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Software Development and Its Validation for Semi-Automatic Measurement of Multifunction Calibrator

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Abstract: This paper describes an early development of built-up software for semi-automatic measurement of the multifunction calibrator using the direct method with the high-resolution digital multimeter (DMM) and its validation. The software was developed by SNSU-BSN to control the calibrator and DMM using the GPIB interface. The key advantages of this development were that the software could be used easily, safely, and fast with high accuracy and precision. The developed software has been validated by comparing it to manual measurement. The type A uncertainties achieved by semi-automatic measurement were less than 0.1 μV/V for dc voltage, 0.2 μA/A for dc current, 2 μV/V for ac voltage at 1 kHz, 100 μA/A for ac current at 1 kHz, and 0.1 μΩ/Ω for resistance with each absolute normalized error of the comparison was less than 1. It showed that both the manual and semi-automatic measurements had a good agreement in each measurement, and also the evaluated type A uncertainty in the semi-automatic measurement was smaller than the manual measurement.

Keywords: Software development, Software validation, Multifunction calibrator, Normalized error, Semi-automatic measurement, Type A uncertainty

1. Introduction

The role of calibration and testing laboratories is very important in the quality assurance of many sectors, including the energy sector. The instrument standards used for energy testing are a multifunction calibrator and a high-resolution digital multimeter (DMM), Insulation tester, Earth tester (IEC 61215-1), PV meter, and many others. This paper focused on two standards, multifunction calibrator and DMM, which can calibrate the dc voltage, dc current, ac voltage, ac current, and resistance quantities.

However, calibration of these instruments is usually performed by manual measurement. In practice, this kind of measurement requires much time, exhausting, and hard to perform manually. In 2005, Leo and Chan [1], had been successfully changed the manual measurement of DMM from handwritten raw data to digital data by a camera. However, this application was hard to be performed. It needed expensive additional equipment, such as a camera, interface card, and high-performance Personal Computer (PC). Fortunately, the multifunction calibrator and DMM can be controlled automatically using the PC by General Purpose Interfacing Bus (GPIB) interface. In 2006, Capua et al. had been implemented automatic measurement of the calibrator Fluke 5500A and DMM Fluke 45 using GPIB to determine the calibration interval of DMM [2]. In 2013, Mageed and El-Rifaie had also established the automatic measurement using GPIB to perform the calibration with rapid and consistent measurement [3]. Both Capua and Mageed used the commercial software (LabVIEW) for the automatic measurement.

Besides National Metrology Institutes (NMIs) and research institutes, several manufacturers had developed methods for automatic measurement through display software, such as Fluke [4], Keysight [5], and Transmille [6]. National Measurement Standards – National Standardization Agency of Indonesia (SNSU – BSN), as the NMI of Indonesia, had also been implemented

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commercial software Met/Cal to change the measurement process from manual to semi-automatic measurement [7]. However, Met/Cal is a non-graphical user interface (GUI) software, so the operator has to write the measurement points using the specific syntax within a programming language. Moreover, the commercial software supports semi-automatic measurement only, because it cannot be integrated with additional hardware to perform the connection change in full-automatic measurement. Therefore, SNSU – BSN needs to build a new software for improving the semi-automatic measurement with the graphical user interface Microsoft Visual Basic.

The advantage of built-up new software is fit-for-purpose, such as providing the display data, warning notification, and having unambiguous information regarding the performance of the system. Furthermore, the semi-automatic software can be integrated with a built-up hardware system for full-automatic measurement in the future.

A built-up process of the new software had been initialized by SNSU – BSN, and the early testing and performance have also been done [8]. In this paper, the software developed by SNSU-BSN was described, especially how the software worked and its validation as the requirement of the international standard ISO/IEC 17025:2017 [9].

According to Tasić and Flegar [10], there were two different understandings of software validation. The first one was that software was reviewed and executed completely to detect faults (provoke failures), which was the most suitable for the developer's point of view. The second one was testing the functionality of software only, which was usually done by the end-user or inspection body. National Physical Laboratory (NPL) – NMI of United Kingdom, has provided guidance in detail to validate software in the measurement system [11]. However, the validation process in this paper was more focused on functional testing. The validation of developed software was performed by directly comparing to reference values generated from manual measurement at the same condition in several days, and then all comparison results of both the manual measurement and semi-automatic measurement were evaluated by calculating the normalized error (E_n).

