an attempt to rotate or change its position. The position of the servo motor will not remain stationary indefinitely, as the "pulse" signal must be repeated every 20 ms to maintain the motor's position.

A servo motor consists of a DC motor, a gear system attached to the DC motor shaft, which serves to slow down the shaft rotation and increase the torque of the servo motor, a control circuit, and a potentiometer that determines the rotational position limit of the motor shaft by changing its resistance as the motor rotates.

F. ROTARY ENCODER

A rotary encoder is an electromechanical device that converts angular position into digital or analog output signals. Typically, rotary encoders use optical sensors to generate serial pulses that can be read to determine position, movement, and direction. The output of a rotary encoder consists of the frequency of two waves, called wave A and wave B, as well as a reference wave known as wave Z [13].

The rotary encoder operates with two digital signals, namely CLK and DT, which are controlled by a rotating disk equipped with two contact tracks. When the knob is rotated, these two signals (CLK and DT) will change their logic status, generating pulses. Then, one of the CLK or DT pins will change first, followed by the change in the other signal. The sequence of pulse changes is used to determine the direction of rotation. If CLK changes status before DT, the knob rotation is considered clockwise. However, if DT changes status before CLK, the knob rotation is considered counterclockwise. The microcontroller reads the status changes on the CLK and DT pins to calculate the number of rotations and the direction of rotation.

In addition to the rotation signals, this rotary encoder is also equipped with a push button on its shaft. When the button is pressed, the SW pin will change its status to low (on). This feature can be used to switch functions or modes, for example, to toggle between coarse and fine adjustments.

G. LIMIT SWITCH

A limit switch is a device used to open or close the electrical current flow in a circuit, depending on its mechanical structure. This device has three terminals: the common terminal, the normally closed (NC) terminal, and the normally open (NO) terminal. The NC, NO, and standard terminals can be used to interrupt or establish the current flow in the circuit. A limit switch is a type of switch equipped with a valve that replaces a button. Its operating principle is similar to a Push-On switch, meaning it will only connect when the valve is pressed to a specific limit and will disconnect when the valve is not pressed [14].

H. HEATING ELEMENT (HEATER)

A heating element is the primary component in a heating device, converting electrical energy into heat energy through the process of electrical resistance. These heating elements are commonly found in various everyday appliances such as electric irons, water heaters, ovens, room heaters, and other heating devices.

The heating element operates based on the principle of the Joule effect, where an electric current flowing through a conductor (typically in the form of a wire with a specific resistance) generates heat energy due to the resistance. This heat energy is generated from collisions between the flowing electrons and the atoms in the conductor material, causing the atoms to vibrate more rapidly, which in turn produces heat.

I. RELAY MODULE

A relay is a type of switch that is operated using an electric current. Inside the relay, a low-voltage coil is wrapped around a core. When current flows through the coil, an iron armature is attracted toward the core. This armature is connected to a lever equipped with a spring. When the armature is attracted, the position of the contacts changes from a normally closed state to a normally open state [15].

Relays are necessary for electronic circuits to connect components and interfaces between the load and the electronic control system, which often have different power sources. Physically, the switch or contactor in the relay is separated from the electromagnet, ensuring that the load and control system are also divided.

J. LIQUID CRYSTAL DISPLAY (LCD)

An electronic display is a component used to display numbers, letters, or other symbols. A Liquid Crystal Display (LCD) is one of the commonly used electronic displays. LCDs are made with CMOS logic, which works by not emitting light but instead reflecting the surrounding light against a front-lit screen or transmitting light from a backlit source. The number of characters that an LCD can display depends on its specifications.

Over time, LCD technology has evolved, resulting in the development of LCDs with touchscreen capabilities.

A Human Machine Interface (HMI) is a system that connects humans and machines. HMI can be presented in various forms, including controllers and status visualization, which can be accessed manually or through real-time computer visualization. The purpose of using HMI is to enhance interaction between the operator and the machine through a monitor display. HMI can visualize machine data for monitoring and connect online in real time. HMI provides a depiction of the machine's condition, such as a map of the production machine on the monitor screen, allowing operators to see which parts of the machine are currently operating.

Additionally, HMI includes visualization for machine control, such as push buttons, input references, and other controls, which enable the machine to operate as intended. Moreover, HMI can display alarms if hazardous conditions occur within the machine. Additionally, HMI can display summarized machine performance data in graphical form. The HMI system typically operates online and in real-time by reading data sent through the I/O ports used by the controller.

