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An Implementation of Measurement System Analysis for IoT-Based Waste Management Development

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***Abstract*—A measurement system is a process that consists of standards, employees, and methods for measuring particular quality characteristics. Measurement System Analysis (MSA) attempts to evaluate a measuring system's precision, accuracy, and consistency so that clients receive high-quality goods. The previous study implements the MSA for machinery and industrial lines, electronics manufacturing, agricultural and poultry, aviation, and even employee monitoring and inspection. Elsewhere, waste management has problems, especially with capacity measurement instruments and weight sensors. This study aims to: (i) build an IoT-based waste management system; and (ii) evaluate the developed system by implementing the MSA technique, focusing on measurement equipment. Gauge Repeatability And Reproducibility (GR&R) study type 1, (GR&R) *study*, and Analysis of Variance (ANOVA) are conducted to evaluate the measurement instrument of the waste management system. The study findings that the total variance of the GR&R is 20,95 %, and the distinct categories are 6. Thus, as the Automotive Industry Action Group (AIAG) GR&R recommendation, the measuring system is marginal (acceptable in certain conditions). Moreover, the ANOVA result indicates that interaction and operators did not affect measurement outcomes because the blue dots remain inside the acceptable range.**

Keywords: ***measurement system analysis (MSA), gauge R&R, anova, IoT, waste management***

***Abstrak*—Sistem pengukuran adalah proses yang terdiri dari standar, karyawan, dan metode untuk mengukur karakteristik kualitas tertentu. *Measurement System Analysis* (MSA) umumnya digunakan untuk mengevaluasi presisi, akurasi, dan konsistensi dalam sistem pengukuran sehingga dapat menghasilkan barang berkualitas tinggi. Studi sebelumnya mengimplementasikan MSA untuk permesinan dan produksi industri, manufaktur elektronik, pertanian dan peternakan, penerbangan, dan bahkan inspeksi karyawan. Di tempat lain, pengelolaan sampah memiliki masalah, terutama pada instrumen pengukuran kapasitas dan sensor berat. Penelitian ini bertujuan untuk: (i) membangun sistem pengelolaan sampah berbasis IoT; dan (ii) mengevaluasi sistem yang dikembangkan dengan menerapkan teknik MSA, dengan fokus pada instrumen pengukuran. *Gauge Repeatability* And *Reproducibility* (GR&R) study type 1, (GR&R) study, dan *Analysis of Variance* (ANOVA) dilakukan untuk mengevaluasi instrumen pengukuran sistem pengelolaan sampah. Temuan studi bahwa total *variance* GR&R adalah 20,95%, dan *distinct categories* adalah 6. Jadi, kategori GR&R yang direkomendasikan oleh *Automotive Industry Action Group* (AIAG), sistem pengukurannya dapat diterima dalam kondisi tertentu. Selain itu, hasil ANOVA menunjukkan bahwa interaksi dan *operator* tidak mempengaruhi hasil pengukuran karena parameter tetap berada dalam rentang yang dapat diterima.**

Kata kunci: ***measurement system analysis (MSA), gauge R&R, anova, IoT, pengelolaan sampah***

I. Introduction

A measurement system is a process that consists of standards, employees, and methods for measuring particular quality characteristics. Measurement System Analysis (MSA) is one of the essential quality techniques used to analyse the adequacy of gauge variation in order to guarantee the quality of the measurement system and associated products. MSA aims to evaluate a measuring system's precision, accuracy, and consistency. Inaccurate measurement results will cause the delivery of low-quality goods to customers.

MSA is essential when developing a product so that clients receive high-quality goods. Some research employs the MSA approach to determine the quality of the product that will be manufactured. For instance, research about machinery and industrial lines [1]–[5], electronics manufacturing [6]–[9], agricultural and poultry [10]–[12], aviation [13], and even employee monitoring and inspection [14].

Several studies implement the MSA approach to determine the product quality produced by a machine

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or production line. In Martínez *et al.* [1] study, MSA is used to automatically inspect machined metal components to discover faults even when their orientation and shape are quite similar to the surface finishing. As a result, the system is acceptable for industrial applications according to its low false rejection rate. Research [2], [3] adopt the Six Sigma define, measure, analyse, improve, and control (DMAIC) methodology to deploy MSA. Maged *et al.* [2] successfully implementing Six Sigma can dramatically lower the rejection rate, reducing the cost of poor quality by up to 45%. However, Zgodavova *et al.* [3], in their research with a Bakery Machine Manufacturer case study, cannot effectively lower the scrape rate by solely adopting the DMAIC methodology.