2. Experimental Section

The semi-automatic measurement software had been built using Visual Basic based on the standard method of Software Development Life Cycle (SDLC), namely V-Model [12]. The V-model life cycle has an advantageous methodology i.e., development and testing work in parallel and every phase needs to be checked and approved before moving forward. The V-model is the easiest and most suitable method to be implemented in the measurement system.

Basically, V-model gives a relationship between each development stage and testing stage. The development stage consists of requirements, functional specifications, and design. The testing stage consists of module/integration testing, system testing, and acceptance testing. Also, between the two stages of development and testing, there is a coding phase.

The requirements phase is the input to the design which solves the problem in the measurement system, such as warming up of the calibration system (pre-measurement stage), collecting the DMM measured data (measurement stage), and generating the measurement report (report stage). The functional specifications include a full explanation of each function, consisting of software and hardware environment, description of software's functions, input and output data, special restrictions that will be applied to the system, and software management. The design phase models the way a software application will work. Some aspects of the design include architecture, user interface, platforms, programming, communications, and security.

The requirements, functional specifications, and design phase, especially for the hardware environment and its communication, were described in the Materials sub-section. Meanwhile, the requirements, functional specifications, and design for developing the software and its module and system testing were described in the Measurement Procedure sub-section, as well as the acceptance test ensuring the requirements had been met were described in the Validation sub-section.

A. Materials

This semi-automatic measurement system consisted of hardware and software. The hardware used for this system were multifunction calibrator as a unit under test (UUT), DMM as standard (STD), and cable to connect the instruments [13,14,15]. In principle, some measurement instruments, either the calibrator or the DMM, with different types and models could be controlled with the software, but here for practical reason, the instruments used in this practice were Fluke 5720A multifunction calibrator and Fluke 8508A reference multimeter.

The supporting equipment were the PC and GPIB IEEE-488. In this system, GPIB was used to send commands from the PC to the calibrator and DMM, as well as transfer the data from the DMM to the PC. Figure 1 illustrates a block diagram of the measurement system consisting of the PC connected using a GPIB USB – IEEE 488 bus to the calibrator and DMM.

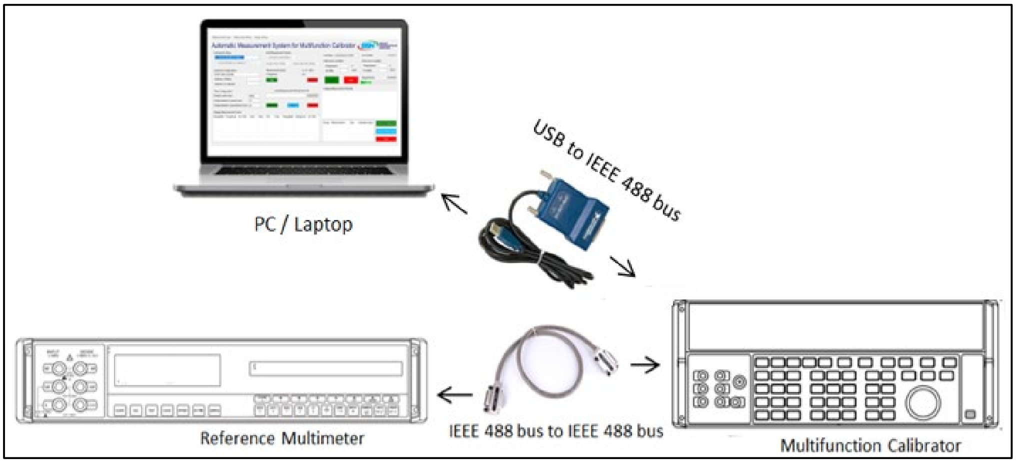

Figure 1. Block Diagram of Measurement System

B. Measurement Procedure

The software was run on the PC to control the measurement process of UUT and STD. It consisted of several panels and menus for helping the calibration operator through the measurement procedure divided into three stages: pre-measurement stage, measurement stage, and reporting stage.

