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DIGITALIZATION OF AN ANALOGUE WEIGHING SCALE USING THE RESISTANCE SENSOR (POTENTIOMETER)

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Abstract

This study aims to modernize the normal analogue weighing scale, making it work precise, user-friendly and feature-rich thus enhancing its utility and appeal in both domestic and professional setting. The normal analogue weighing scales, might be reliable and straightforward, but lack the precision, ease of data integration, and user-friendly interfaces of modern digital scales. The need to frequently read and interpret the analogue dial can lead to inaccuracies, especially for users requiring precise weight measurements. The device consists of a resistance sensor in the form of a potentiometer which converts the displacement of the weight on the rocker arm of the mechanical weight scale to proportional resistance change and this in turn is converted to a proportional voltage change by a signal conditioning circuit. The sensor was attached to the rocker arm so that the movement of the rocker arm will directly affect the potentiometer displacement. The output voltage display from the sensor and signal conditioning stage is fed to an analog to digital. The device uses the popular ADC ICL7107 equipped with LCD driver to drive four seven segment displays that displays the weight measured in kilogram (kg). Several tests were carried out after construction of the device and the test results shows that the device worked satisfactorily and it was able to measure from 1-10kg and 1-22lbs (pounds) with ±2% accuracy. The reading of the digitized weighing scale designed, were used to compare that of a standard analogue type. The result obtained that there was a mean difference of 0.1667kg between the readings of the modified scale and the analogue type which served as the source control. A simple product moment correlation coefficient was used to compare the two readings and the result obtained indicated that there was correlation (1.060) between the readings of the two scales.

Keywords: analog, digitized weighing scale, correlation coefficient, user friendly, potentiometer.

1.0 Introduction

The need for digital weight measuring scale in our society nowadays cannot be overemphasized, because of its accuracy, efficiency, precise, and exact measurement of weights of various objects (Akindele et al., 2018; Fagbemi et al., 2014; Pradeep et al., 2013). Although the analogue weighing scale are sometimes recommended for their simplicity, durability and the lack of need for batteries or electricity but Several limitations that can impact their effectiveness, accuracy, and user experience. These limitations include manual reading errors, lack of precision, difficulty in reading measurements, and the absence of advanced features such as data storage and connectivity. Analogue weighing scales, though relatively cheap and do not require power supply are however associated with problems of zero error, calibrating, inaccurate results and so on. (Fagbemi et al., 2014). The previously invented weighing scale, were manual, less accurate, not reliable enough and, also has calibration problems

(Olalekan et al., 2023). Recent advances in electronics, physics, material sciences and other branches of science and technology has resulted in the development of many sophisticated and high precision measuring devices and systems, catering to varied measurement problems in different disciplines and industries, which eventually gave birth to the world of digitalization. It becomes more advantages by designing and constructing a cheaper and more efficient digital weighing scale in solving these problems (Olalekan et al., 2023). The goal of this paper, is to show that a designed digital weighing scale is more accurate, efficient and more reliable than the analogue counterpart, on the bases of undergo some modifications. The designed digitized machine is a system that utilized to read weight measured in the conventional analogue form to digital form in order to achieve high precision in measurement calibration. Since the trend nowadays is to use digital weighing scale instead of the analogue weighing system is adopted mostly in this part of the world and so the demand increases to design variety of advanced digital weighing system at competitive level. (Fagbemi et al., 2014). Although much research works on the digitization of the analogue weighing scale has been published, but these have different methods and applications. For example, (Mahajan et al., 2014), in their research works, they used load cell, HX711 load cell amplifier, Arduino Uno Microcontroller, Rand an LCD module, a 40kg Load cell. The load cell was used to send output signals of the mechanical weights measured to the HX711 Module which amplifiers and sends the output to the Arduino microcontroller. The microcontroller calibrates the output signal with the aid of the load cell amplifier mode before sending signal which is already converted to the LCD module for display. The digital weighing scale was developed, which was used to measure weights ranging from 0- 10kg which was very accurate (Fagbemi et al., 2014). The developed digitized weight scale utilizes the following; power supply, resistance sensor, signal conditioning circuit, input scaling circuit, ADC ICL7107 equipped with LCD driver to drive four seven displays, which display the weight measured in kilogram (kg).

