DESIGN AND DEVELOPMENT OF AN ANALOG MULTIMETER MODEL FOR A WIDER VIEW IN A CLASSROOM SETTING

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ABSTRACT: *Analog multimeters have been considered as one of the most important tools to mold the skills of electronics and electrical students in dealing with instrumentation. Traditionally, discussion and demonstration of the multimeter's functionality are done through mock-up materials on a wood board to magnify the size, and through manual manipulation of the pointer or by performing a demo-by-group in a classroom. However, using this strategy with a large number of students (i.e.,40-50 class size), assurance to meet the learning objectives is not certain. Modern electronic devices (e.g., PC, laptops, tablets, etc.) may magnify the display with the use of LCD. Nevertheless, it has issues with ease of use and it does require additional gadgets and assistants to hold the camera while doing the demo. In this study, we design and develop a voltage-ohm-milliammeter (VOM) model. It is an all-in-one device that uses a raspberry pi that mimics the functionalities of the actual multimeter and displays the readings, enough to be seen by the whole class. We leveraged the raspberry pi and imaging technology to carry out the necessary tasks. The usability scale test results of the device show the effectiveness of the model.*

Keywords: raspberry pi, image processing, analog multimeter, multitester, volt-ohmmeter tester, electronic device, instrumentation

1. INTRODUCTION

A multimeter or a multimeter, also known as a VOM (volt-ohm-milliammeter), is an electronic measuring instrument that combines several measurement functions in one unit. It is a hand-held device useful for basic fault finding and field service work for electrical and electronics equipment. A typical multimeter can measure voltage, current, and resistance [1] as shown in Figure 1. Analog multimeters use a microammeter with a moving pointer to display readings [2].

Figure 1. A portion of an analog multimeter, the Sanwa YX360TRF

Although digital multimeter has become popular, and several people are using them these days, analog multimeters are still used in schools and higher education institutions (HEIs) to mold the skills of electronics and electrical students in dealing with instrumentation. One clear reason is that there is something that an analog multimeter can do that a digital multimeter cannot. Hence, analog multimeters are still used in teaching students how to find faults in electrical and electronics equipment [3]. These include: (a) capability to perform continuity test at a glance; (b) advantageous when testing signals with fluctuations; (c) does not get overheated; (d) can measure voltage and current even without a battery; and (e) last for a long time.

The way teachers introduce this electronic instrumentation topic to students varies accordingly. Some use the multimeter or VOM itself for demo purposes, while others use varied instructional materials (IMs) such as mock-ups, visual aids, illustration boards, etc. IMs are tools or collections of materials, which include objects (e.g., animated or unanimated) and human and non-human resources that a teacher may utilize in delivering instructions to help achieve desired course learning objectives [4]. They may provide aid to a student in concretizing his learning experience to make the learning more interactive, interesting, exciting, and enjoyable. Any resources that a teacher uses to help him teach his/her students is an instructional material (IM); and the selection of IMs that meet the needs of students and fit the constraints of the teaching and learning environment, is a key feature of effective teaching [5]. For example, in teaching electronics instrumentation-related topics, an analog multimeter is usually used for demonstration purposes.

To gather more information on the pedagogic practices and the instructional materials used by teachers or faculty in USTP handling basic electronics and electrical subjects, a survey was conducted. The respondents' average number of years in teaching the subject is 5 years. Results of the survey reveal that due to insufficiency of the number of multimeters available for use in the class, the faculty usually require students to bring their own multimeter during lectures. However, 75% of them answered that there is an average of less than 50% of the total student population in a class who can bring their own multimeter when attending classes. This requires the faculty members to strategize the delivery of the VOM topic, which includes the use of the actual VOM by group or through visual aids, illustrations, drawings, or mock-ups.

Traditionally, teachers in HEIs introduce the lesson in front of the whole class using the typical Volt-Ohm-milliammeter (VOM) instrument with a size of 4-inches by 5-inches. However, the VOM instrument is good enough for a very few numbers of students to see and actually read the scale readings. Hence, this may result in less student participation, since there is a high likelihood that they tend to do something else out of the topic, which may, in turn, cause unnecessary disturbances to others. As such, this approach requires the teacher to explain the lesson by group (i.e., usually 5 to 6 persons for 1 VOM). Although this may promote increased student engagement or participation, unfortunately, it requires repetitive explanation, thus, making it time-consuming.