B.1. Pre-measurement Stage

In the beginning, the operator had to determine the procedure by selecting the instrument model on the "Instrument Setup" panel. The operator then selected the bus address of the calibrator and DMM on the “Interface Configuration” panel. To select the configuration time delay of measurement, there was a “Time Configuration” panel consisting of three menus. “Delay to start” menu gave the warm-up time for the measurement application to run, the “Delay between 2 points” menu gave the idle time between two measurement points, and the “Delay between 2 parameters” menu provided time lag between two measurement parameters. This configuration is shown in Figure 2.

The second step was to determine the measurement parameter in the “Measuring Setting” menu. For example, it provided configuration setting of cable connection, digit of resolution, filter application, fast or normal measurement, and external or internal guard in dc voltage measurement. The example of the “Measuring Setting” configuration is shown in Figure 3.

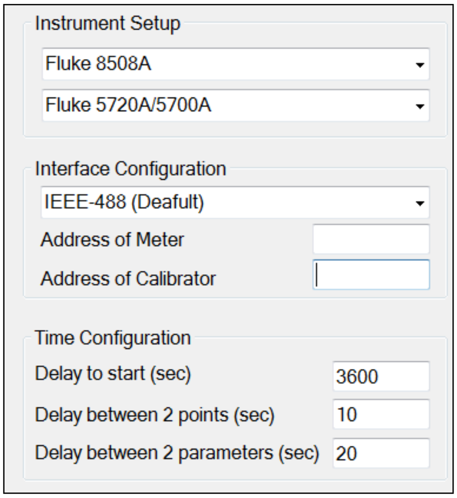

Figure 2. Instrument Setup, Interface Configuration, and Time Configuration Panel

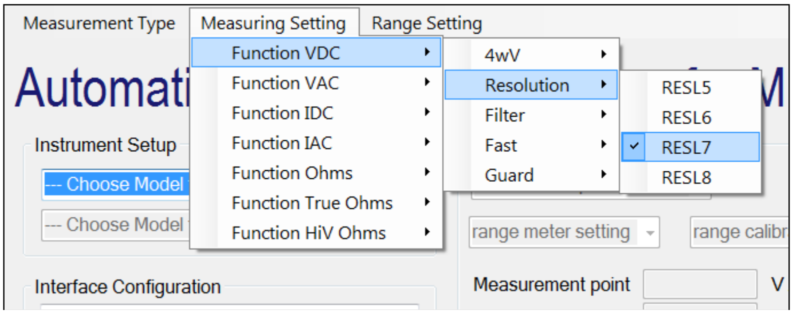

Figure 3. Measurement Parameter Configuration Menu

B.2. The Measurement Stage

At this measurement stage, the operator could set whether the measurement was in the lock or unlock mode in the “Range Setting” menu as shown in Figure 4. In the lock mode, the software locked the measuring point at the chosen range while in unlock mode it let the measuring point in the auto range.

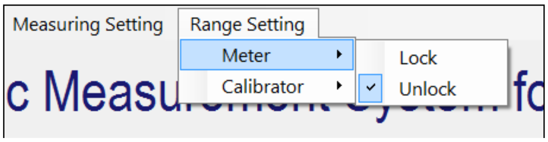

Figure 4. Range Setting Menu

There was “Edit Measurement Points” panel in this measurement stage to configure the quantity to be measured, to choose the range on the calibrator and DMM, to input the measurement point, and to insert the frequency value for ac quantities. The "Load Measurement Points from file” panel could be used to recall the measuring points and their configuration from a spreadsheet. These features are shown in Figure 5.

