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Evaluating Manual vs. IoT-Driven Automated Calibration Methods for Scale Weights

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Abstract - *This study aims to compare manual calibration methods with automated calibration methods based on the Internet of Things (IoT) for scale weights, in accordance with the OIML R-51-1:2006 standards. The research employs three distinct types of scale weights: Cylindrical Knob, Cylindrical Hook Weight, and Cylindrical Slotted Weight. The comparison of these calibration methods is carried out using two key metrics: Correction Values and Standard Deviation Analysis. The experimental results indicate a trend where the accuracy of calibration diminishes as the weight of the scale increases. Specifically, when evaluating the three types of scale weights at a nominal test weight of 50 grams, the correction values obtained are relatively small, showing differences of 0.12, 0.1, and 0.02 for Cylindrical Knob, Cylindrical Hook Weight, and Cylindrical Slotted Weight, respectively. These findings suggest that the impact of weight on calibration accuracy is consistent across the types tested. In addition, Standard Deviation Analysis reveals that the IoT-based automated calibration method consistently achieves lower standard deviation values compared to the manual method. This indicates that the automated method provides more consistent and reliable calibration results. Overall, the study concludes that the IoT-based automated calibration method offers a significant improvement in performance over traditional manual methods for all three types of scale weights. This advancement highlights the potential for IoT technology to enhance the accuracy and efficiency of calibration processes in various industrial applications.*

Keywords : *IoT-Based Calibration, automation, calibration, conveyor scale, internet of things, scale weight*

I. INTRODUCTION

Calibration weights are essential for ensuring the accuracy of mass measurements and are defined by specific physical and metrological properties, such as shape, size, material, surface quality, nominal value, density, magnetic properties, and maximum permissible error[1]. The conventional method for calibrating these weights involves manually alternating between test weights and reference weights on a scale pan to determine their mass. This approach, however, introduces several risks, including the possibility of weights falling during handling, which can alter their physical and metrological properties. Furthermore, the risk of falling weights, particularly those of significant mass, poses safety hazards to calibration personnel. To achieve precise calibration results, it is crucial that the calibration environment remains stable, with air pressure consistent with atmospheric conditions. Consequently, additional instruments, such as thermohygrometers and barometers, are often required to monitor and control environmental conditions effectively.

Previous research on automatic calibration systems for test weights, who utilized a vertically and horizontally movable table powered by an electric motor[2]. This system enabled automatic placement changes of standard and test weights on a loading plate. Their system proved to be 50% faster in the calibration process and reduced standard deviation compared to manual calibration. However, their study lacked an integrated environmental condition measurement tool. Similarly, the Korean Testing Laboratory (KTL) utilized a 3-axis robotic arm with a weight holder for moving standard and test weights with a nominal value of 20 kg. This research revealed that the automatic calibration method provided lower correction values and standard deviations compared to manual calibration. Nonetheless, their system faced challenges in accommodating test weights of varying dimensions due to its fixed x, y, and z positional constraints[3]. A more recent study developed an automatic mass comparator capable of calibrating sub-milligram test weights of various shapes (wire, sheets, disks) using an ultra-microbalance, load cell, and a 3-axis motorized stage. This research focused solely on the automatic calibration of sub-milligram weights, with data acquisition still performed by linking the system to software on a computer[4].

The prototype aims to demonstrate improved calibration efficiency and reduced uncertainty, offering a cost-effective solution with enhanced productivity. Data from calibration, including environmental conditions, will be recorded and stored in Google Sheets for comprehensive analysis. The expected outcome is that the automatic calibration system will show superior performance in terms of correction values and reduced standard deviation, highlighting its potential advantages over manual calibration methods. The key objective of this research is to evaluate the effectiveness of the automatic calibration prototype by comparing its performance with manual calibration. This comparison will focus on Correction Values by comparing the correction values obtained from both manual and automatic methods and Standard Deviation to measuring the consistency and reliability of calibration results. The expected outcome is that the automatic calibration system will show superior performance in terms of correction values and reduced standard deviation, highlighting its potential advantages over manual calibration methods.

II. RESEARCH METHODS

This study employs the R&D (Research and Development) method, adopting the ADDIE approach, which includes the phases of Analysis, Design, Development, Implementation, and Evaluation[5]. the research stages are presented in a diagram illustrated in Figure 1.

