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

Muhammad Azzumar¹, Lukluk Khairiyati¹, Miftahul Munir¹, Mohamad Syahadi¹, Hadi Sardjono¹, Agah Faisal², Windi Kurnia Perangin-angin¹, Nibras Fitrah Yayienda¹, Hayati Amalia¹, Ashri Khusnul Chotimah Alwahid Setiawan²

¹Center for Research and Human Resource Development National Standardization Agency of Indonesia (PUSRISBANG-BSN), Banten, Indonesia
²Directorate of National Measurement Standards for Thermoelectricity and Chemistry National Standardization Agency of Indonesia (SNSU TK-BSN), Banten, Indonesia

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...
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.

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.
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.

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.
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.
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 $(23 \pm 3)^{\circ}C$ and relative humidity of $(65 \pm 10)\%$. 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 $100 \text{ V}$, for ac voltage was $100 \text{ V at 50 Hz}$, for dc current was $1 \text{ A}$, for ac current was $1 \text{ A at 50 Hz}$, and for resistance was $1000 \Omega$.

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]:

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

$$E_n = \frac{X_{SA} - X_M}{\sqrt{4.u^2(X_{A,SA}) + 4.u^2(X_{A,M}) + 8.u^2(X_B)}}$$  (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):

\[
E_{n,S} \approx \frac{x_{SA}-x_{M}}{\sqrt{u^2(x_{SA})+u^2(x_{A_M})}} \tag{3}
\]

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](image)
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.
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

<table>
<thead>
<tr>
<th>Measurement Point</th>
<th>Semi-automatic Average Value</th>
<th>Semi-Automatic Type A Uncertainty</th>
<th>Manual Average Value</th>
<th>Manual Type A Uncertainty</th>
<th>Simplified Normalized Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>XSA</td>
<td>u(XSA)</td>
<td>XM</td>
<td>u(XM)</td>
<td>(E_{n.s})</td>
</tr>
<tr>
<td>Vdc 100 V</td>
<td>100.00058</td>
<td>0.00000049</td>
<td>100.00058</td>
<td>0.0000075</td>
<td>0.11</td>
</tr>
<tr>
<td>Vac 100 V, 50Hz</td>
<td>100.0044</td>
<td>0.0001860</td>
<td>100.0042</td>
<td>0.0006834</td>
<td>0.11</td>
</tr>
<tr>
<td>Idc 1 A</td>
<td>0.9999214</td>
<td>0.00000001</td>
<td>0.9999217</td>
<td>0.000003</td>
<td>0.38</td>
</tr>
<tr>
<td>Iac 1 A, 50 Hz</td>
<td>1.001005</td>
<td>0.0000644</td>
<td>1.001042</td>
<td>0.0000525</td>
<td>0.22</td>
</tr>
<tr>
<td>R 1000 Ω</td>
<td>1000.0035</td>
<td>0.0000316</td>
<td>1000.00348</td>
<td>0.0000374</td>
<td>0.20</td>
</tr>
</tbody>
</table>

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.

5. Acknowledgment

The authors would like to acknowledge the Director of National Measurement Standards for Thermoelectricity and Chemistry – National Standardization Agency of Indonesia (SNSU TK – BSN) and Head of Center for Research and Human Resource Development – National Standardization Agency of Indonesia (Pusrisbang SDM – BSN) who have provided the facilities and support to carry out this research.

This work was supported by the National Innovation System Research Incentive (INSINAS) funding from Directorate of Industrial of Technology Development, Ministry of Research and Technology / National Research and Innovation Agency (Kemenristek / BRIN) with decree no. # 46/E1/KPT/2020 and # 59/INS-1/PPK/E4/2020.

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


[17]. Isabelle Blanc, “Bilateral comparison report of DC resistance (1 mΩ, 100 Ω and 100 MΩ) between LNE (France) and KIM-LIPI (Indonesia)”, Metrologia, Vol. 57 (1A), pp. 01007, 2020.

Muhammad Azzumar was born on June 26, 1990, in Jakarta. He received his Bachelor of Electrical Engineering at the University of Indonesia in 2012 and also obtained his Master of Electrical Engineering at the University of Indonesia in 2013. In 2022, he joined the Research Center for Testing Technology and Standards - National Research and Innovation Agency of Indonesia (BRIN) as a Junior Researcher. His current research interests include applied metrology and measurement, computer-human interaction, artificial intelligence, internet of things, and control engineering.