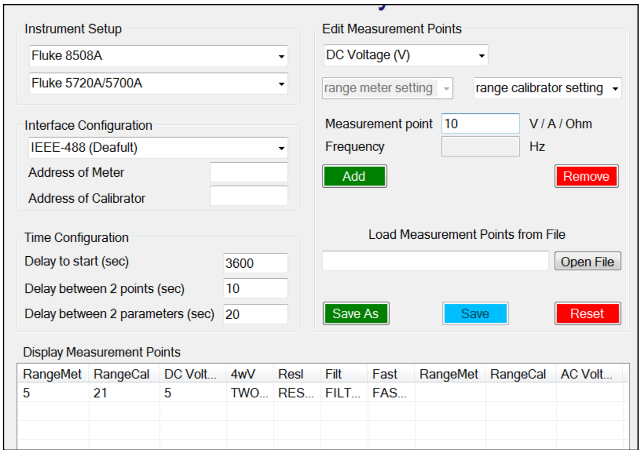

Figure 5. Edit Measurement Point and Load measurement Point form file panel

Before and after running the measurement, the environment temperature and humidity were recorded in the "Initial room condition" and "Final room condition" panel. To begin the measurement process, the operator clicked on the "Start" button and next an alert came out to warn the operator to confirm the cable connections between instruments. This alert would appear again when shifting to another parameter to notify that the connection was suitable for the measurement. The alert is shown in Figure 6.

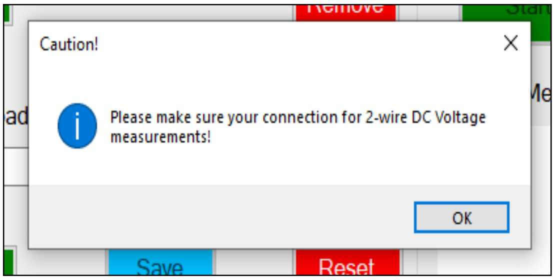

Figure 6. The Pop-up Alert Display for 2-wire DC Voltage

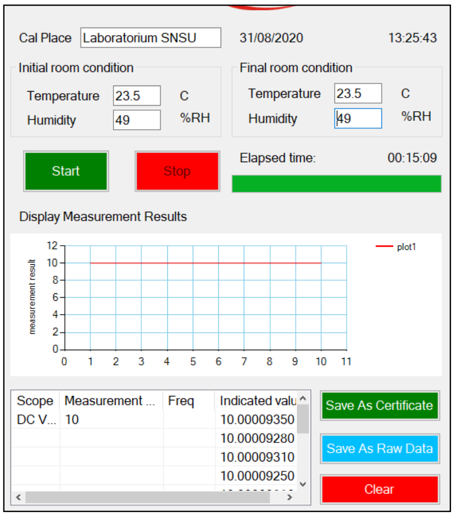

Figure 7. The Display of Updated Result in Related Fields

Along the measurement process, the software presented updated values and the obtained measurement results were tabulated as raw data. These results then could be published as a certificate of calibration when the calculation of correction and uncertainty was completed using a template. This option is shown in Figure 7.

B.3. The Report Stage

Finally, in the reporting stage, the correction value and expanded uncertainty of measurement results were evaluated based on the JCGM ISO/GUM guidelines with a 95% confidence level and a coverage factor of k = 2 [16].

C. Validation

According to ISO/IEC 17025:2017 [9], the laboratories should validate their developed methods. The validation should be as extensive as necessary to meet the needs of the given application or field of application. One of the techniques that could be used for method validation was a comparison of results achieved with other validated methods [9]. One of the validated methods was the manually direct measurement method adopted from EURAMET cg-15 [15]. Thus, the validation carried out in this paper was to compare the results of semi-automatic measurement with manually direct measurement.

C.1. Technical Requirement

This semi-automatic measurement was then compared to the manual measurement based on the internal procedure that was adopted from EURAMET cg-15 and also established in SNSU - BSN. The comparison was performed to validate the semi-automatic measurement. The comparison of both measurement techniques was observed under the same controlled condition. The standard instruments used in both measurement techniques were set and conditioned in a room with an ambient temperature of (23 ± 3)°C and relative humidity of (65 ± 10)%. Furthermore, all configurations of both measurement techniques were similar.

For the comparison, the number of repeatability was determined to be five times in each measurement. Moreover, the quantities value for this comparison was also determined, for dc voltage was 100 V, for ac voltage was 100 V at 50 Hz, for dc current was 1 A, for ac current was 1 A at 50 Hz, and for resistance was 1000 Ω.