Another approach used by the teachers is via visual aids through drawings or illustrations of a multimeter instrument. However, this strategy suffers from difficulties in making the whole class (with 40 to 50 students) understand VOM readings and how it works since it still needs an actual demo. Additionally, it is time-consuming, particularly for teachers who need to comprehensively draw the VOM image on the board to discuss its functionality (e.g., reading the voltage, current and resistance values, etc.). This hinders the teachers to cover the entire topic on time.

There have been some attempts to improve the approach to present and demonstrate the usage and functionality of the multimeter to the whole class, but most of them still use mock-up materials on wood board to magnify the size by manual manipulation of the pointer [3]. Other strategies like performing a demo-by-group may work and may be acceptable, but will still fall short in some aspects. Using this strategy in a classroom with 40-50 students, the interactive learning or actual engagement and mastery may also be affected. As such, it may not be effective to meet the learning objectives. One of which is the huge amount of time required to deliver a certain topic as it should be done by pair or group. Modern electronic instructional materials can magnify the display using a camera, smartphone, Laptop, and Desktop Computer with the camera are capable to magnify the display with the use of an LCD projector larger than the traditional approach in teaching Analog Multimeter. Nevertheless, it does have issues with ease of use. In particular, PCs should be present when using a webcam. Also, smartphones may be connected to a projector, but this requires that the phone must support video output and not all smartphones support video output, thus it requires additional gadgets and assistants to hold the camera while doing the demo. To summarize, the following problems are identified when using the traditional way based on the survey conducted and the related literature we have come across [6-7] of demonstrating scales and functions of electronic instrumentation:

a. *Time-consuming.*

Frequent drawing of the VOM scale on the board requires a huge amount of time. Although actual VOMs are most of the time used by the instructor, it will also require discussions by the group that obviously entails an additional amount of time. Thus, may result in an inability to tackle other topics as reflected in the syllabus.

b. *Less interactive learning.*

Classroom discussions create an opportunity for teachers to lead a class through a subject and build upon students' knowledge. Unfortunately, this is sometimes at the expense of less active students when not managed well. Thus, in the context of teaching electronics instrumentation by presenting a multimeter mock-up (i.e., board-based VOM scale) or illustration only (i.e., without the aid of demonstration) to the whole class with 40-50 students, does not pave the way for students to be engaged in the discussion as there is no actual demo of testing the voltage, current or resistance of the electronic components.

c. *Less attention among students*

Unclear illustrations or drawings displayed in front of the class may not heighten the interest of students to follow through the discussion on how the multimeter works as there is no actual demo or engagement on the VOM device and components for a better learning experience.

With those identified shortcomings and limitations of the traditional way of using VOM instructional service, this study attempts to find methods to develop an improved analog multimeter for a wider view in a classroom setting.

In this study, we design and develop a raspi-based voltage-ohm-milliammeter (VOM) model that mimics the functionalities of the actual multimeter and displays in a wider view, the readings (i.e., voltage, current, and resistance) of an electronic component being measured. We leveraged the advent of imaging technology as well as the advantages of the raspberry pi to carry out the tasks necessary to complete the proposed multimeter model.

Specifically, the study aims to design the instructional multimeter model that provides a wider view of the multimeter readings good enough to be clearly seen by the entire class while measuring the voltage, current, and condition of a specific electronic component. Furthermore, the device can efficiently analyze the captured image of the actual multimeter and consequently display the actual readings and their equivalent values via an HDMI/USB port-driven projector or TV screen. As such, the device can promote an interactive learning process as the teacher can require students to answer first and display the results (i.e., equivalent readings of the analog multimeter) at a specific time during discussion for checking purposes. This is also beneficial to students themselves as it allows a self-paced approach in studying electronic instrumentation specifically with the use of an analog multimeter.