The Nextion Liquid Crystal Display (LCD) is a display interface used as an indicator or monitoring device for equipment or machines. The Nextion LCD Human Machine Interface (HMI) is equipped with the Nextion Editor software, which features a WYSIWYG (What You See Is What You Get) graphical user interface (GUI). The 3.2-inch Enhanced Models touchscreen module can display a lot of data and interfaces very well. The advantage of the Enhanced Models is that they have their own EEPROM memory, which is non-volatile and used in computers and other electronic devices.

K. DS18B20 TEMPERATURE SENSOR

The DS18B20 temperature sensor is a component that can convert environmental temperature changes into electrical quantities. This sensor communicates with the microcontroller via a digital sensor using a 1-wire protocol. The serial code of this sensor type is unique, as each sensor has a distinct serial code, allowing multiple DS18B20 sensors to be used on a single 1-wire communication line. Dallas Semiconductor is the company that developed the DS18B20 digital temperature sensor. The DS18B20 sensor uses the 1-wire communication protocol for temperature readings. This sensor has a precision that allows it to read 9-12 bits[16].

This sensor has several advantages, including its suitability for use in difficult-to-reach locations, as output data is digital, ensuring that no data degradation (damage or loss of data quality) occurs [17].

II. RESEARCH METHODS

A. RESEARCH DESIGN

This research aims to develop and test a simulation of an automatic tissue processing tool based on the ESP32, featuring time settings displayed on a touchscreen. The system in this tool uses the ESP-32 microcontroller, which controls the time and temperature during its operation. In this simulation tool, four containers are used, which consist of the fixation, dehydration, clearing, and infiltration processes.

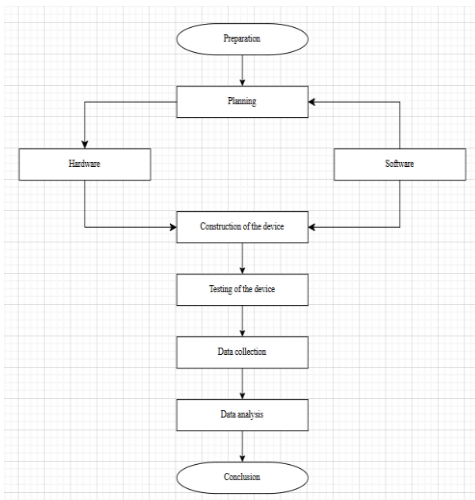

FIGURE 1. Proposed study stage flow

Fig. 1 shows the preparation stage. In this stage, the author creates a proposal with the title of the research to be conducted. After that, the author plans the design of the hardware and software that will be used in the study to develop the tool. Once the tool is completed, the next step is to test the tool that has been made. The next stage is data collection. Once sufficient data is obtained, the next step is to analyze the collected data, and the final step is to conclude the data to determine whether the tool is feasible or not.

B. DESIGN OF THE DEVICE

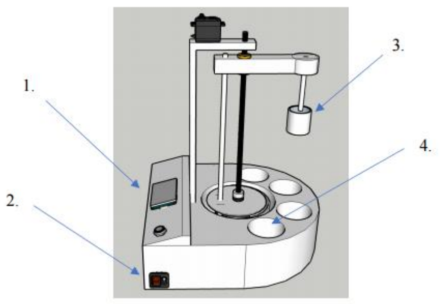

FIGURE 2. Design Simulation of an Automatic Tissue Processing

Fig.2 shows the design of the "Simulation of an Automatic Tissue Processing Tool based on ESP32 with Time Settings on a Touchscreen" module.

1) LCD Display: Functions as the user interface.
2) Sample Basket: Functions for Placing Tissue Samples.
3) Container Holder: Functions as a place for reagents/fluids.
4) AC Power Socket: Functions as a power supply with a power cable and an on/off switch.