C.2. Validation Criteria

The validation was performed by using the normalized error (E_n) evaluation. It represented the degree of equivalency where both uncertainties in the measurement result were included. The mathematical model of normalized error is shown in equation (1) [17,18]:

$$E_n = \frac{X_{SA} - X_M}{\sqrt{U^2(X_{SA}) + U^2(X_M)}} \tag{1}$$

Where X_{SA} was the average value of the semi-automatic measurement result and X_M was the average value of the manual measurement result, $U(X_{SA})$ and $U(X_M)$ were their respective expanded uncertainties for the confidence level of 95%.

The evaluation of both expanded uncertainties was performed based on JCGM ISO/GUM by comprising the two types of uncertainty contribution, namely type A and type B uncertainty [16]. The type A uncertainty came from the experimental standard deviation of the mean (ESDM) of the quantity. Meanwhile, the type B uncertainties were mainly determined by the condition, configuration, and method. However, in this comparison, all of these were similar since they used the same instruments. Therefore, the type B uncertainties of both measurements should be equivalent. If these uncertainties typed within the assumption were submitted to the equation (1), then the manipulated equation for this kind of comparison could be expressed in equation (2):

$$E_n = \frac{X_{SA} - X_M}{\sqrt{4.u^2(X_{A\_SA}) + 4.u^2(X_{A\_M}) + 8.u^2(X_B)}} \tag{2}$$

Where $u(X_{A\_SA})$ and $u(X_{A\_M})$ were the respective type A uncertainty, and $u(X_B)$ was type B uncertainties contribution. An important thing to remember was that practically the type B uncertainties were not zero and must be absolute. But assumed if that there was no type B uncertainty, the normalized error of (2) could be interpreted as simplified normalized error (E_{n_S}), as shown in equation (3):

$$E_{n\_S} \approx \frac{x_{SA}-x_M}{\sqrt{4.u^2(x_{A\_SA})+4.u^2(x_{A\_M})}} \quad (3)$$

If the calculation result of absolute simplified normalized error ($|E_{n\_S}|$) was less than 1, it meant that the both measurement techniques were in good agreement without evaluating the type B uncertainty. It was because adding the value of type B uncertainty could definitely minimize the normalized error ($|E_n|$), closer to zero. However, if the value of absolute simplified normalized error was more than 1, the type B uncertainty must be taken into account in determining the normalized error.

3. Result and Discussion

A. Measurement Result

The results of each comparison were illustrated in Figure 8 to Figure 12. It showed that the semi-automatic measurement results were close to the corresponding manual measurement results. The type A uncertainties, illustrated as error bars, of semi-automatic measurements were smaller than the type A uncertainties of manual measurements.

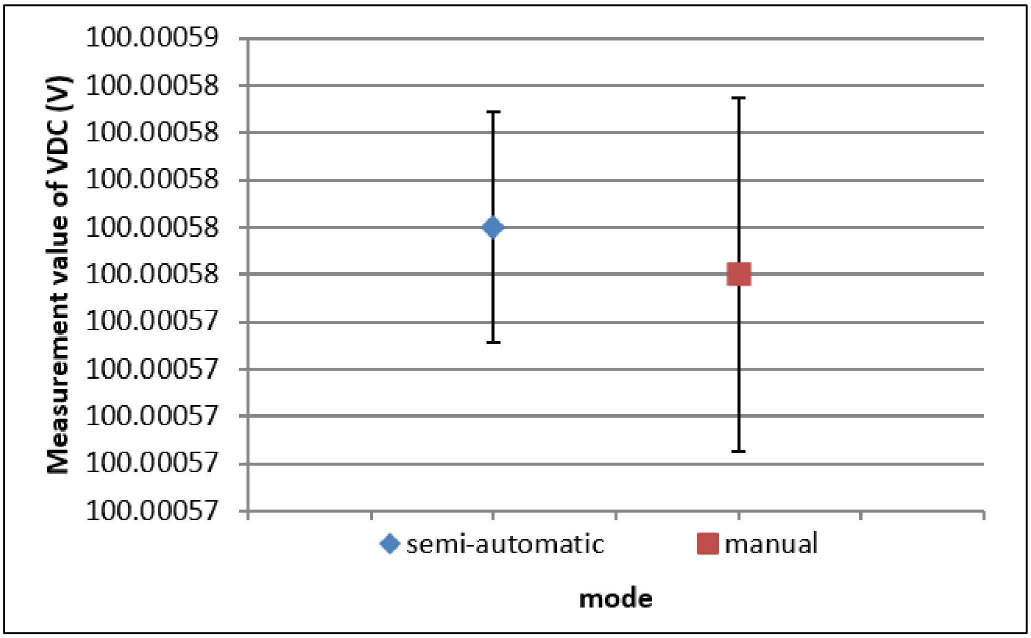

Figure 8. The result of 100 V (dc voltage) in semi-automatic and manual measurements