The output of the study is very beneficial to the different sectors. The improved analog multimeter can be of great help for an educational institution to attain its goals of providing interactive learning in basic electronics, thereby providing quality education in the field of electrical and electronics. It also provides aid for HEIs and other vocational schools to produce students with a significant amount of knowledge and skills in electronics instrumentation and other related areas such as electrical, computer technology, etc. This may also significantly improve the level of students' interactive learning for effective laboratory activity practices in electronic and electrical students at different levels (e.g., secondary level, Senior High School and college level, etc.). High school teachers and HEIs faculty are highly motivated due to the flexibility of the instrument and can avoid difficulties in dealing with delivering instructions to the students.

The following are the capabilities of the proposed model:

1. Ease of use of the model where users just need to plug in the model in the HMDI/USB port-driven projector or TV.
2. Analog to digital readings conversion, which can promote self-paced learning.
3. Allows student-teacher interactive learning or teaching experience through an actual demo or hands-on with the model in front of the whole class.

2. MATERIALS AND METHODS

Our study focuses on the design and development of the multimeter instructional device. It is a model that mimics the behavior of the real volt-ohm-milliammeter (VOM) instrument or multimeter leveraging image processing and raspi technology. The study leverages the concept of developmental research for the systematic study of designing, developing, evaluating instructional programs, processes, and products [8-9]. We develop a device, which contains both the hardware and software requirements allowing the result of the actual multimeter readings to be projected on a bigger screen via projector or TV for a wider view in a classroom setting. In what follows, we discuss the framework of the proposed multimeter model, prototype specification, and wiring diagram.

2.1. Framework of the Proposed Multimeter Model

The development process leverages the raspberry pi module to carry out the necessary tasks to replicate the functionalities of a multimeter by applying image processing and displaying the actual readings on screen. Figure 2 shows the framework of the proposed model. The process starts with capturing the image of an actual multimeter or VOM reading. The captured image will go through the pre-processing step where noise removal and image filter are the main considerations before it will be fed to line or multimeter pointer detection. This will be followed by analyzing the detected line or pointer. The analysis includes getting the angle of the line, which will be used to calculate the measurements or actual readings (i.e., AC/DC voltage, direct current ampere or DCA, and the resistance). For example, if the line detected has an angle of 90^0 with respect to the baseline of the multimeter, we get the equivalent reading using the following formula: readings = (angle-45^0)/1.8 * range_multiplier, where *angle* is the angle of the detected line (pointer) and range_multiplier is the value used depending on the range applied (e.g., multipliers for 750, 250, and 50 are 15, 5, and 1, respectively). Thus, the resulting equivalent voltage is 25V. Such readings and the multimeter image itself will then be shown or displayed on the TV screen or LCD projector, whichever is available. This allows an interactive learning process as the teacher can require students to answer first and display the results (i.e., equivalent readings) at a specific time during discussion for checking purposes.

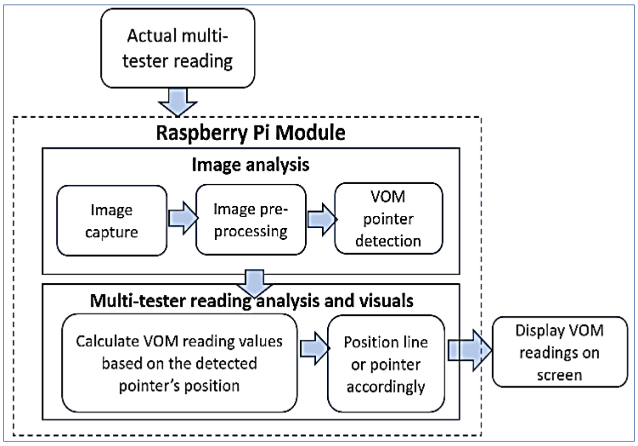

Figure 2. The framework of the proposed multimeter model

Multimeter's Pointer Detection

From the captured image of the VOM, the multimeter's pointer can be represented by a line. Hence, we employ an algorithm that detects a line after performing the image pre-processing step. We leverage the Canny algorithm [13] used in [10-11][14] for edge detection along with the Hough Transform [12]. Based on laboratory testing on image detection, it was found out the small lines division in the scale are not visible. The design uses image pre-processing in the detection of the VOM's pointer. This pointer, when analyzed, will result in the equivalent readings (i.e., voltage, current, and resistance) that the actual VOM has provided. As the pointer can be represented by a line, this study involves line detection. As such, an algorithm leveraging Hough Transform [12], is designed to extract line segments, which consequently detects a straight line as presented below:

1. Edge detection using Canny edge detector
2. Mapping of points to the Hough space and storage in an accumulator.
3. Interpretation of the accumulator to yield a line of infinite length, which is done by thresholding.
4. Conversion of infinite lines to finite lines.

The finite lines can then be superimposed back on the original image.

2.2. Prototype specification

Figure 3 shows the design of the multimeter instructional device and its corresponding parts. This device allows measuring the voltage, current, or resistance of an electronic component. One of the important components of the devices is the raspberry pi that controls the entire system. The device also has a camera that captures the multimeter and the actual readings or measurements. Figure 4 presents the dimensions of the multimeter instructional device. The captured image will then be pre-processed and analyzed to display the readings on screen enough to be visible to the whole class. This means that the physical appearance of the proposed device enables a huge replica of the original *Sanwa* intended for a classroom broadcast discussion. The device also contains other peripheral devices such as a numeric keypad used to input the range used, which in turn, be used in the computation.

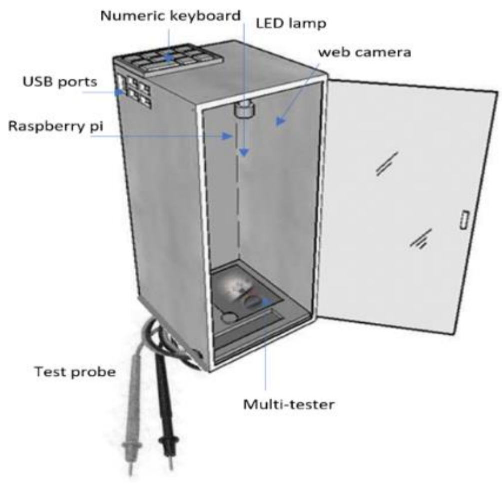

Figure 3. Different parts of the proposed multimeter instructional device

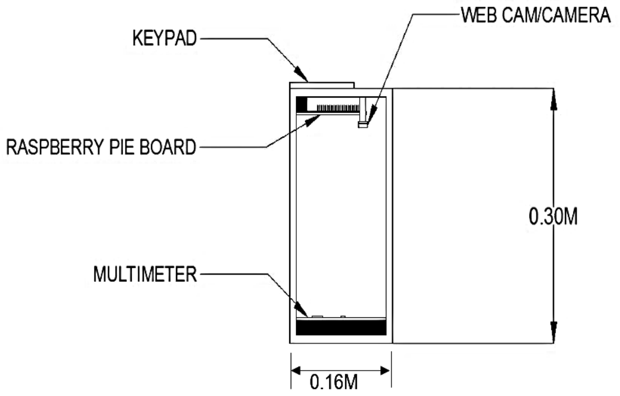

Figure 4. Front view of the proposed multimeter instructional device

2.3. Wiring Diagram

Figure 5 presents the operational wiring diagram of the proposed multimeter model or model leveraging Raspi technology, which functions along with the power adapter. As the study mimics the behavior of an actual multimeter device, the researcher will utilize Raspi 3 that works as a computer itself that can run a Python program allowing to capture an image of a multimeter while measuring the voltage, current, and resistance of an electronic component. The Python program triggers the webcam and the mini LED tube when the user presses the push button (i.e., attached to Pin 2 and Pin 40) connected to the test probe. However, prior to capturing the photo, the selected range has to be entered via the numerical keypad attached to Raspi as the basis for the computation. The captured image will then be processed and analyzed to calculate the equivalent measurement or readings. Finally, the program allows the device to provide a wider view or display of the measurement via an LCD projector that is connected to an HDMI port. Furthermore, to promote student engagement, a program will also be created to trigger the device to display the calculated equivalent measurement after doing their own calculation, as shown in the figure below.