C. BLOCK DIAGRAM

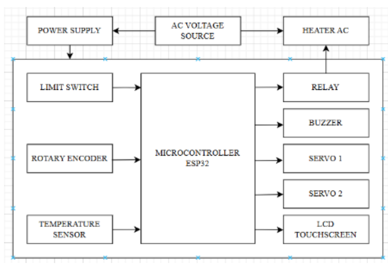

FIGURE 3. Block Diagram

Fig. 3 can be explained as follows:

1) Power Supply Circuit: The 12V DC power supply is stepped down by the step-down circuit to 5V to power the entire microcontroller circuit, two limit switches, two rotary encoders, a temperature sensor, a display, a buzzer, two servo motors, and a relay.
2) Limit Switch Circuit: This circuit contains two limit switches. Limit switch one functions to stop the motor's movement when it moves upwards, and limit switch two functions to stop the motor's movement when it reaches the downward position.
3) Rotary Encoder Circuit: This circuit contains two rotary encoders. Rotary encoder one functions to set the initial position of servo motor 1, and rotary encoder two functions to set the initial position of servo motor 2.
4) Temperature Sensor Circuit: This circuit functions to read the temperature and control it to maintain a specific temperature.
5) Display Circuit: This circuit is designed to display the tool's operation menu.
6) Buzzer: This function provides an audible signal in the form of a beep when the module has completed its operation.
7) Servo Motor 1: This motor functions for mechanical movement up and down.
8) Servo Motor 2: This motor functions for mechanical movement left and right.
9) Relay Circuit: This circuit functions to connect and disconnect the heater's operation.
10) Heater: This component generates heat to melt and warm the paraffin.

D. FLOWCHART

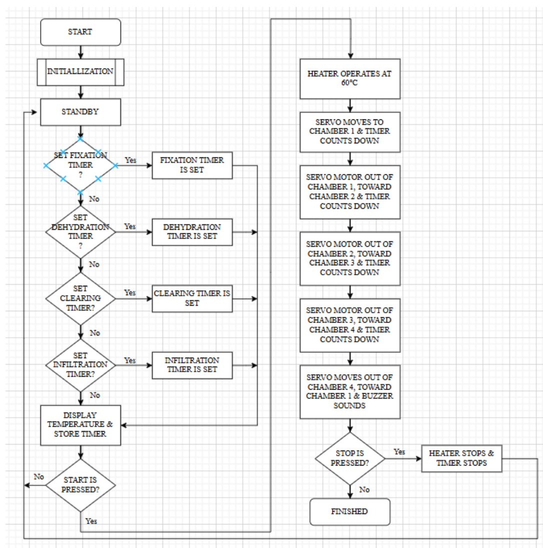

FIGURE 4. Flowchart program of the proposed study

From Fig. 4, it can be seen that when the on/off button is pressed to the 'on' position, the device turns on, and the LCDs the button menu and status while the device is in standby mode. Set the time for the four containers. When the start button is pressed, the device begins operating by turning on the heater until the temperature reaches 60°C, at which point the paraffin melts. Once the temperature is reached and the paraffin has melted, servo motors 1 and 2 will start working to automatically and sequentially move the sample basket to the four containers. When the process in the fourth container is completed, the buzzer will sound to indicate that the process is finished. If the stop button is pressed, the time and temperature functions will stop.

E. ELECTRONIC CIRCUIT DESIGN

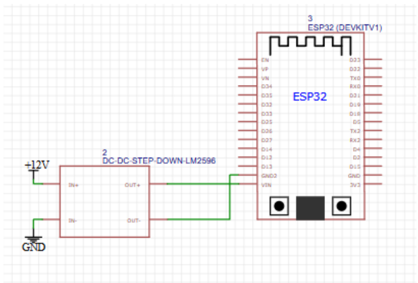

FIGURE 5. Power Supply Circuit

Fig. 5 shows the power supply circuit, a 5V DC power supply circuit that provides a 5V DC voltage supply to the ESP32 microcontroller and controls the entire circuit. The output of the power supply is connected to the Vcc pin and ground on the ESP32.

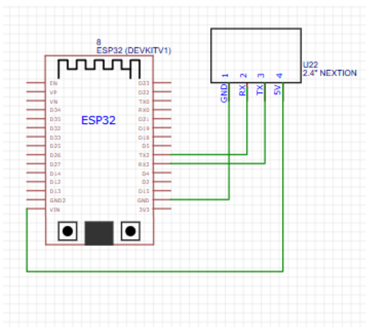

FIGURE 6. Display circuit

Fig. 6 shows the display circuit. There is a display circuit that functions to show the menu, buttons, and various status process information. This LCD circuit has four connecting pins that are connected to the ESP32 microcontroller at the RX, TX, VCC, and GND pins. This circuit is connected to the TX and RX pins of the ESP32.