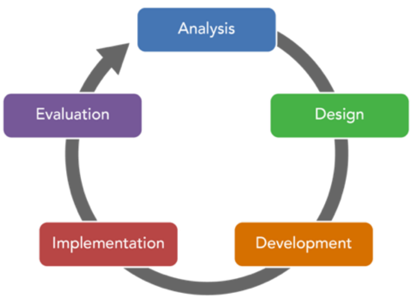

Figure 1. ADDIE Model

Analysis: This phase involves identifying problems and needs in the calibration laboratory of PT Certindonesia, specifically focusing on the calibration of test weights. The calibration capabilities include weights ranging from 1 mg to 20 kg. The analysis revealed that manual calibration processes are challenging due to the labor-intensive and time-consuming nature of repeatedly placing and removing test weights from the scale, especially for larger weights such as 10 kg and 20 kg. Additionally, there is a risk of test weights falling during handling, which could alter their physical properties and potentially injure calibration personnel. Given the high demand for test weight calibration from both internal laboratory needs and customers, there is a need for an automated calibration system that can handle test weights during the calibration process to save labor and time while mitigating risks. With advancements in technology, the implementation of IoT is considered for data acquisition and environmental monitoring to enhance the efficiency and productivity of the test weight calibration process.

Design: In this phase, the automatic calibration system for test weights is designed as a prototype for a maximum test weight of 200 g, which represents 20 kg in the actual system scale. The prototype design includes three main components: input, process, and output. The input section features a push button, BME280 sensor module, and load cell with HX711 signal amplifier. The process section includes the NodeMCU microcontroller, while the output consists of a DC conveyor motor and data storage to Google Sheets via wireless network. The hardware design and construction are shown in Figure 2.

Figure 2. Automatic Test Weight Calibration Prototype

The prototype is depicted in both front and side views. The front view includes four main components: A, the electronics enclosure; B, the section for positioning and moving test weights; C, the weighing pan with an underlying load cell; and D, the area for positioning and moving standard weights. The side view highlights additional features: E, the conveyor belt made from 100 gsm spunbond fabric; F, the female DC power adaptor jack for a 12-volt motor power supply; G, the female micro USB jack from the NodeMCU for a 5-volt primary power source; and H, the push button for resetting and restarting the system.

Development: This phase encompasses the assembly of the prototype hardware and programming. The programming is executed using the Arduino IDE to ensure that the NodeMCU functions as the main control unit for the prototype, aligning with the calibration procedures outlined in OIML R 111-1: 2004[1].

Implementation: During this phase, the prototype is tested to ensure it meets the design specifications and requirements. Tests include evaluating the BME280 sensor for accuracy and reliability, assessing the conveyor's functionality, and verifying the compliance of the test weights with OIML R 51-1:2006 standards[6]. The performance of the prototype in

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automatic calibration and data recording to Google Sheets is also examined.

Evaluation: The evaluation phase involves verifying whether the prototype functions according to the research objectives. Comparative analysis assesses the differences between automatic and manual calibration results, considering variables such as correction values and standard deviation.

III. RESULT AND ANALYSIS

In the implementation stage of this research, the calibration of test weights was conducted using both manual and automatic methods. Three types of cylindrical test weights were utilized: Cylindrical Knob Weight, Cylindrical Hook Weight, and Cylindrical Slot Weight, with nominal values of 200 g, 100 g, and 50 g respectively. To minimize environmental influences, all calibrations were performed at the same location and on the same day. The calibration results were analyzed based on various metrics including the difference in measurement readings, average differences, correction values, standard deviations, and calibration time. A detailed analysis for each type of test weight is as follows:

3.1 Cylindrical Knob Weight

The Cylindrical Knob Weight features a knob on its top, designed to facilitate handling and placement on the scale. In this study, the Cylindrical Knob Weights calibrated were of class M1, with the calibration standard being a class F1 weight of the same nominal value as the test weights. The calibration data for Cylindrical Knob Weights with nominal values of 50 g, 100 g, and 200 g are presented in Table 1.

Table 1. Manual Caliberation Cylindrical Knob

Nominal	Manual Caliberation			Testing Data		
	S	T	S	S	T	S
(g)	(g)	(g)	(g)	(g)	(g)	(g)
	50,0	50,1	50,0	50,0	50,1	50,0
	50,0	50,2	50,1	50,0	50,2	50,1
50	50,1	50,2	50,1	50,1	50,2	50,1
	50,1	49,9	50,0	50,1	49,9	50,0
	50,2	50,2	50,2	50,2	50,2	50,2
	100,0	100,2	100,0	99,9	100,0	100,0
	100,0	100,0	100,0	100,0	100,2	100,1
100	100,0	100,2	100,0	100,2	100,3	100,1
	99,9	100,0	100,0	100,2	100,2	100,0
	100,0	100,0	99,9	100,0	100,0	100,1
	200,0	199,9	200,0	200,2	200,1	199,9
200	200,0	200,1	200,0	200,0	199,9	200,0
	200,0	200,0	200,0	200,0	199,9	200,0
	200,1	200,1	200,0	200,0	200,0	200,1
	200,0	199,9	200,0	200,2	200,1	199,9

Table 2 presents the processed calibration data for Cylindrical Knob Weights using both manual and automatic methods. This data serves as the basis for comparing correction values and standard deviations.

