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Stopwatch Verification Platform: The Development of an Automated Device for Stopwatch Calibration

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Abstract*: Stopwatch is designed to quantify the elapses time between the start activation and deactivation. To ensure the precision of the time taken, calibration of the device is essential. National Institute of Standard and Technology (NIST) has provide complete guidelines on the stopwatch and timer calibration. However, the standards guidelines usually use manual calibration personnel hence may possibly cause inefficiency for calibration works. The 'Stopwatch Verification Platform' is a prototype aimed to replace the manual handling of digital stopwatch calibration with an automated timer-controlled device, without interfering with NIST recommended practice. The 'Stopwatch Verification Platform' is able to automatically trigger start and stop the reference and test stopwatches by integrating with precise timer controller and specific relay connections. The timer controller circuitry is integrated with the reference stopwatch circuitry, with 0.001 second resolutionIt is capable in verifying more units of stopwatches by using one reference. The measurement procedures do not contradict with the NIST recommended practice. This prototype does not alter the uncertainties calculation because it is a well-developed standard formula which is set by international standard.

Index Terms*: calibration, stopwatch, standards, uncertainties

I. INTRODUCTION

Instruments used to measure time interval, such as time elapsed between two events [1], are known as stopwatches. Measurement of time interval means the measurement from an arbitrary starting point that begins at the instance when the stopwatch is started [1]. The base units measured in seconds as implemented by International System of Units (SI) [1]. Generally, calibration will check the accuracy of the measurement instrument and determines the traceability of the measurement with respect to national standards. Calibration processes and standards are governed by the Legal Metrology Regulations. ISO 17025 provides guidelines for calibration and testing facilities.

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Referring to the 'Recommended Practice Guide for Stopwatch and Timer Calibrations' by National Institute of Standards and Technology (NIST), stopwatch calibration or verification is simply comparison between the device under test (DUT) and the measurement reference, or standard [1], in order to determine the error or uncertainties of data obtained. If a time interval standard is used, it is compared to the DUT's display; if a frequency standard is used, it is compared to the DUT's time base oscillator [1]. However, this project focuses primarily on calibration referring to a time interval standard.

Stopwatch calibrations are perhaps the most commonly-performed calibration, specifically laboratory calibration. In the lab, stopwatches are calibrated against a standard in order to obtain the offset of the DUT with respect to the reference. This offset values are usually stated in percentage values on the calibration certificate and will be quantified with the measurement uncertainty statement. The calibration of stopwatches usually has a low cost compared to other type of calibration equipment and the acceptable measurement uncertainties are relatively large. Even so, it is crucial to make sure the calibrations establish traceability to the SI for legal, business and scientific purposes [2]. After calibrations, periodic tests and inspections are carried out to make sure the instruments are providing valid results.

II. BACKGROUND

Verification of stopwatches normally is carried out manually by most calibration companies due to the cost and flexibility. Calibration personnel has to manually start and stop the reference stopwatch and the DUT at the same instant to obtain and compare the readings between the units. This method produces measurement uncertainties due to the calibration personnel's reaction time. The method also is inconvenient because the calibration points for stopwatch usually range up to 3 hours, hence may cause discrepancies in the calibration data due to the personnel ability for constant alert during long period of calibration time. Calibration personnel need to be careful during the period of calibrating, as if mistake is made within the period, measurement need to be repeated from the beginning. Another issue is that measurement is done on per unit basis hence if more than one unit need to be calibrated then more time is needed to complete the task. This prototype is developed to encounter this issue, such that the calibration personnel has to only set up the desired calibration point on the timer controller, then the device will automatically start to integrate 0.001 second resolution reference unit and the DUT.

The alarm will sound at 1 minute before the measurement completed so that the personnel need to ready to record the readings before the timer controller stop the reference unit and the DUT measurement. The prototype is developed using PIC16F628A microcontroller.

Another microcontroller type that can be use in this project include Arduino Microcontroller. The use of Arduino as the main microcontroller due to its cost and programmer-friendly where the success of its implementation can be seen in several areas: educational kit [3-5], electronic game board [6-7], can crusher [8], etc.