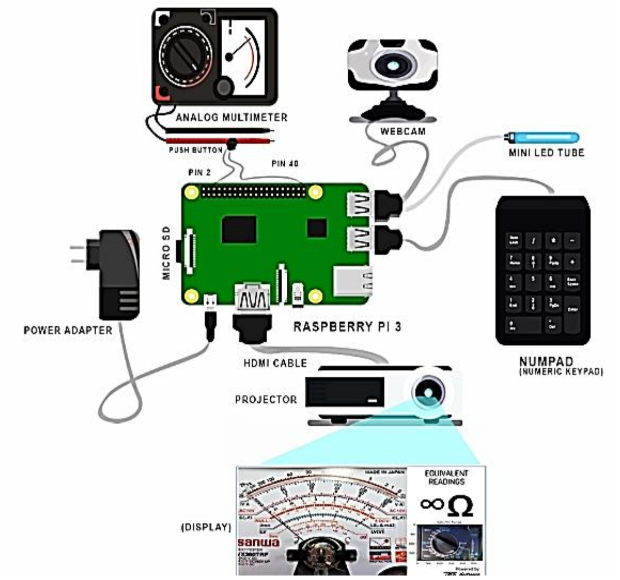

Figure 5. Wiring diagram of the proposed multimeter device

3. RESULTS AND DISCUSSION

Figures 6, 7, and 8 present the sample screenshots of our multimeter device outputs. The user may choose to measure the voltage, current, or resistance of an electronic component. Depending on the user's choice, the model includes the range of measurement. For example, if the user chooses the "Measure voltage" button, range values are 1000, 250, 50, 10, 2.5, 0.25, and 0.1. Figure 5 shows the screenshot of the AC/DC voltage measurement. This demonstrates that as per captured image of the actual multimeter readings, our multimeter device yields 42.2 V having 50 as the selected range value.

Figure 6. Sample screenshot of AC/DC voltage measurement

On the other hand, Figure 6 shows the sample screenshot of the resistance measurement with the range values of 100000, 1000, 100, 10, and 1. Given the captured image, our device yields 35.0 Ω under the assumption that the user chose 10 as the range value.

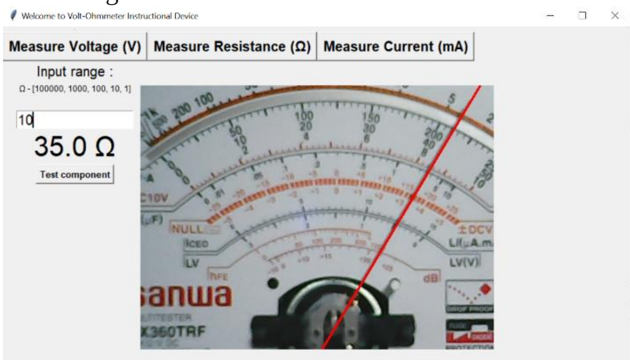

Figure 7. Sample screenshot of the resistance measurement

Similarly, Figure 7 shows a sample screenshot of a direct current ampere or DCA measurement with the range values of 250, 25, 2.5, and 0.05. If the user chooses the 250 range value, the device displays 211.1mA.