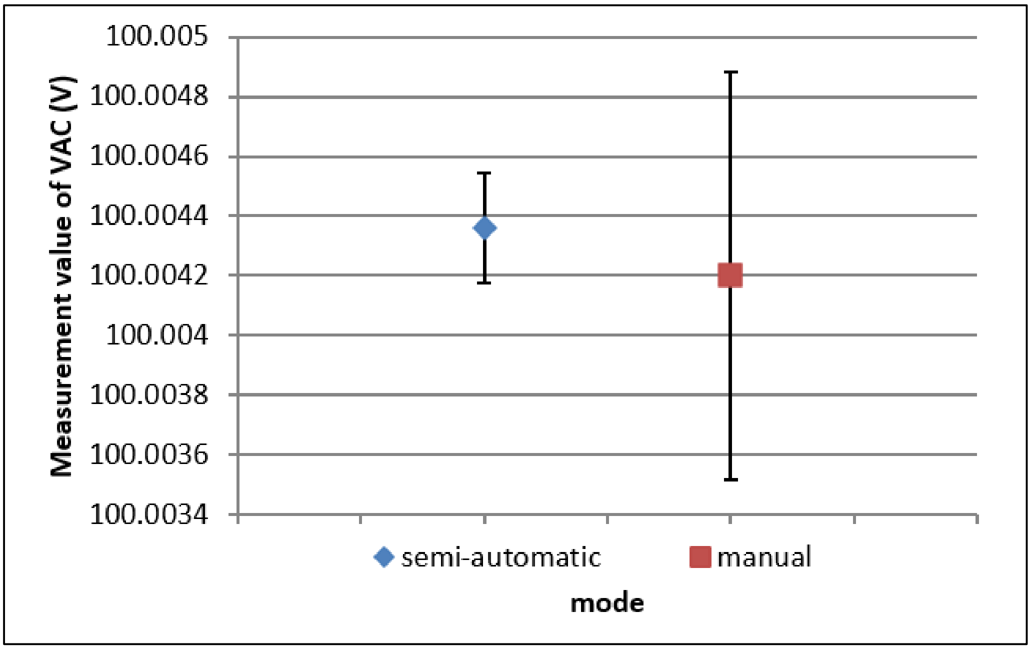

Figure 9. The results of 100 V (ac voltage) at 50 Hz in semi-automatic and manual measurements