III. METHODOLOGY

A. Stopwatch Calibration Methods

In general practice, stopwatch is calibrate using several methods which are direct comparison method, time base method and totalize method [9]. For direct comparison method, the DUTs are compared to that traceable time interval references, which is the audio signal broadcasted by the officials of a region [9]. The operator is required to manually start the stopwatch during the beginning of the tone, and then stop it at the end of the tone. This method does not require specific equipment, but its measurement uncertainty is relatively large due to the operator's start and stop reaction time, especially during short time interval.

In the time base method, it measures directly the frequency of the quartz oscillator in a stopwatch by adopting the frequency counter with an acoustic pickup [9]. Although this method has low measurement uncertainties, however this method requires to use several specific equipment. Besides that, time base method will not check the functionality of the stopwatch but only checks on the time function. Hence, this will require function tests to be separately performed.

In the totalize method, the display of the stopwatch is compared to the laboratory time interval reference [9]. The measurement uncertainty of this method is lower than the direct comparison method, but higher than the time base method [9]. This method requires two test instruments: signal generator and a universal counter. The operator manually starts the stopwatch and open the gate of the counter at the same time, and then stop it using the same method after some period of time [1]. Then the readings are compared. This method has uncertainty due to human's reaction time [10] and uses more equipment than the direct comparison method.

The criteria of these three methods are summarized as in Table I below:

Table- I: Summary of stopwatch calibration methods

	Direct-Comparison	Time-Base	Totalize
Require special equipment		√	√
Measurement uncertainty	√		
Functionality check	√		√
One reference verify one DUT	√	√	√

This project focuses primarily on the design and construction of the software and hardware configurations for the product prototype. The product prototype is to be deployed and tested, including software simulation and hardware test-runs [11].

This project will utilize both quantitative and qualitative data collection tools, including software and hardware simulations, and test-runs of models. The model designed and constructed must fulfil the criteria: possessing an integrated standard stopwatch reference unit with resolution of 0.001 seconds, able to start and stop automatically after reaching the desired calibration point with broad range, possess the alarm function to remind the calibration personnel before reaching the calibration point, and able to verify more units of stopwatches by using limited (one) unit of reference stopwatch. The project implemented the Systems Development Life Cycle (SDLC), which includes the planning, designing, creating, testing and deploying a hardware and software configurations.

B. Planning

From literature reviews, several areas were being studied to understand the calibration of digital stopwatch, the disadvantages of existing calibration methods and the importance of establishing traceability to international standards [12].

Several points have been identified and captured for stopwatch calibration potential issues. The problems were related to manual verification of digital stopwatches, which random errors possibility high due to human reaction time. This error could contribute towards the uncertainty of the DUT. General calibration points for digital stopwatches could range from 30 seconds to 3 hours, some companies also request extended calibration points such as up to 36 hours, which is impossible for the calibration personnel to keep it aware. Another problem possessed by this manual calibration is that only one DUT can be verified by using one reference standard. This could lead to decrease in working efficiency.

The possible functionalities for the product are drafted, aiming to solve the problems encountered especially in manual calibration of digital stopwatches. The functions include automated functionalities by using timer controller with high range, alarm reminder function and the integration of one reference stopwatch unit to verify more units of stopwatches.

C. Designing

Precise timer controller with range of 99 hours 99 minutes have been designed using Proteus ISIS for its circuitry while MikroC Compiler for its programming codes. The PIC16F628A is use as the microcontroller because the input and output pins are sufficient for the circuit operation. Fig. 1 shows the Proteus ISIS schematic of timer controller circuitry.

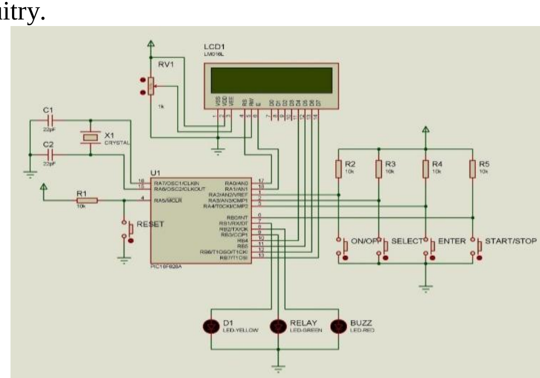

Fig. 1. Proteus ISIS schematic of timer controller.