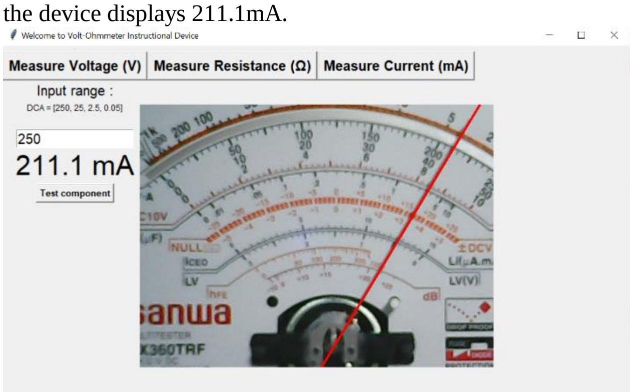

Figure 8. Sample screenshot of current/DCA measurement

3.2 System Usability Evaluation

For purposes of measuring the usability of our model, we used the System Usability Scale (SUS) instrument. SUS is a tool used to measure the usability of software, mobile devices, websites, and other applications. As per the definition provided by ISO 9241-11 with over 1300 references or articles and publications, SUS provides an overall usability test measurement, which has become an industry standard. SUS contains important characteristics such as efficiency, effectiveness, and satisfaction. Effectiveness signifies how the users successfully attain their objectives and efficiency, at the same time, how much resource and effort are exerted in achieving those objectives; while satisfaction determines whether or not the experience was satisfactory [15-17].

SUS used a 10-item questionnaire that is provided as a usability test to calculate a system's score. Respondents answer questions using a 5-point scale from 1 as "Strongly Disagree" to 5 as "Strongly Agree". We floated a survey questionnaire following the 10-item questions of SUS. Fifteen (15) respondents were asked to answer each given question from 1 to 5 by the degree of their agreement with the statement given, having 1 being lowest (Strongly Disagree) and 5 as the highest (Strongly Agree).

Figure 9 shows the Odd Items result of the respondents. The survey results reveal that the respondents find the device very usable and are most likely to recommend the system.

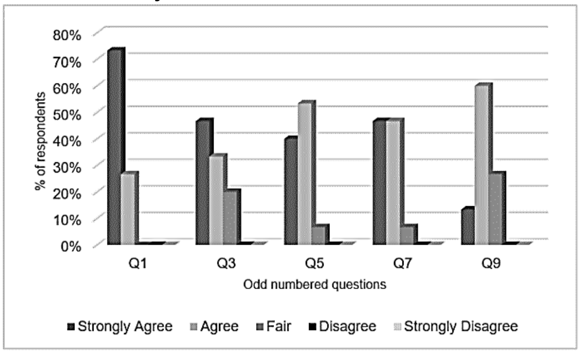

Figure 9. System Usability Test Results (Odd Items)

Figure 10 shows the Even item result of the respondents. The survey results reveal how the respondents view the effectiveness of the model. As a result, the SUS final score average, survey scored 82.8%. As per the requirements set by the SUS instrument, a score above 68% is being considered above average. Thus, the results reveal the usability and acceptability of the instructional device.

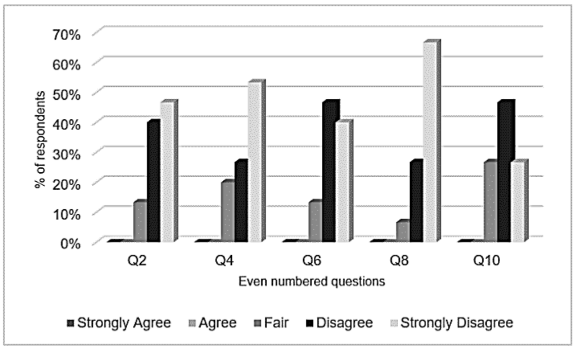

Figure 10. System Usability Test Results (Even Items)

4. CONCLUSION AND RECOMMENDATION

A. CONCLUSION

In this study, we present an innovative instructional material or device that is used to provide a wider view of the analog multimeter readings good enough to be clearly seen by the entire class while testing the current condition of a specific electronic component and measuring the AC/DC voltage and direct current ampere or DCA. Furthermore, our instructional device can efficiently analyze the captured image of the actual multimeter readings. Such readings and the multimeter image itself will then be shown or displayed on the TV screen or LCD projector, whichever is available, thereby allowing an interactive learning process as the teacher can require students to answer first and display the results (i.e., equivalent readings of the analog multimeter) at a specific time during discussion for checking purposes. This is also beneficial to students themselves as it allows a self-paced approach in studying electronic instrumentation specifically with the use of an analog multimeter.

B. RECOMMENDATION

Although the instructional device shows a significant level of acceptability by the respondents, the device does require the user to input the range. Creating a module that automatically detects the range will be considered a significant improvement of the device. Also, the study covers current, voltage, and resistance readings only. The test of leakage for diode may be worth considering in future work.

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