Moreover, Saikaew [4], Tsenev, and Asenova [5] attempted to use MSA with gauge repeatability and reproducibility (GR&R) and analysis of variance (ANOVA) techniques to computer numerical control (CNC) machines [4] and quality control of an automatic production line [5]. The process became more acceptable as both groups were able to analyse the performance effectively. In other words, it is feasible to implement GR&R, and ANOVA approaches to an industrial system or development.

Rejected goods or defective products in the industry are an issue in themselves. The company's waste from defective products can be separated into two categories: disposed or recycled. Some industries consider recycling waste to minimise losses. However, processing this waste requires special handling and increases the company's expenses. Picking up an industry in Batam as an example, they decide to sort and recycle defective plastic bottles. To accomplish this, however, needs proper management and technology, as well as precise measuring and weighing. Approved by Anagnostopoulos *et al.* [15], capacity and weight sensors are one of the challenges and an essential element of waste management. Although this is a challenge, finding a suitable approach is necessary to produce accurate, precise, and reliable weighing measurement results.

A previous study on the application of the MSA methodology on weighing scales in waste management has not yet been found. However, the MSA method is commonly implemented in the automotive industry and industrial engineering, and it is obviously feasible for developing an industrial system. Therefore, in this study, we utilise the MSA method with the GR&R and ANOVA approaches to develop IoT-based waste management. This study aims to: (i) build an IoT-based waste management system; and (ii) evaluate the developed system by implementing the MSA technique, focusing on measurement equipment.

II. An Overview: Used Components and Technologies

A. Industrial Weighing Scales

The utilisation of scales is crucial in industry. Gaining profit from many customers requires the deployment of precise measurement tools. No one is harmed if the measuring instrument provides accurate results. The scale of the indication affects the balance's reliability. If the indicator ratio is comparatively small, then the accuracy and specific details are more accurate. This accuracy is achieved through digital technologies.

In this study, digital scales were used. The selection of digital scales was based on the industry's requirements in Batam, where this research was done. This scale has the advantage of being more practical and user-friendly. Digital scales can be used in automated computations to measure weight. Digital scales offer more functions as measurement instruments, including more efficient and accurate digital scales. The digital scale is connected to the HX711, a module for accessing data from the load cell to the Raspberry Pi. HX711 is a precision 24-bit Analog-to-Digital Converter (ADC) able to interface directly with a bridge sensor for weighing scales and industrial control applications [16]. The specification weighing scales module and HX711 ADC used are defined as shown in Table 1.

B. Scanner

The barcode scanner is a two-dimensional collection of QR codes that is both simple and useful. Barcode scanners can contain product data in manufacturing codes, identification numbers, serial numbers, model numbers, and many others. A barcode scanner is, in concept, an input device similar to a keyboard or scanner. In addition, the usage of barcodes allows computer systems to rapidly and accurately identify the item. The details of the barcode scanner are given in Table 1.

C. PyQt5

PyQt is a package of Python programs for developing Qt and Python-based Graphical User Interface (GUI) applications. In other words, PyQt can access the functionality given by Qt with Python code. This design employs the Qt, QLineEdit, QLabel, and QPushButton features provided by PyQt. QLineEdit is used to display input data or data that has not yet been processed. QLabel is related to data values that are read by outputs that data have read. QLabel is also used to display the value of the scale and time programmed in Python. The frame rate of the GUI is calculated by subtracting the time required to launch the GUI from the time expected to complete GUI processing. That ensures the processing data rate is displayed while the GUI runs at the framerate.