The relay connection is designed to automatically start and stop the digital stopwatches with control signal to the relay is from the output of timer controller. The design circuit also include the alarm function. This alarm has difference as compare to typical alarms for general timers, which turn on only after the countdown of time ended. This alarm is designed to be turned on one minute before the countdown ends, regardless of the time range being set. The circuit also has LCD display module to display the information. The LCD module uses 4-bit interface because this could save the pins on the PIC microcontroller. Additionally, an uninterruptible power supply has been installed to provide backup power supply during emergency. Fig. 2 shows the relay connections from the microcontroller and the interaction of relay contacts with toggle switch.

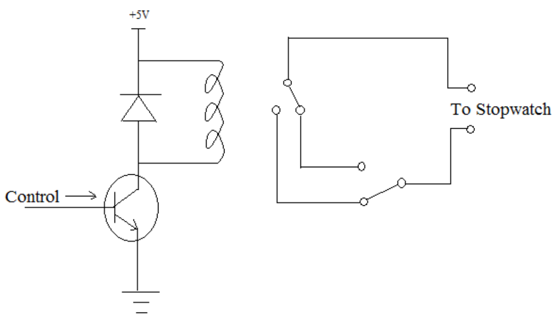

Fig. 2. The schematic of relay connections with toggle.

The printed circuit board (PCB) for the overall circuit is designed by using Proteus ARES. The design of product casing is done by using AutoCad software packages, as shown in Fig. 3.

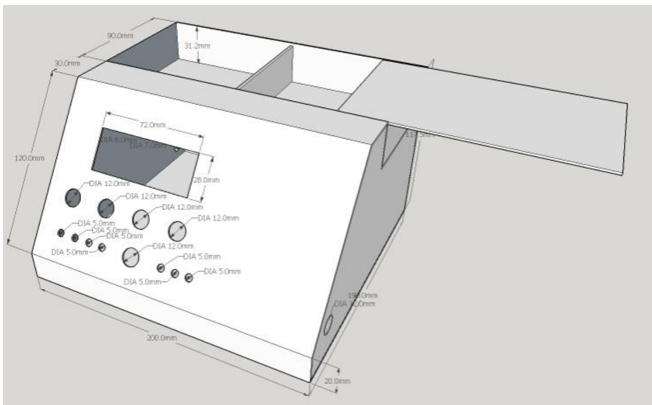

Fig. 3. Design of product casing using AutoCad.

There are several main things to be programmed, which include the timer countdown functions, the relay function, the alarm function and the LCD output display functions. Before constructing the programming codes in MikroC, a programming flowchart has been constructed. This is to set up a clear direction or guidance for the ease of constructing programming codes. The programming flowchart is constructed based on the functionality of the desired model and the conditions for each functions. The flowchart constructed is shown in Fig. 4.