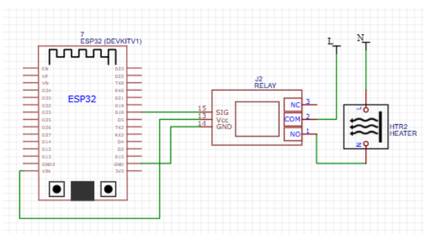

FIGURE 7. Heater circuit design

Fig. 7 shows the heater circuit powered by AC electricity, which functions to generate heat and warm up and melt the paraffin in container 4. To control the heater, the system uses a relay to turn the heater on and off. The relay module has three connecting pins that are connected to the microcontroller. This circuit is connected to the D18 pin of the ESP32.

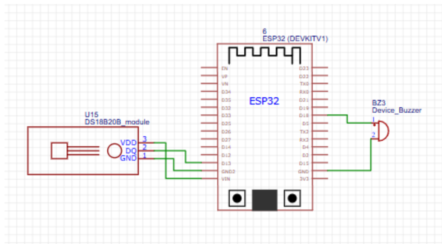

FIGURE 8. Temperature sensor and buzzer circuit

Fig. 8 shows the temperature sensor and buzzer circuit. The temperature sensor measures the temperature generated by the heater, and the buzzer emits a sound signal. This circuit is connected to the D13 and D5 pins of the ESP32.

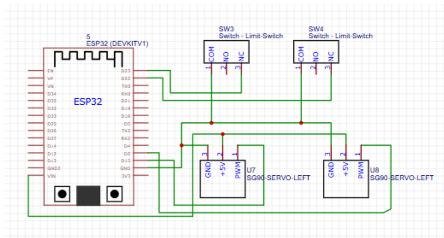

FIGURE 9. Servo motor and limit switch circuit

Fig. 9 shows the servo motor and limit switch circuit. The servo motor functions to move the mechanical parts of the module up, down, left, and right. The limit switch serves as a switch to stop the servo motor's operation. This circuit is connected to the D2, D15, D22, and D23 pins of the ESP32.

F. DEVICE SPECIFICATIONS

In the design of the automatic tissue processing simulation device, the specifications are as follows :

1) Power Supply: 220V AC
2) DC Output Voltage: 5 Volt
3) Display: 3.2" Nextion Touchscreen LCD
4) Mechanical Drive: 1 Vertical Servo Motor, 1 Horizontal Servo Motor
5) Heater: AC Voltage Heating Element
6) Temperature Sensor: DS18B20
7) Microcontroller: ESP32
8) Paraffin Container Temperature: 60°C
9) It uses a Buzzer as an alarm when the device has finished working.

10) Device Dimensions: 34cm x 34cm x 50cm

G. DATA COLLECTION TECHNIQUES

After the module design and planning are completed, the following process is to measure and test the temperature and time data using time and temperature measurement tools.

Then, the measurement results are compared to verify whether each design and plan meets the expectations. This step enables the calculation and data processing necessary to determine the accuracy and error of this module.

After conducting tests and recording data in the testing table above, the accuracy percentage of the device can be calculated. This research analyzes the accuracy and deviations from the obtained data using formulas.

III. RESULT AND EXPLANATION

This section presents the results of the analysis and a discussion of the module that has been created. This section will also show the data obtained from several measurements, in which the author performed five measurements for each measured parameter.

A. PHYSICAL FORM OF THE DEVICE

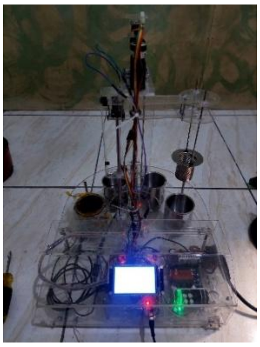

FIGURE 10. Physical form of the device

Fig. 10 shows the completed device form.

B. FUNCTIONAL TEST

Before conducting the testing process, measurements, and data analysis on the device's performance, a function test is required to ensure that each component of the device is working correctly.