Table 2. Comparison Data of Manual and Automatic Methods

Manual							Otomatis						
Nominal	ΔI	ΔIrata	Mc	Mt	Stdev	t	Nominal	ΔI	ΔIrata	Mc	Mt	Stdev	t
(g)	(g)	(g)	(g)	(g)	(g)	(s)	(g)	(g)	(g)	(g)	(g)	(g)	(s)
	0,10							-0,05					
	0,15							0,15					
50	0,10	0,04	0,00	0,04	0,11	257	50	0,00	0,05	0,00	0,05	0,10	139
	-0,15							-0,05					
	0,00							0,20					
	0,20							0,05					
	0,00							0,15					
100	0,20	0,10	0,00	0,10	0,08	260	100	0,15	0,08	0,00	0,08	0,07	131
	0,05							0,10					
	0,05							-0,05					
	-0,10							0,05					
	0,10							-0,10					
200	0,00	-0,01	0,00	-0,01	0,08	262	200	-0,10	-0,03	0,00	-0,03	0,07	136
	0,05							-0,05					
	-0,10							0,05					

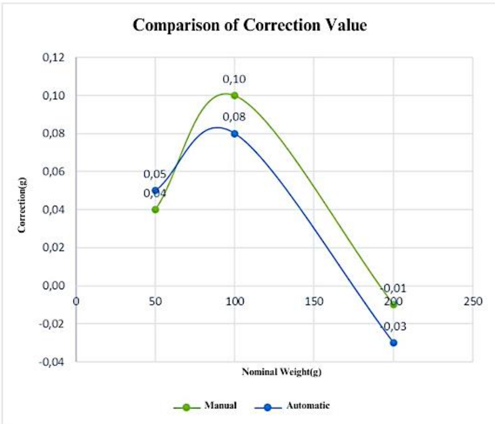

Figure 3. Comparison of Corrections for Cylindrical Knob Weights

Figure 3 illustrates the comparison of correction values between manual and automatic calibration methods for Cylindrical Knob Weights. The largest correction difference observed is 0.02 g for the 200 g nominal weight. This indicates that both methods exhibit nearly equivalent levels of accuracy.

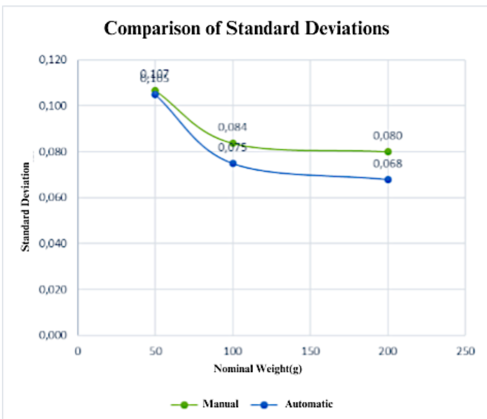

Figure 4. Comparison of Standard Deviation for Cylindrical Knob Weights

Figure 4 shows that the standard deviation of calibration results for Cylindrical Knob Weights using the automatic method is smaller compared to the manual method, with the largest reduction reaching 0.12 g for the 200 g nominal weight. This indicates that the automatic method provides greater consistency than the manual method.

3.2 Cylindrical Hook Weights

The Cylindrical Hook Weights feature a hook at the top, which allows the weights to be suspended. This design is often longer and thinner compared to the knob type. The M1 class Cylindrical Hook Weights are calibrated using the same standard weights, which are F1 class weights. Calibration data for nominal weights of 50 g, 100 g, and 200 g are presented in Table 3.

Table 3. Manual Caliberation Cylindrical Hook Weights

Nominal	Manual Caliberation			Testing Data		
	S	T	S	S	T	S
(g)	(g)	(g)	(g)	(g)	(g)	(g)
	50,0	50,2	50,1	50,1	50,1	49,9
	50,1	50,1	50,0	50,0	50,2	50,1
50	50,1	50,2	50,1	50,1	50,2	50,1
	50,0	50,3	50,2	50,1	50,3	50,2
	50,1	50,2	50,0	50,1	50,3	50,2
	100,0	100,1	100,0	100,2	100,3	100,2
	100,0	100,1	100,1	100,1	100,2	100,2
100	100,0	100,0	100,0	100,2	100,2	100,1
	100,0	100,1	100,0	100,1	100,2	100,2
	100,0	100,1	100,0	100,1	100,2	100,1
	200,0	200,2	200,1	200,2	200,2	200,1
200	200,1	200,1	200,1	200,2	200,3	200,2
	200,1	200,1	200,0	200,1	200,3	200,2
	200,0	200,2	200,1	200,2	200,2	200,1
	200,1	200,2	200,0	200,2	200,3	200,2

Table 4 presents the processed calibration data for Cylindrical Hook Weights using both manual and automatic methods., including the correction values and standard deviations.