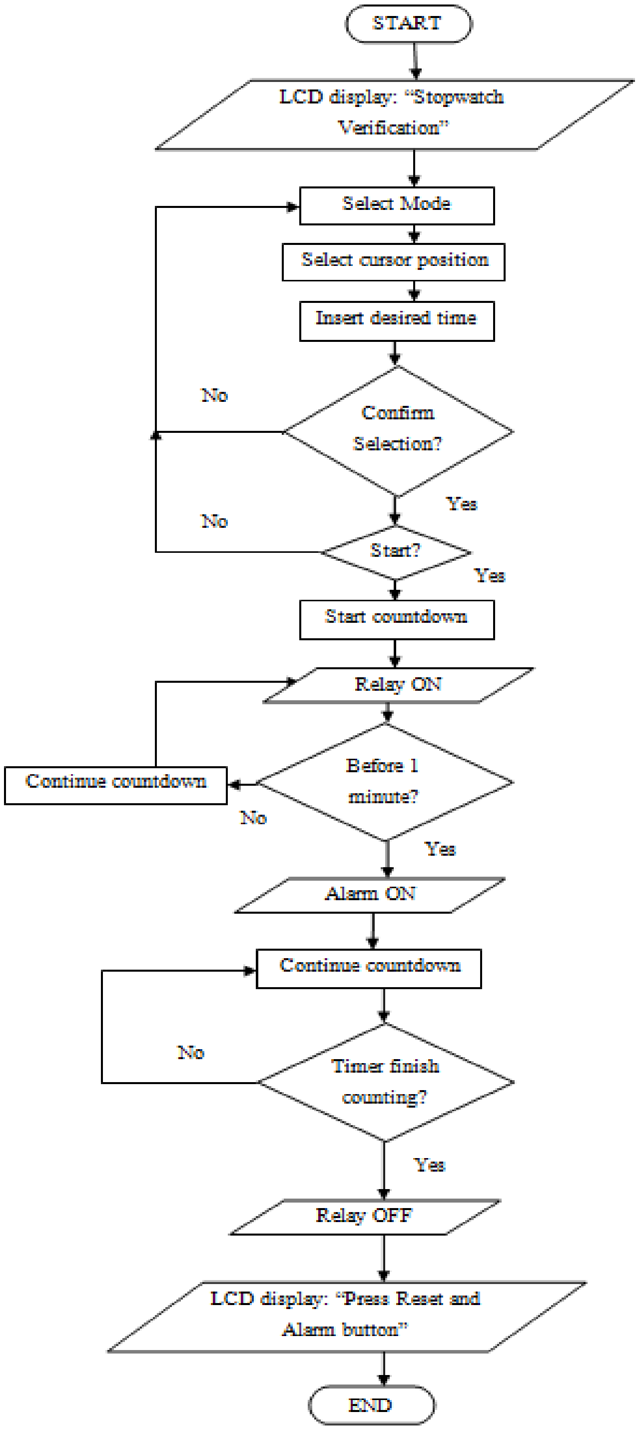

Fig. 4. Programming flowchart for desired operations.

From the flowchart, the programming codes are designed and constructed using MikroC. Then it is compiled and linked with the circuitry designed in Proteus. Software simulations are carried out by observing the operation of the programming codes on the circuitry designed. This helps in showing the operation of the model-to-be and for troubleshooting purposes.

D. Constructing

Appropriate components are chosen based on two criteria: operations and ratings. Table II shows the components chosen and its respective functions in the circuit.

Table- II. Major components and respective functions

Components	Functions
PIC16F628A	Used as microcontroller, which is the major component in the timer control circuit.
16x2 LCD Module (LM016L)	Used as display module for convenience of operations.
4MHz Crystal Oscillator	Connected as the oscillator circuit. The function of an oscillator circuit is to provide an accurate and stable periodic clock signal to a microcontroller.
22pF Capacitor	
Resistor (10kohm and 3.3kohm)	To protect the next components from excessive current flow.
Push Button	Used as Mode, Start, Reset, Enter and Cursor buttons.
Latch Button	Used as Alarm button. To manually deactivate the alarm.
5-volts Relay	Used together to change the contacts for start and stop of stopwatches. Toggle switch also acts as Test switch for calibrations of short calibration points.
Toggle Switch	
LED (Red)	To indicate the activation of alarm.
LED (Green)	To indicate the activation of relay.
Transistor	Act as switching device, to switch on the relay circuit.
Diode	To protect the components in the relay so that they do not get damaged when the voltage is passed through the coil.

Before soldering the designed connections on the strip board, the components are checked to make sure that they are in good condition and able to function optimally. Checking these components may help in saving time and ensure that the overall circuit will not be affected by the defected components. After the checking of components is successfully done, the components are soldered on a circuit board based on the circuit designed. Continuity checks are carried out to ensure the correct connections of all components on the circuit board.

E. Testing and Deploying

To ensure the programming code is working with desired functionality, the hex file of programming code is programmed into the circuitry design in Proteus ISIS after software simulation is done. Appropriate corrections were made to obtain desired functionalities especially for timer controller unit and the relay connections.