2.0 METHODOLOGY

2.1 Design Consideration and Analysis

The design of the circuit for the digitized weighing scale follows the block diagram of figure 1. It consists of a power supply that provide power to the circuit, resistance sensor in the form of a potentiometer which converts the displacement of the weight on the rocker arm of the mechanical weight scale to proportional resistance change and this in turn is converted to a proportional voltage change by a signal conditioning circuit. The sensor was attached to the rocker arm so that the movement of the rocker arm will directly affect the potentiometer displacement. The output voltage from the sensor and signal conditioning stage is fed to an input scaling circuit enroute to the analog to digital converter. The device uses the popular DC ICL7107 equipped with LCD driver to drive four seven segment displays that displays the weight measured in kilogram (kg).

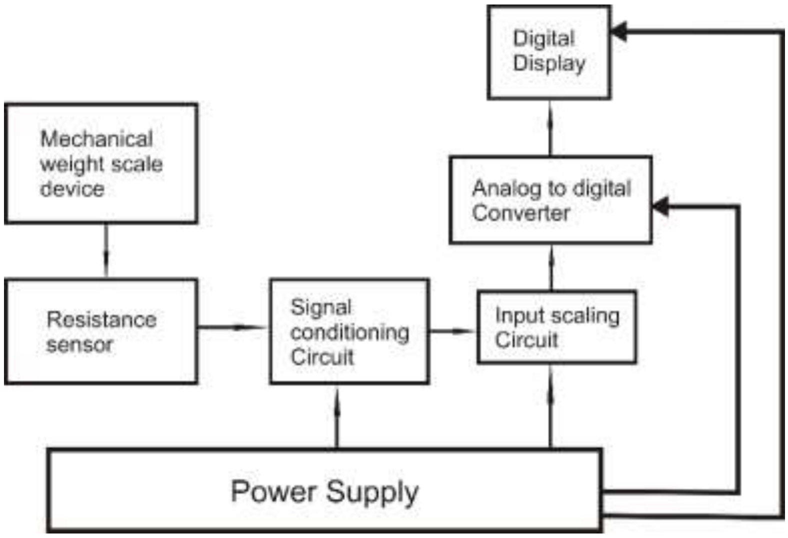

Figure 1.0: Block Diagram of the Digital Weight Scale.

2.2 Design of Power Supply

The circuit requires a DC supply of +5V and -5V mainly for the ADC ICL7107 and also +12V and -12V for them op-amps in the circuit. Figure 2.0 shows the power supply diagram. The transformer is a step-down transformer of 220V to 12V AC This AC voltage is rectified to DC by the bridge rectifier D1-D4. The capacitor C1 and C2 serve as filter capacitors (Egwaile and Oyedoh, 2019).