Table 4. Comparison Data of Manual and Automatic Methods

Manual							Otomatis						
Nominal	ΔI	ΔIrata	Mc	Mt	Stdev	t	Nominal	ΔI	ΔIrata	Mc	Mt	Stdev	t
(g)	(g)	(g)	(g)	(g)	(g)	(s)	(g)	(g)	(g)	(g)	(g)	(g)	(s)
	0,15							0,10					
	0,05							0,15					
50	0,10	0,13	0,00	0,13	0,05	259	50	0,10	0,13	0,00	0,13	0,02	138
	0,20							0,15					
	0,15							0,15					
	0,10							0,10					
	0,05							0,05					
100	0,00	0,07	0,00	0,07	0,04	261	100	0,05	0,07	0,00	0,07	0,02	137
	0,10							0,05					
	0,10							0,10					
	0,15							0,05					
	0,00							0,10					
200	0,05	0,10	0,00	0,10	0,06	264	200	0,15	0,09	0,00	0,09	0,04	136
	0,15							0,05					
	0,15							0,10					

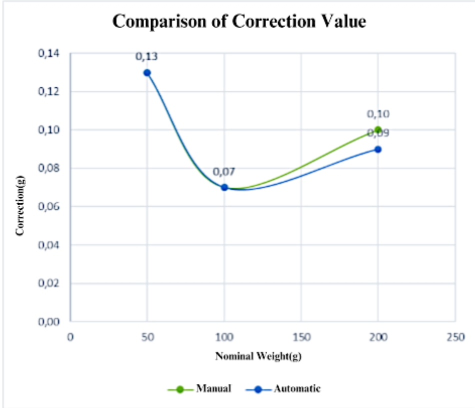

Figure 5. Comparison of Corrections for Cylindrical Hook Weights

Figure 5 shows that for the 50 g and 100 g nominal weights, there is no difference in correction values between the manual and automatic calibration methods for Cylindrical Hook Weights. For the 200 g nominal weight, there is a difference of 0.01 g, which remains within the acceptable accuracy tolerance.

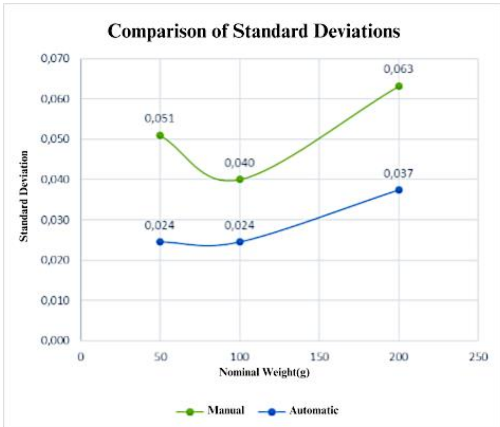

Figure 6. Comparison of Standard Deviation for Cylindrical Hook Weights

Figure 6 shows that the standard deviation of calibration results for Cylindrical Hook Weights is smaller with the automatic method compared to the manual method, with the largest difference being 0.26 g. This underscores that the automatic method is more stable and reliable.

3.3 Cylindrical Slot Weights

The Cylindrical Slot Weights feature a slot that allows them to be stacked or arranged on top of one another. This design facilitates the incremental addition or removal of mass. The M1 class Cylindrical Slot Weights are calibrated using F1 class standard weights. Calibration data for nominal weights of 50 g, 100 g, and 200 g are presented in Table 5.