Hardware test-run is completed after installing PCB along with the uninterruptible supply in the product casing. This is done to determine if the controller circuit is able to function properly and to make sure relatively small error [8] is obtained for the timer controller unit.

IV. RESULTS AND DISCUSSIONS

A. Software Simulation

Before installing the components on the strip board, software simulation is conducted by using Proteus and MikroC. By linking the programming codes constructed in MikroC with the circuitry designed in Proteus, the operations of the circuit were clearly observed.

From observations, the timer circuit works as expected. The results show that LCD module has displayed “Stopwatch Verification” when the power supply is turned on. Then following instructions on the display module, MODE push button is pushed to select mode: ON or OFF. Then CURSOR push button is pushed to adjust the cursor position to enter the time required. The MODE push button functions to enter the time required, then the ENTER push button is used to confirm the selection. Finally, START push button is used to start the timer.

Once the timer circuit is started, the green LED has lights up, which indicate the relay is activated. The timer counts down accordingly. Then the TEST switch must be triggered in order to change the connection between relay and stopwatches. Any values of time can be inserted to the timer for countdown, as long as the timer reaches the final 1 minute before countdown ends, the red LED lights up. This indicates the alarm is functioning. The red LED can be manually deactivated by pressing the latch button to disconnect it from the control circuit. After the countdown ends, the green LED turns off, indicating the relay has deactivated. TEST switch should be triggered at this point to restore the original connections. The whole operation can be restarted by pressing the RESET button. At the end of every countdown, the ALARM latch button must be pushed again to connect the red LED (alarm) to the control circuit.

B. Hardware Test-Run

Test-run are conducted to examine the operations of the designed model of Stopwatch Verification Platform. When 5-volt power supply is connected to the model, the LCD module shows “Stopwatch Verification”. Then the model functions as how the software simulations had worked. The result functions of the buttons and switches are summarized in Table III:

Table- III: The functions of buttons and switches of the model

Button	Function
RESET	To reset the operations of the timer circuit and relay circuit.
MODE	• To select mode of the timer, either ON or OFF mode. • To enter the required time for countdown after the cursor position is selected.
CURSOR	To select the position of cursor for ease of inserting the required time for countdown.
ENTER	To confirm the selection of countdown time.
START/STOP	To start or stop the timer countdown.
ALARM	To manually deactivate the alarm by disconnecting the buzzer from the control circuit.
TEST	• To change the connection between the relay and the stopwatches in order for the stopwatch to start and stop automatically. • To carry out calibration of short calibration points.

Other than testing the functionality of circuit and model, test-run is conducted using two units of digital stopwatches, where one unit as the reference model and the other one as the DUT. The model is functioning in the proper manner.

C. Error Analysis

Accuracy is the ratio of the error to the full scale output, expressed in percentage reading. Tolerance is the permissible deviation from a specified value. From NIST Handbook 105-5, the tolerance for stopwatches is ±0.02 % of the time interval tested [1]. As a result, organizations and jurisdictions that rely exclusively on digital stopwatches might require that devices be calibrated to a tolerance of 0.01 %, or even 0.005 % [1].

By using appropriate formulas, the calculations are done to obtain the permissible error for the device under test, which in this case is AERO stopwatch. Permissible Error and Mean Error for AERO Stopwatch shown in both Table IV and Table V. The details listed as below:

- DUT: AERO Stopwatch
- Specifications: ±5sec/day
- Tolerance: ±0.01%
- Relative Accuracy: ±0.005787037%

Table- IV: Permissible Error for AERO Stopwatch

Cal. Point	Accuracy ±	Permissible Error ±
30 s	0.001736111	0.004736111
1 m	0.003472222	0.009472222
5 m	0.017361111	0.047361111
10 m	0.034722222	0.094722222
30 m	0.104166667	0.284166667
1 hr	0.208333333	0.568333333
3 hr	0.625	1.705

Table- V: Mean Error for AERO Stopwatch

Cal. Point	Error 1	Error 2	Error 3	Mean Error
30 s	-0.002	-0.002	-0.002	-0.002
1 m	-0.011	-0.011	-0.011	-0.011
5 m	-0.006	-0.006	-0.006	-0.006
10 m	-0.016	-0.016	-0.016	-0.016
30 m	-0.096	-0.096	-0.096	-0.096
1 hr	-0.159	-0.159	-0.159	-0.159
3 hr	-0.268	-0.268	-0.268	-0.268

In Fig. 5, the graph has observed that the measured mean error is within the range of permissible error. Hence, the product prototype indicate that it has working with acceptable accuracy.