D. Internet of Things (IoT)

The Internet of Things (IoT) continues with the growing number of interconnected, engaging physical elements. The IoT paradigm [17] is critical to supporting the integration of communication technologies and diverse

Table 1. The specifications of the proposed system

Module	Features/Specifications
Wireless Electronic Floor Scale	• Capacity / Division: 2000kg • Keyboard: 6 Keys • Weight Unit Kg/ Lb/ Oz/ others • Power Supply: AC: 110/220 V (± 10%) or DC: 4 V/4Ah rechargeable battery • Platform: Plaid Steel Platform / 2000kg : 100cm x 100cm
Mini Barcode Scanner 1D-2D Portable	• Support 1D and 2D • Support Android and iOS • Scan speed: 200scans/sec • Read preciseness: 0.1mm(4mil) • Scan scope: 10mm~250mm • Reading distance: 2.5~600mm(100% UPC/ EAN) • Bit error rate: 1/5 million • Interface: Bluetooth 4.0 • Battery: DC 3.7V, 1000mA Li-ion battery • Current: 100mA(working), 30mA(storage) • Operating temperature: $0^{o}C \sim 45^{o}C$ • Storage temperature: $-20^{o}C \sim 60^{o}C$ • Humidity : 5%~95% non-condensing
Raspberry Pi 4 Model B	• Broadcom BCM2711, Quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz • 8GB LPDDR4-3200 SDRAM • 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE • Gigabit Ethernet • 2 USB 3.0 ports; 2 USB 2.0 ports. • 2 × micro-HDMI ports (up to 4kp60 supported) • 2-lane MIPI DSI display port • H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode) • OpenGL ES 3.1, Vulkan 1.0 • 5V DC via USB-C connector or GPIO header (minimum 3A) • Operating temperature: 0 – 50 degrees C ambient
Raspberry Pi 7" Touch Screen Display	• 7" Touch screen Display. • Screen Dimensions: 194mm x 110mm x 20mm (including standoffs) • Viewable screen size: 155mm x 86mm • Screen Resolution 800 x 480 pixels • 10 finger capacitive touch. • Connects to the Raspberry Pi board using a ribbon cable connected to the DSI port. • Will require the latest version of Raspbian OS to operate correctly.
24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales (HX711)	• Two selectable differential input channels • Gain: 32/64/128 • On-chip power supply regulator for load-cell and ADC analog power supply • Output Rate (Hz): 10/80 • Simultaneous 50 and 60Hz supply rejection • Current consumption including on-chip analog power supply regulator:normal operation < 1.5mA, power down < 1uA • Operation supply voltage range:2.6 ~ 5.5V • Operation temperature range:-40 ~ +85°C • 16 pin SOP-16 package • Applications: Weigh Scales, Industrial Process Control

application solutions, such as tracking and monitoring [18], wired and wireless sensor networks, expanded communication protocols, and presented intelligence for objects. The IoT can generate many applications to enhance sectors, including transportation, education, health, agriculture, the environment, and industry.

In this study, load cell sensors and a scanner generated data that was managed centrally via raspberry pi. It was proposed to integrate several objects via serial, Bluetooth, and Wi-Fi. Additionally, the information is displayed on a 7-inch monitor and stored in a web-based database.

III. Method

A. Proposed System Design

Overall, this research provides a waste management system in the form of defective infant feeding bottles that will be recycled later. The proposed hardware and system consist of a device that can scan recyclable objects, weigh products, and automatically send the data into the system. The waste could be monitored from anywhere, courtesy of the system's IoT-integrated server base. The hardware is installed, and the GUI for user-friendliness is created. In addition, a reliable measuring device is required for the weighing operation, implying the MSA method.

First, the proposed hardware and block diagrams constructed in this study are represented in Fig. 1. It can be seen that raspberry pi is central single-board processor management. It is connected to the scanner via Bluetooth and to weighing scales through a 4-pin CB connector. Raspberry pi is also integrated with a display monitor, which is in line with to waste management server. The system will receive user and waste code data from the scanner. The user and waste code are read by the raspberry pi, which then processes the data. If the user or the waste code is not matched with the database, the user or the scale will not accomplish the weighing process. If it is equivalent to the existing record, the raspberry pi will acquire the scale value from the weighing scale. Then, the weighing scale will provide the scale's data or value. In addition, the raspberry pi will process the data and transmits it to the database.