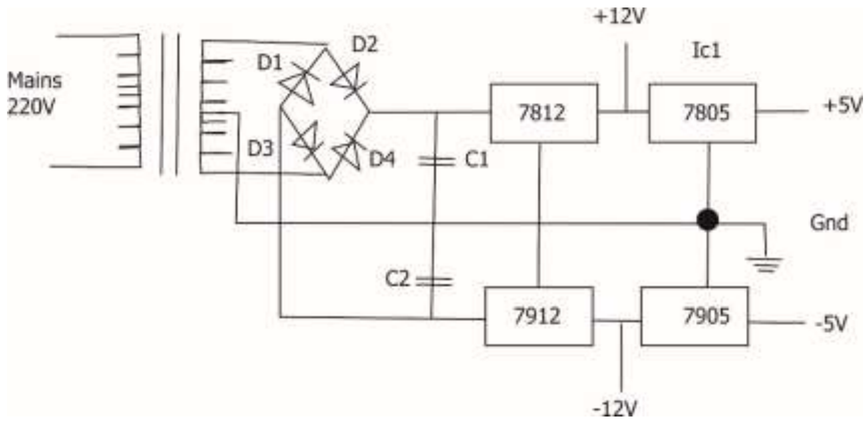

Figure 2.0: Power Supply Schematic

Peak out voltage form bridge Rectifier

$$V_{P.R} = V_P - 2Vd$$

where;

$$V_p = Peakvoltage$$

$$Vd = P - N \qquad (1)$$

Where;

Vp= Peak Voltage

Vd = P-N junction drop

An I.C bridge Rectifier RBPC6005 used in the design and has the following specifications.

KBPC005 Bridge Rectifier

Output Current = 6A

I surge (max) = 125A

$V_{RRM} = 100V$

$= \frac{.I_O}{2FC}$

$$C = \frac{.I_O}{2FVr} \tag{2}$$

Where;

Io = regulator Output Current

Vr = Ripple voltage = 1V

To obtain the regulated +5V and -5V, a voltage regulator 7805 and 7905 was used in the design to get these voltages.

2.3 Design of the Mechanical Weight Scale

This stage refers to the mechanical desktop weight scale device that has maximum readings of 0- 10kg (0-221b). The readout scale has a rocker arm that moves the pointer internally and it is this arm an armature was attached and that will move the resistance sensor up and down as the scale fluctuates up and down with respect to the amount of weight placed on it.

2.4 Design of the Weight Resistance Sensor

This resistance is the type used in volume control. These volume controls potentiometers do not have a linear resistance response as shown form observation during testing of the resistor. The response closely resembles logarithmic curve hence the signal conditioning circuit was needed. The resistance of the variable resistor was 100kΩ.The resistance sensor used in this design is a variable resistor or potentiometer that was attached to the rocker arm of the mechanical weight scale. This arraignment was adopted as a simple and cheap means of converting a mechanical weight scale to an electrical and electronic unit.

2.5 Design of the Signal Conditioning Circuit

The voltage from the resistance sensor is expected to be linear and there is the possibility of non-linearity and so the signal conditioning stage is expected to process this signal to make it linear and to calibrate the processed voltage to the appropriate level for the ADC to accept and display. Figure 3.0 shows the signal conditioning circuit. It uses the non-linear properties of the diode as applied in this circuit. The slope of the resulting curve at any pint is the conductance of the diode at the corresponding value of voltage. The circuit component values can now be determined;