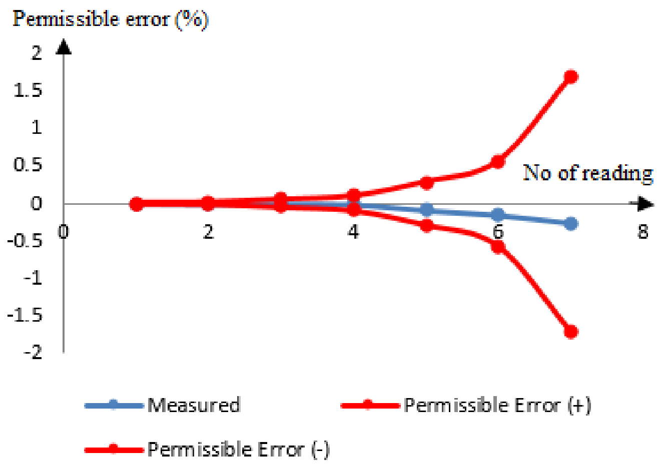

Fig. 5. Error analysis comparing permissible error with mean error.

D. Project Significance

The Stopwatch Verification Platform is operating based on the direct comparison method for the calibration of stopwatches as recommended by NIST. Both the reference and DUT are start and stop at the same instant in order to compare the readings for both stopwatches. The Stopwatch Verification Platform successfully complies of the ability to start and stop automatically after reaching the desired calibration point (the time entered to the timer for countdown), possess the alarm function to remind the calibration personnel before reaching the calibration point and able to verify more units of stopwatches by using limited (one) unit of reference stopwatch.

This Stopwatch Verification Platform possesses some advantages when compared to the manual calibration of the direct comparison method. This prototype is possibly able to eliminate the random error caused by human reaction time by having the automation feature to start and stop the stopwatches with the aid of timer and relay circuits.

The prototype also has alarm functions for reminding the calibration personnel before the countdown ends. Some stopwatches have very unique functions, which the readings would get blurred out after being stopped. This situation could cause the calibration personnel to miss the readings and have to start the calibration all over again. The alarm allows the calibration personnel to have sufficient to prepare to take the readings. The product also includes an uninterruptible power supply as backup power supply.

Finally, the prototype has increased the efficiency for which with only one unit of reference units, three units of DUT can be verified. Table VI shows the summary of comparisons between the designed Stopwatch Verification Platform and manual verification of stopwatch.

Table- VI. Comparison with conventional verification method

	Stopwatch Verification Platform	Conventional Verification
Start and stop	Automatic	Manual
Alarm	Activates 1 minute before calibration point ends	None
Human measurement uncertainty	No	Yes
Quantity of DUT that can be verified using one reference unit	Three	One
Requires expensive equipment	No	Yes
Portable	Yes	No
Expandable calibrations for other devices	Yes	No

V. CONCLUSION

The prototype is constructed successfully and is able to meet the required operations to solve the problems as stated in problem statement. The product is completed with aid of software packages, including Proteus ISIS, AutoCad and MikroC Compiler. The validity of the circuit is resolved with confirmation done by software simulations, then through hardware test-runs.

The Stopwatch Verification Platform is said to work desirably not only because it has fulfilled the operations requirements, but also the error analysis has done to prove that the product is working within acceptable accuracy.

At the end of this project, the Stopwatch Verification Platform is successfully designed and constructed. The design of the circuit is demonstrated by the simulations made. Good ethical and safety measures in engineering practice are emphasized in this project especially during the soldering process. In conclusion, the project objectives were all met with the successful construction of Stopwatch Verification Platform which fulfils all the design criteria.

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