Second, Fig. 2 shows the GUI of the proposed IoT-based waste management system developed using PyQt5. These include the following function of the section display:

1. Information of username, id user code, and department
2. Waste information, including waste code, type of waste, date of the last measurement, range measurement, and the business group.
3. Date and time
4. Measurement result
5. ADD button functioned to add waste data to the database
6. CANCEL button to postpone saving data
7. Warning notification when the time interval from the last measurement of waste is less than 8 hours
8. OVERWRITE button to rewrite the last measurement of waste data. This button will only

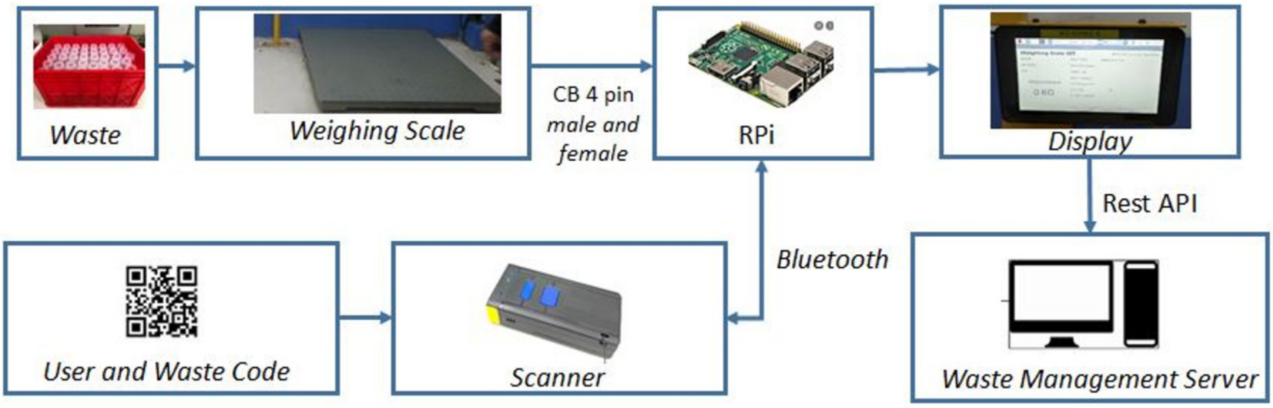

Fig. 1. The entire block diagram of the waste management system

Fig. 2. GUI of the waste management system

appear if a warning notification is present

9. Text input box for entering waste code and user code via keyboard.

B. Measurement System Analysis

MSA is a system analysis that determines the specifications for selecting the most suitable measuring instrument and an acceptable measurement system. This analysis examines measuring instruments' accuracy, methods, and preventative maintenance systems for measuring instruments. This examination is performed to determine the overall variance of the measuring instrument to prove that the measurement system is accurate, precise, and reliable.

Firstly, GR&R Study Type 1 is a typical measurement technique that evaluates the effect of bias and repeatability on data from a single operator and reference. Gage capability is usually mentioned as *cg* and *cgk* as well. The *cg* value is determined by comparing the study variance (gauge measurement spread) to the tolerance value (the potential capability). Furthermore, the *cgk* is utilised to estimate the measurement bias value, the difference ratio between the operator's average measurement result, and the target or given reference value (the actual capability).

$$cg = \frac{\frac{k}{100} \times (Tolerance)}{VS} \tag{1}$$

$$cgk = \frac{\frac{k}{200} \times (Tolerance) - \left|\bar{x}_g - x_m\right|}{VS/2} \tag{2}$$

where *cg* is the capability gauge, *cgk* is the bias of capability gauge, k is the tolerance %, V is the number of standard deviation for process distribution, S is the standard deviation, $\bar{x}_g$ is the reference value, and x_m is the measured data average.

Secondly, this study applied GR&R Study methodology. Reproducibility is the variation in measurements performed by various operators, whereas repeatability is the variation in measurements made by the same operator and instrument. The variability of the measuring procedure and the total variation can be expressed as follows

$$\sigma^2_{gauge} = \sigma^2_{repeatibility} + \sigma^2_{reproducibility} \tag{3}$$

$$\sigma^2_{Total} = \sigma^2_{Part} + \sigma^2_{gauge} \tag{4}$$

where σ^2_{gauge} is the variance of gauge or system, $\sigma^2_{reapetability}$ is the variance of measurement tools component, $\sigma^2_{reproducibility}$ is the variance of operators component, is the total variance of data, and σ^2_{Part} is the variance of parts component or it can also be mentioned as the estimated standard deviation o.