Lukluk Khairiyati was born on November 29, 1979, in Kulonprogo. She completed her Bachelor of Electrical Engineering at Universitas Gadjah Mada in 2004 and also obtained her Master of Electrical Engineering at the University of Indonesia in 2014. In 2019, she joined the Center for Research and Human Resource Development BSN as a Junior Researcher and the Technical Implementer of Calibration at the Electrical Laboratory of SNSU BSN. Her current research interests include applied metrology and measurement, and Instrumentation.

Miftahul Munir was born on July 13, 1987, in Jambi. He completed his Bachelor of Electrical Engineering at Universitas Gadjah Mada, Indonesia in 2010 and also obtained his Master of Science in Electrical Engineering at Western Michigan University, United States in 2019. In 2022, he joined the Research Center for Testing Technology and Standards - National Research and Innovation Agency of Indonesia (BRIN) as a Junior Researcher. His current research interests include Electric Power System, Low Current Measurement and Metrology for Electric Vehicle.

Mohamad Syahadi was born on June 13, 1983, in Demak. He received a B.S. degree in electrical engineering from Diponegoro University, Semarang, Indonesia, in 2008, and an M.S. degree in electrical engineering from Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, in 2020. In 2022, he joined the Research Center for Photonics - National Research and Innovation Agency (BRIN) as a Junior Researcher. His research interests include optoelectronics, optical fiber sensors and Electrical Metrology.

Hadi Sardjono was born on April 21, 1960, in Bangkalan. He received his Bachelor of Electrical Engineering from the University of Brawijaya in 1986 and also obtained his Master of Engineering Science at the University of Indonesia. From 2021 to the present at Research Center for Testing Technology and Standards - National Research and Innovation Agency (BRIN) as a Principal Researcher. His research interests to date include calibration, instrumentation and electrical metrology.
Agah Faisal was born on February 14, 1981, in Jakarta. He completed his undergraduate education at Padjajaran University majoring in Physics in 2003 and also completed his Master’s degree at the University of Science and Technology in 2011. From 2011 until now he is a member of the Electrical and Magnetic Technical Commission in the Asia Pacific Metrology Program (TCEM-APMP). In 2010 until now he is the head of the Electrical Laboratory of SNSU BSN. His current research interests include applied metrology and measurement, and Instrumentation.

Windi Kurnia Perangin-Angin was born on August 20, 1986, in Bangun Setia. He received his Bachelor of Electrical Engineering at the University of Indonesia in 2010 and also completed his Master in Science of Measurement at the University of Science and Technology South Korea in 2017. He is currently pursuing a PhD Technische Universität Braunschweig majoring in Electrical Engineering. In 2022, he joined the Research Center for Energy Conversion and Conservation - National Research and Innovation Agency (BRIN) as a Junior Researcher. His current research interests include microwave power measurement standard, RF impedance, and electric power system.

Nibras Fitrah Yayienda was born on July 21, 1991, in Surabaya. She completed her Bachelor of Physics Engineering at the Sepuluh Nopember Institute of Technology in 2013. In 2015, she joined the Center for Research and Human Resource Development BSN as an Assistant Researcher and is a Technical Implementer of Calibration at the Electrical Laboratory of SNSU BSN. She is currently pursuing a Master of Electrical Engineering at the University of Indonesia. Her current research interests include applied metrology and measurement, and Instrumentation.

Hayati Amalia was born on September 21, 1990, in Kediri. She completed her Bachelor of Electrical Engineering at the Sepuluh Nopember Institute of Technology (ITS) Surabaya in 2012. She began joining the Center for Research and Human Resource Development BSN in 2019 as the Assistant Researcher and became the Technical Implementer of Calibration at the Electrical and Time Laboratory of SNSU BSN. She is currently pursuing a Master’s Degree at the Bandung Institute of Technology (ITB). Her current research interests include applied metrology and measurement, and Instrumentation.

Ashri Khusnul Chotimah Alwahid Setiawan was born on March 19, 1993, in Bandung. She completed her Bachelor of Physics Engineering at the Sepuluh Nopember Institute of Technology in 2016. In 2019, she joined the Directorate of National Measurement Standards for Thermoelectricity and Chemistry (SNSU TK) BSN until now as an Evaluator of Physical Standard Traceability and is a Technical Implementer of Calibration at the Electrical Laboratory of SNSU BSN. Her current research interests include applied metrology and measurement, and Instrumentation.