Table 5. Manual Caliberation Cylindrical Slot Weights

Nominal	Manual Caliberation			Testing Data		
	S	T	S	S	T	S
(g)	(g)	(g)	(g)	(g)	(g)	(g)
	50,0	50,1	50,0	50,0	50,1	50,1
	50,0	50,2	50,0	49,9	50,2	50,1
50	50,0	50,1	50,0	49,9	50,1	50,1
	50,0	50,0	50,0	50,0	50,2	50,2
	50,0	50,1	50,0	50,0	50,2	50,2
	100,0	100,2	100,0	100,1	100,3	100,0
	100,0	100,3	100,0	100,1	100,2	100,0
100	100,0	100,1	100,0	100,1	100,2	100,0
	100,0	100,2	100,0	100,0	100,2	100,1
	100,0	100,2	100,0	100,1	100,3	100,1
	200,0	200,2	200,1	200,1	200,2	200,1
200	200,1	200,3	200,1	200,2	200,3	200,0
	200,0	200,2	200,0	200,1	200,3	200,1
	200,0	200,3	200,1	200,1	200,3	200,1
	200,2	200,2	200,0	200,2	200,3	200,1

The calibration data for slot cylindrical weights, both manually and automatically,are analyzed to obtain correction values and standard deviations, as shown in Table 6.

Table 6. Comparison Data of Manual and Automatic Methods

Manual							Otomatis						
Nominal	ΔI	ΔIrata	Mc	Mt	Stdev	t	Nominal	ΔI	ΔIrata	Mc	Mt	Stdev	t
(g)	(g)	(g)	(g)	(g)	(g)	(s)	(g)	(g)	(g)	(g)	(g)	(g)	(s)
	0,10							0,05					
	0,20							0,20					
50	0,10	0,10	0,00	0,10	0,06	261	50	0,10	0,11	0,00	0,11	0,05	135
	0,00							0,10					
	0,10							0,10					
	0,20							0,25					
	0,30							0,15					
100	0,10	0,20	0,00	0,20	0,06	264	100	0,15	0,18	0,00	0,18	0,04	139
	0,20							0,15					
	0,20							0,20					
	0,15							0,10					
	0,20							0,20					
200	0,20	0,18	0,00	0,18	0,05	266	200	0,20	0,17	0,00	0,17	0,04	138
	0,25							0,20					
	0,10							0,15					

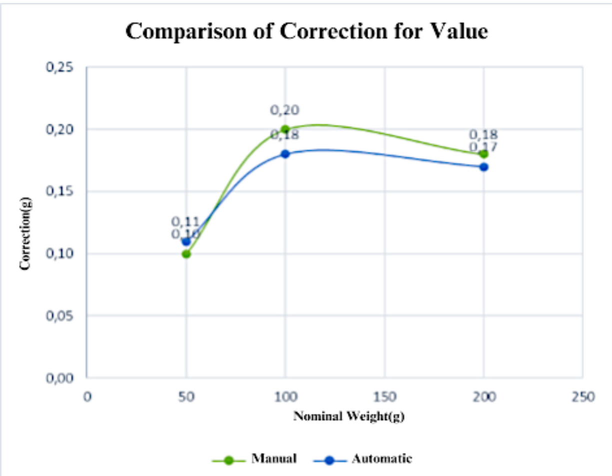

Figure 7. Comparison of Corrections for Cylindrical Slot Weights

Figure 7 illustrates that the largest correction value difference in the calibration results for Cylindrical Slot Weights is 0.02 g for the 100 g nominal weight, indicating that the results from both methods are very close.

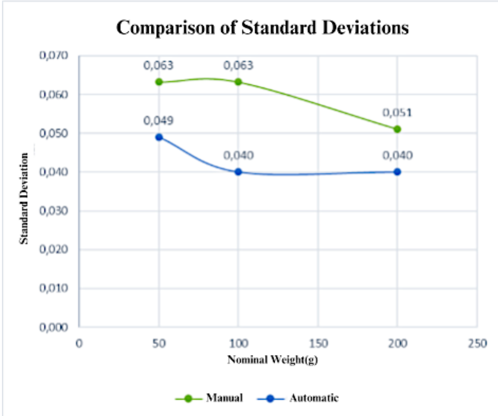

Figure 8. Comparison of Standard Deviation for Cylindrical Slot Weights

Similar to other weights, the standard deviation of calibration results using the automatic method is relatively smaller compared to the manual method, as shown in Figure 8. The largest reduction in standard deviation, 0.23 g, is observed for the 100 g nominal weight. This demonstrates a higher level of reliability with the automatic method.

VI. CONCLUSION

From the analysis, despite the very minimal differences in correction values between the two methods, the automatic method proves to be superior in terms of stability and efficiency. The automatic calibration method offers advantages in result consistency (evidenced by smaller standard deviations) and time efficiency (faster calibration process). Based on the average calibration times for various types of weights, the automatic method demonstrates a time efficiency improvement of up to 52%. Therefore, for calibration tasks requiring precision and time efficiency, the automatic method is recommended. Additionally, the automatic method's ability to handle various weight shapes without affecting the calibration process further underscores its effectiveness and versatility.

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