The repeatability value or Equipment Variation (EV) is the variation of the measurement value while measuring the same product multiple times under the same person or operator conditions.

$$EV = K\sqrt{MSE} \tag{5}$$

where K is is a constant whose value depends on each operator's number of trials and is the mean square of error.

Then, the reproducibility or Appraiser Operator Variation (AV) value is the variation value derived from measurements performed by the same measuring device with various operators.

$$AV = \sqrt{\frac{Ms_a - Ms_{ab}}{bn}} \tag{6}$$

where Ms_a is the mean square of operator variation, Ms_{ab} is the mean square of the interaction, b is the number of parts/samples, and n is the number of replications.

Product variation value, also known as Process Variation (PV), is the measurement variation value acquired by measuring multiple products with the same operator. The value of interaction variation, or Interaction Variation (IV), is the average variation of measurements from various products and operators.

$$PV = \sqrt{\frac{Ms_b - Ms_{ab}}{an}} \tag{7}$$

$$IV = \sqrt{\frac{Ms_b - Ms_E}{n}} \tag{8}$$

where Ms_b is the mean square of parts/samples variation, and a is the number of operators.

The value of the GR&R variation, also known as the Combined GR&R, is the sum of the (3) – (8). Furthermore, to evaluate the status of the measuring system by computing the GR&R using the matrix.

$$R\,\&\,R = \sqrt{\left(EV^2 + AV^2 + IV^2\right)} \tag{9}$$

$$GaugeR\,\&\,R = \frac{\sqrt{\left(EV^2 + AV^2 + IV^2\right)}}{USL - LSL} \times 100\% \tag{10}$$

where USL and LSL respectively are the upper and lower specifications limits.

Based on the measurement findings, the USL (Upper Specification Limits) and LSL (Lower Specification Limits) tolerance values reflect the upper and lower specification limits of a particular quality product as determined by the customer. According to the Automotive Industry Action Group (AIAG) [19], using the percentage value of the Gauge R&R to conclude is dependent upon the following three conditions, as shown in Table 2.

In addition, the number of distinct categories or classification ratios, denoted by *ndc*, can also be utilised to evaluate the condition of the measuring system. The ndc value is the number of distinct categories, which σ^2_{Part} is the estimated standard deviation of the part and $\sigma^2_{R\&R}$ is the standard deviation of the Gauge R&R estimation. The measurement system is considered acceptable if the number of distinct categories surpasses five.

$$ndc = \frac{\sigma^2_{Part}}{\sigma^2_{R\&R}}. \tag{11}$$

Thirdly, analysis of variance is a statistical technique used to calculate the average difference between three or more groups by comparing their variance values. The data from the experimental design were evaluated using the ANOVA table presented in Table 3, which was used to calculate the sum of square values.

Table 2. The AIAG GR&R recommendation [19]

% Contribution	% Study Var	Number of Distinct	Suggestions
1% or less	10% or less	More than 10	Acceptable
1% – 9%	10% – 30%	5 – 10	Marginal (acceptable in certain conditions)
More than 9%	More than 30%	Less than 5	Unacceptable

Table 3. Source of variation for general GR&R study using ANOVA methodg

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	F-value
Operator	$ss_O = \sum_{i=1}^{a} \frac{y^2_{i....}}{bn} - \frac{y^2_{...}}{abn}$	α-1	$MS_O = \frac{ss_O}{\alpha - 1}$	$\frac{MS_P}{MS_{OP}}$
Types of Products	$ss_P = \sum_{i=1}^{b} \frac{y^2_{.j.}}{bn} - \frac{y^2_{...}}{abn}$	b-1	$MS_P = \frac{ss_P}{b-1}$	$\frac{MS_O}{MS_E}$
Interac-tion	$ss_{OP} = \sum_{i=1}^{a}\sum_{j=1}^{b} \frac{y^2_{ij.}}{n} - \frac{y^2_{...}}{abn} - ss_A - ss_B$	(α-1)(b-1)	$MS_{OP} = \frac{ss_{OP}}{(\alpha-1)(b-1)}$	$\frac{MS_{OP}}{MS_E}$
Error	$ss_E = ss_T - ss_O - ss_P - ss_{OP}$	αb(n-1)	$MS_{OP} = \frac{ss_{OP}}{(\alpha-1)(b-1)}$	
Total	$ss_T = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y^2_{ijk} - \frac{y^2_{...}}{abn}$	αbn-1	$MS_E = \frac{ss_E}{(\alpha b)(n-1)}$	