Table 1 can be explained as follows:

1) The on/off switch functions are indicated by the device turning on or off.
2) The LCD functions are indicated by the LCD lighting up and displaying the image (menu).
3) The time setting button functions, indicated by the adjustable time.
4) The start button functions, indicated by the device starting to operate when the start button is pressed.
5) The heater functions are indicated by the change in the actual temperature value on the LCD.
6) The temperature display on the LCD indicates that the temperature sensor is functioning correctly.
7) The servo motor one functions, indicated by the movement of the basket as it moves up and down.
8) Servo motor two functions, indicated by the movement of the basket moving left and right.
9) The buzzer functions, indicated by the sound of the buzzer when the device has finished operating.
10) The limit switch functions, indicated by the servo motor stopping when the limit switch is pressed.
11) The rotary encoder functions, indicated by the sample basket being correctly positioned in the container.

TABLE 1. FUNCTIONAL TEST

No	Part of the device	Test Result
1	Switch on/off	Pass
2	Liquid Crystal Display	Pass
3	Time setting button	Pass
4	Start button	Pass
5	Heater	Pass
6	Temperature sensor	Pass
7	Servo motor 1	Pass
8	Servo motor 2	Pass
9	Buzzer	Pass
10	Limit switch	Pass
11	Rotary encoder	Pass

C. STANDARD OPERATING PROCEDURE (SOP)

Standard Operating Procedure (SOP) is a series of written steps created to guide users in operating a device correctly and efficiently. The SOP is designed to ensure that the device functions properly as intended. Below is the Standard Operating Procedure for the designed device:

1) Connect the device's power cable to the AC power source.
2) Press the on/off button and set it to the "on" position to turn the device on.
3) Place the sample in the sample basket.
4) Set the time for each container by pressing the "1," "2," "3," and "4" buttons on the LCD. If the

time for each process is not set, it will automatically default to 1 minute.
5) Wait for the paraffin to melt at 60 degrees Celsius.
6) Once the paraffin has melted, the device will start operating automatically.
7) When the device has finished operating, the sample basket will return to its initial position, which is above the fixation container, and the buzzer will sound for approximately 3 seconds.
8) Press the on/off button and set it to the "off" position to turn the device off.
9) Disconnect the device's power cable from the AC power source.

D. TESTING AND DATA ANALYSIS

The module testing is carried out using a time and temperature measuring device, namely a stopwatch and a digital thermometer. Testing of each parameter value is performed 5 times for both time and temperature measurements.

All measurement data will be processed using calculations based on formulas to analyze the accuracy and error of the module.

Table 2. Time measurement results

Chamber	Timer Set (s)	Measurement results					Error (%)	Accuracy (%)
		1	2	3	4	5		
Fixation	120	120	120	121	120	121	0,33	99,67
Dehydration	180	182	181	182	181	182	0,88	99,12
Clearing	180	178	178	178	179	178	1,01	98,99
Infiltration	240	242	242	242	243	244	1,07	98,93

The comparison of measurements between the reference measuring device and the module time resulted in the following accuracy values: fixation accuracy of 99.67%, fixation time error of 0.33%, dehydration time accuracy of 99.12%, dehydration time error of 0.88%, clearing time accuracy of 98.99%, clearing time error of 1.01%, infiltration time accuracy of 98.93%, and infiltration time error of 1.07%.

Table. Figure 3 shows the comparison of temperature measurements between the reference measuring device and the module, resulting in an accuracy value of 98.58% and an error value of 1.42%.

Table 3. Temperature measurement results

Chamber	Temp. Set	Measurement results					Error (%)	Accuracy (%)
		1	2	3	4	5		
Infiltration	60	59,6	58,58	58,9	59,41	59,24	1,42	98,58

IV. CONCLUSION

The simulation of an ESP32-based automatic tissue processing device with time settings displayed on a touchscreen has been successfully developed, following the planned design of its main components and technical specifications. Testing of the device module demonstrated high accuracy in time measurements across various stages: fixation time accuracy was 99.67% with an error of 0.33%, dehydration time accuracy was 99.12% with an error of 0.88%, clearing time accuracy was 98.99% with an error of 1.01%, and infiltration time accuracy was 98.93% with an error of 1.07%. Furthermore, temperature measurement and testing in the infiltration container showed an error percentage of 1.42% and an overall accuracy of 98.58%, indicating the reliable performance of the developed module in both timing and temperature control for tissue processing applications.

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