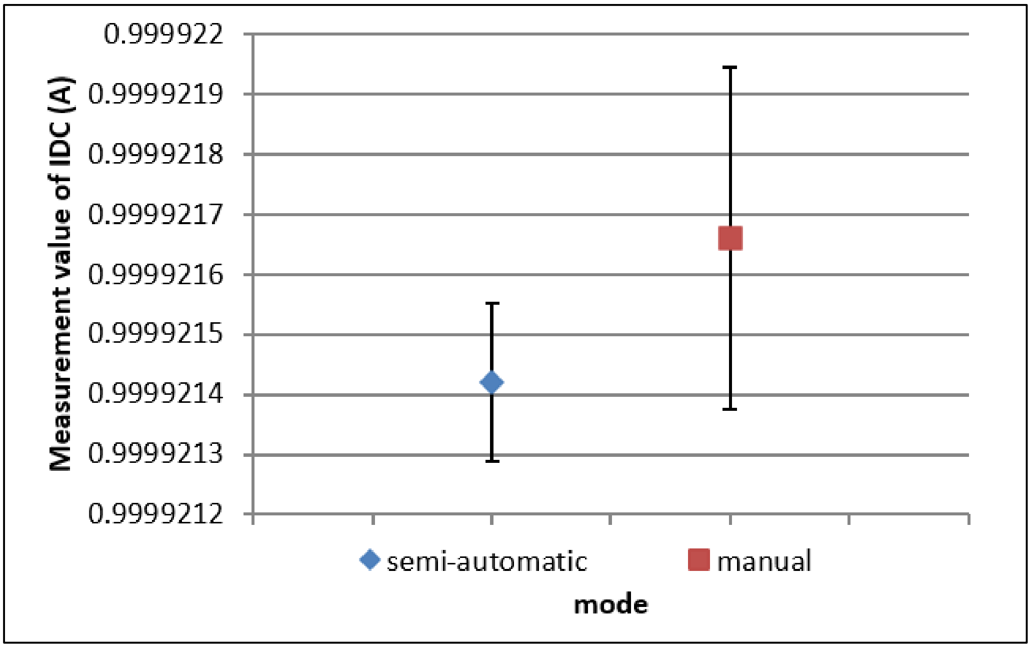

Figure 10. The results of 1 A (dc current) in semi-automatic and manual measurements

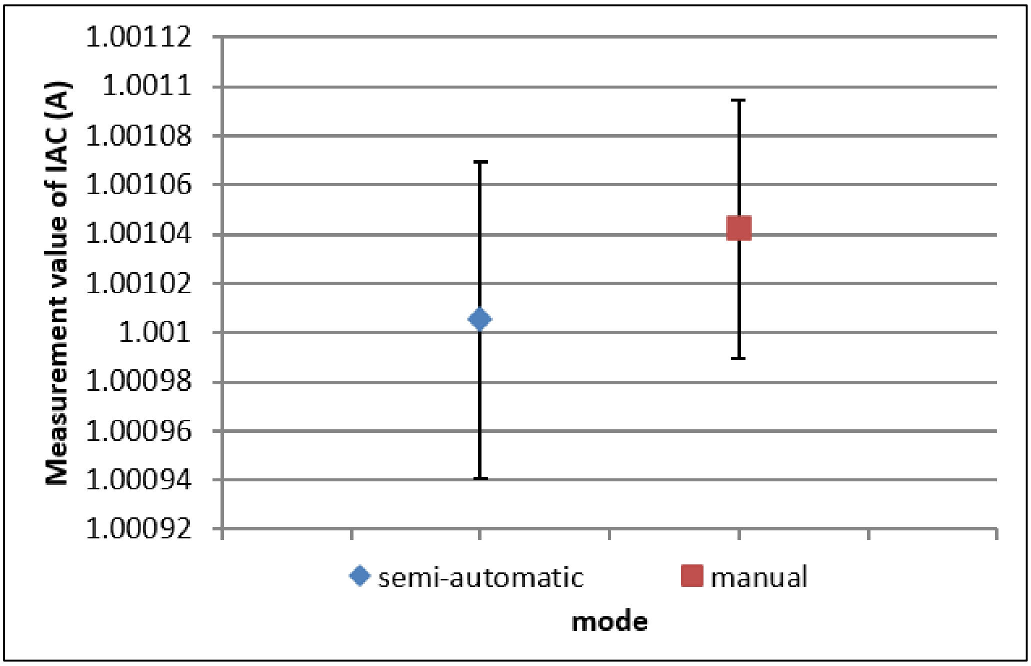

Figure 11. The results of 1 A (ac current) at 50 Hz in semi-automatic and manual measurements