Table 4. The GR&R study type 1 operator-1 result

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
cg	0.74	0.84	0.83	0.95	1.36	0.81	1.18	1.73	0.99	0.96
cgk	0.6922	0.7039	0.7822	0.914	1.3016	0.4867	1.1047	1.5181	0.7510	0.7905
%Var (Repeatability)	13.579	11.933	12.017	10.507	7.376	12.329	8.509	5.797	10.119	10.373
%Var (Repeatability and Bias)	14.446	14.206	12.784	10.945	7.68295	20.548	9.05194	6.587	13.315	12.650
(p-value)	0.685	0.235	0.647	0.726	0.619	0.013	0.52	0.081	0.051	0.134
Tolerance (VHN)	10	10	10	10	10	10	10	10	10	10
Reference (VHN)	4.2	4.2	4.4	3.6	4.1	4.1	3.7	3.8	3.8	4.3

Table 5. The GR&R study type 1 operator-2 result

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
cg	0.52	0.78	0.73	1.61	1.13	1.27	0.60	1.13	1.44	0.94
cgk	0.4897	0.4847	0.6459	1.3555	1.0842	0.9621	0.5562	0.8583	1.3512	0.6980
%Var (Repeatability)	19.194	12.791	13.624	6.197	8.854	7.899	16.541	8.854	6.957	10.602
%Var (Repeatability and Bias)	20.419	20.630	15.481	7.377	9.223	10.394	17.979	11.650	7.401	14.327
(p-value)	0.774	0.02	0.425	0.037	0.678	0.018	0.657	0.03	0.434	0.045
Tolerance (VHN)	10	10	10	10	10	10	10	10	10	10
Reference (VHN)	4.2	4.2	4.4	3.6	4.1	4.1	3.7	3.8	3.8	4.3

Table 6. The GR&R study type 1 operator-3 result

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
cg	0.65	0.91	0.61	1.27	0.89	2.02	1.33	1.71	1.76	1.25
cgk	0.4922	0.6744	0.4622	1.2153	0.8539	1.9030	1.2517	1.5435	1.5109	1.0000
%Var (Repeatability)	15.440	10.973	16.444	7.899	11.243	4.940	7.510	5.831	5.692	8.000
%Var (Repeatability and Bias)	20.316	14.828	21.637	8.229	11.711	5.255	7.989	6.479	6.619	10.000
(p-value)	0.174	0.051	0.2	0.642	0.743	0. 279	0.468	0.138	0.045	0.042
Tolerance (VHN)	10	10	10	10	10	10	10	10	10	10
Reference (VHN)	4.2	4.2	4.4	3.6	4.1	4.1	3.7	3.8	3.8	4.3

IV. Result and Discussion

In general, IoT deployment in the waste management system was accomplished with success. The GUI's user-friendly design makes it easier for system operators to run the system. Data acquisition can be performed and stored on company-owned servers. Moreover, the loadcell sensor is then evaluated as part of the measuring equipment.

A. GR&R Study Type 1

The GR&R Study Type 1 examines measurement variance that combines the effects of bias and repeatability on readings from a single operator and a reference. Also obtained is the % Var (Repeatability) value, which has the same meaning as cg, and the % Var (Repeatability and Bias) value, which has the same meaning as *cgk*. The default *cg* and *cgk* values are 1.33. The values of %Var (Repeatability), %*Var* (Repeatability and Bias), and *p*-value (bias) are less than 15 percent and 0, respectively.

The results in Table 4 indicate that operator-1 has variable *cg* and *cgk* values due to varying reference values. Where *cg* is between 0.74 and 1.73 and *cgk* is between 0.4 and 1.51, there are measurements surpassing the standard limit of 1.33, especially part 5 and part 8 measurements. This shows that operator-1 was unable to consistently and accurately measure. Moreover, the *p*-value (bias) of operator-1's measurements is less than 0.5. (industrial tolerance is 0.5). That indicates that operator-1 is still biassed but tolerable.

Similar to operator-1, in operator-2 (Table 5), several measures do not exceed the standard limit of 1.33, except for part 4 and part 9. The value of % Var *(*Repeatability) and % Var (Repeatability and Bias) is less than 15%, and the *p*-value (bias) is greater than 0. Comparable results are also demonstrated by operator 3, as seen in Table 6.

In addition, a filter was applied to the GR&R Study Type 1; as a result, the measuring instrument or system improved; nonetheless, there was a considerable change in the numbers for part 7 (Table 7). The cg and cgk values for operators 1, 2, and 3 were not above 1.33. Conversely, the values of %Var (Repeatability) and %Var (Repeatability and Bias) exceed 15%. Nevertheless, in part 7, there is still a bias, which shows that the system's software needs to be improved even more to get the best results.

Table 7. The filtering GR&R type 1 part-7 (S7) result

Parameters	Operator-1	Operator-2	Operator-3
cg	0.63	0.69	0.65
cgk	0.3162	0.48	0.26
%Var (Repeatability)	15.811	14.49	15.49
%Var (Repeatability and Bias)	31.62278	20.70	38.73
(p-value)	0.015	0.081	0.005
Tolerance (VHN)	10	10	10
Reference (VHN)	4.5	4.5	4.5

Table 8. The GR&R study result

Source	VarComp	%Contribution (of VarComp)	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.0287248	33.06	0.169484	1.01690	57.50
Repeatability	0.0285503	32.86	0.168968	1.01381	57.32
Reproducibility	0.0001745	0.20	0.013211	0.07927	4.48
Part-To-Part	0.0581592	66.94	0.241162	1.44697	81.82
Total Variation	0.0868840	100.00	0.294761	1.76857	100.00

Number of Distinct Categories = 2

Table 9. The filtering GR&R study result

Source	VarComp	%Contribution (of VarComp)	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.0003229	4.39	0.0179694	0.107816	20.95
Repeatability	0.0002640	3.59	0.0162470	0.097482	18.94
Reproducibility	0.0000589	0.80	0.0076770	0.046062	8.95
Part-To-Part	0.0070363	95.61	0.0838825	0.503295	97.78
Total Variation	0.0073592	100.00	0.0857856	0.514714	100.00

Number of Distinct Categories = 6

B. GR&R Study

From the GR&R Study, it was obtained that the %Contribution (of VarComp) value for the total GR&R was 33.06%. And %Study Var (%SV) for a total GR&R of 57.50%. The value exceeds 30%, so the measurement system can be considered unacceptable or needs improvement. In addition, the %Contribution (of VarComp) Repeatability and Reproducibility values of 32.86 % and 0.20 %, respectively, explain why the error variance of measurement results generated by the equipment and the error variance caused by Part-To-Part is 66.94 % (shown in Table 8). This means Part-To-Part affects measuring findings. As per the AIAG recommendation in Table 2, the measurement system is unacceptable and requires improvement because the number of distinct categories was 2 (less than 5).

Furthermore, a filter was carried out in the GR&R Study as an improvement step. The results presented in Table 9 are %Contribution (of VarComp) for a total Gauge R&R of 4.39% (less than 9%, marginal as the AIAG's recommendation) and %Study Var(%SV) for a total Gauge R&R of 20.95% (less than 30%, acceptable in certain condition as the AIAG's suggestion). Thus, it may be concluded that the measurement system is adequate but requires additional modification whereby the total VarComp Gauge R&R value is less than 10. When examined from the %Contribution (of VarComp) Repeatability and Reproducibility values of 3.59% and 0.80%, respectively, these values indicate that the error variance of the measurement results is produced by the instrument or whenever measurement findings are inconsistent. Moreover, the error variance caused by Part-To-Part is 97.78%. It means that Part-To-Part dramatically affects the measurement results. The number of distinct categories also obtained a value of 6, where the value is greater than 6. So compared to AIAG's acceptance criteria (Table 2), it can be said that the measurement system carried out is acceptable.