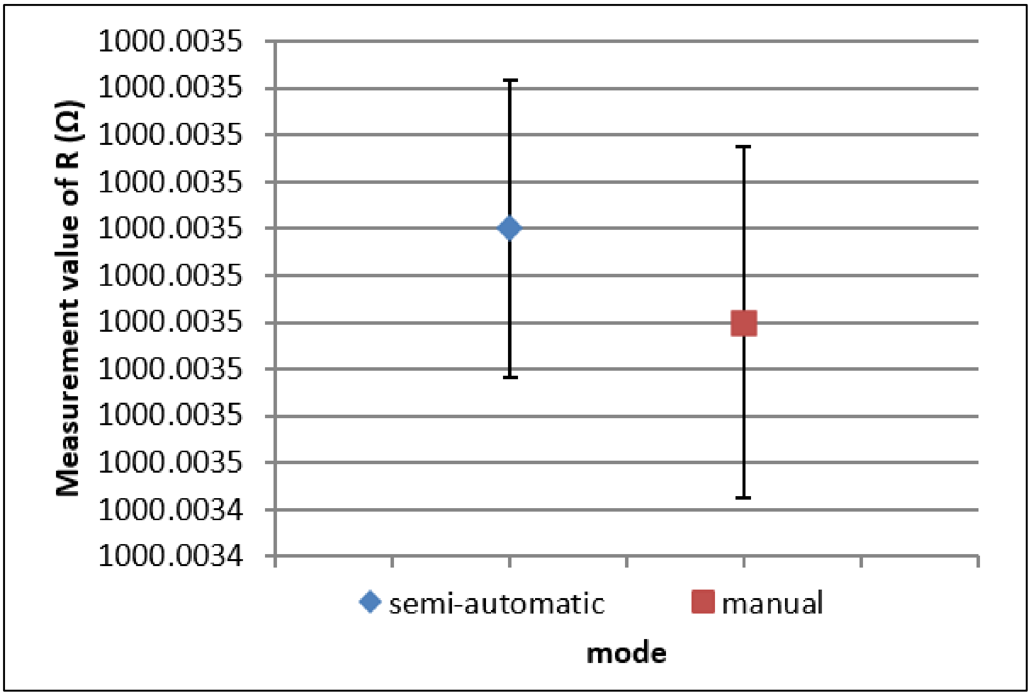

Figure 12. The results of 1000 Ω (resistance) in semi-automatic and manual measurements

Overall, these results indicated that the type A uncertainty of measurement was improved when using the semi-automatic measurement. This was because the automatic measurements were more controllable in the time of data sampling than the manual measurements which were highly dependent on user to determine the time of data sampling. As for ac current 1 A at 50 Hz using manual measurement had a smaller type A rather than automatic measurement, this was possibly due to the interference with the power line frequency. It proved that for high accuracy instrument, the measurement point should be different with power line frequency to avoid interference.

B. Validation Analysis

The simplified normalized errors were then calculated to ensure the validity of semi-automatic measurement. The calculation of normalized errors was summarized in Table 1.

Table 1. The calculation of normalized errors for both semi-automatic and manual measurements

Measurement Point	Semi-automatic Average Value	Semi-Automatic Type A Uncertainty	Manual Average Value	Manual Type A Uncertainty	Simplified Normalized Error
X	X_{SA}	$u(X_{A\_SA})$	X_M	$u(X_{A\_M})$	$\lvert E_{n\_s} \rvert$
Vdc 100 V	100.00058	0.0000049	100.00058	0.0000075	0.11
Vac 100 V, 50Hz	100.0044	0.0001860	100.0042	0.0006834	0.11
Idc 1 A	0.9999214	0.0000001	0.9999217	0.0000003	0.38
Iac 1 A, 50 Hz	1.001005	0.0000644	1.001042	0.0000525	0.22
R 1000 Ω	1000.0035	0.0000316	1000.00348	0.0000374	0.20

The simplified normalized error value from each quantity was less than 1, therefore the semi-automatic measurement with the developed software of SNSU BSN was valid. Furthermore, both the manual and semi-automatic measurements had a good agreement with each other.

4. Conclusions

The developed software of SNSU BSN has been validated by directly comparing to manual measurement as reference, using the simplified normalized error. The comparison of semi-automatic and manual techniques was performed under similar controlled environment conditions, configuration settings, and measurement method. Furthermore, the same instruments are used in both measurements, so the type B uncertainty value was identical and can be neglected. Therefore, the normalized error calculation could be simplified to check the validity of the measurement.

The comparison results showed that the type A uncertainty of measurement was improved when using the semi-automatic measurement. The validation result presented that both the semi-automatic and manual measurements had a good agreement in each other.

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The authors of Muhammad Azzumar, Lukluk Khairiyati, and Miftahul Munir are the main contributors and share equally in this paper.

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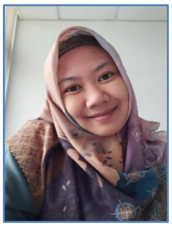

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