C. ANOVA

In this study, ANOVA is used to determine whether the operator and parts have an influence or not on the measurement results. The tests involving three operators and ten types of parts indicate that interaction and operators

Table 10. The ANOVA result

Source	DF	SS	MS	F	P
Parts	9	23.3836	2.59818	79.20	0.000
Operators	2	0.1022	0.05110	1.56	0.212
Parts * Operators	18	0.4925	0.02736	0.83	0.659
Error	270	8.8570	0.03280		
Total	299	32.8353			

Table 11. The ANOVA filtering program result

Source	DF	SS	MS	F	P
Parts	9	1.92000	0.21333	32.91	0.000
Operators	2	0.01167	0.00583	0.90	0.408
Parts * Operators	18	0.10500	0.00583	0.90	0.579
Error	270	1.75000	0.00648		
Total	299	3.78667			

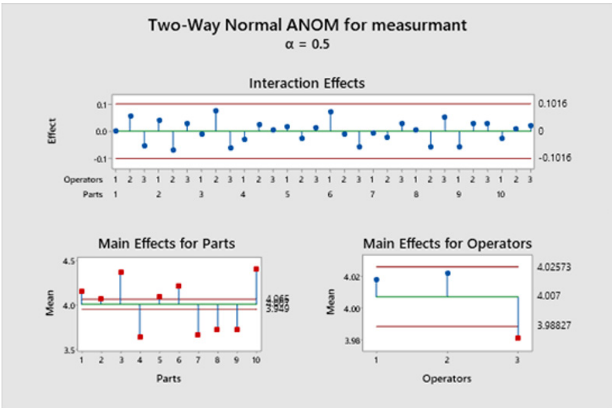

Fig. 3. The ANOVA effect in Minitab without a filtering program

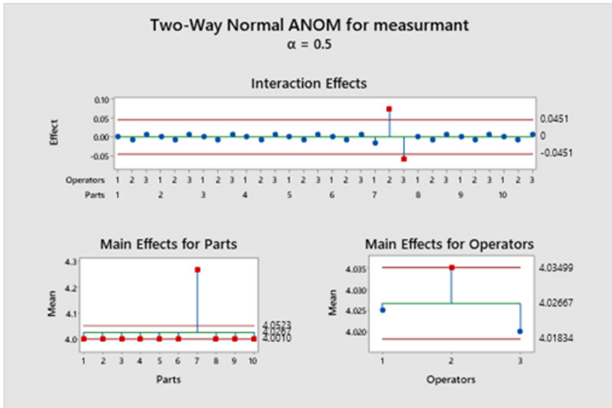

Fig. 4. The ANOVA effect in Minitab with a filtering program

did not affect measurement outcomes because the blue dots remain inside the acceptable range. Table 10 and Fig. 3 show that many parts exceed the tolerance limit, affecting the measurement results. As an improvement, a filtering program was implemented. Table 11 and Fig. 4 illustrate that interaction does not impact measurement (although the interaction in part 7 exceeds the tolerance limit). Similarly, the operator has no impact on the measurement results because the blue dots remain inside the acceptable range. In addition, the parts affect the measurement findings since the points exceed the tolerance limit by a wide margin.

V. Conclusion

Based on the results and discussion, it can be concluded that the study successfully implemented IoT in a waste management system with a friendly-user GUI. In addition, assessments of measurement tools were conducted in this study. The GR&R Type 1 was carried out to assess the quality of IoT-based waste management measuring instruments. The measurement findings acquired by operators 1, 2, and 3 were highly biased. Although adding a filtering program has improved the results, part7 measurements are still unstable. According to the GR&R study, the overall variance of the GR&R is 20.95 %, and the distinct categories are 6. Thus, as the AIAG's acceptance criteria, the measuring system is appropriate (but needs further improvement). In addition, the measurement results are less than 30 %, and the number of distinct categories is greater than 5, which means marginal or acceptable in certain conditions, as the AIAG's recommendation. So, the ANOVA test conducted either before or after the addition of the filtering program demonstrates that the operator has the same measurement ability in providing measurement results, that the difference in parts affects the measurement results, and that there is no interaction between operators and parts that results in different effects on measurement results. Further research will focus on comparing several types of weighing scales with ADC converter modules to achieve improved and acceptable measurement results in compliance with AIAG guidelines.

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