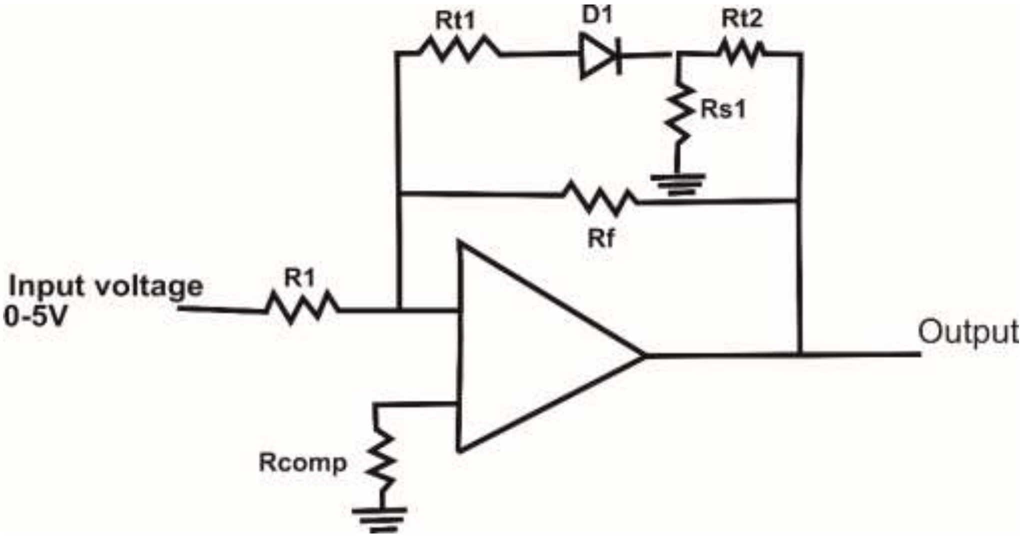

Figure 3.0: Signal Conditioning using basic Non-Linear Feedback Circuit

2.5 Design of the Input Scaling Circuit

The output from the signal conditional circuit is been calibrated or scaled before been fed to the ADC converter.

2.6 Design of the Analog to Digital Converter (ADC) and the Digital Display

The function of the ADC is to convert the analog voltage from the scale converter circuit to digital signal that would be processed and eventually displayed on a seven-segment display, which used to display the weight value during measurement and the types used is the LED common anode display. This stage was realized with the dedicated ADC chip ICL 7107. The circuit in figure 3 is a typical circuit for a full scale of 2V.

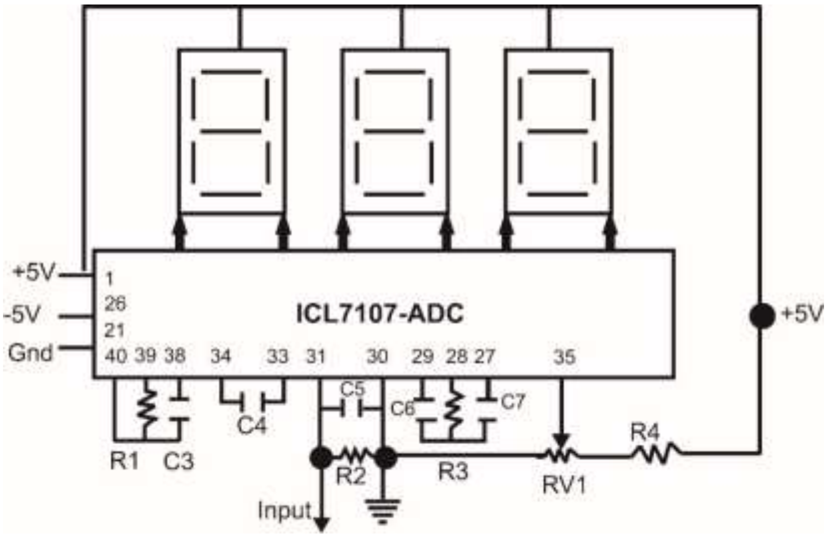

Figure 4.0: ICL 7107 Analog to Digital Converter Circuit

2.7 Full Circuit Diagram

The complete circuit diagram of the digital weight scale is presented in figure 5.0. The transformer T1 is a step-down transformer of 220V to 12V AC This AC voltage is rectified to DC by the bridge rectifier D1-D4. The capacitors C1 and C2 serve as filter capacitors. The voltage regulators 7812, 7912, 7805 and 7905 are voltage regulators to supply a constant voltage of +12V, -12V, +5V and -5V respectively. Rt is the resistance sensor used in this circuit for converting the weights for measurement to proportional voltage changes. The output of the sensor is connected to IC1 which is the signal conditioning stage. This stage uses the diode at the feedback to modify the gain of the amplifier circuit so that the response of the resistance sensor is more linear. The output from the signal conditioning stage corresponds to the British pounds scale (1b) and to achieve the S.I, kg scale using the variable resistor R2. IC2 is serving as a buffer for effective drive to the analog to digital converter stage. The function of the ADC stage is to convert the analog voltage from the sensor and the signal conditioning stages to digital and display digitally.

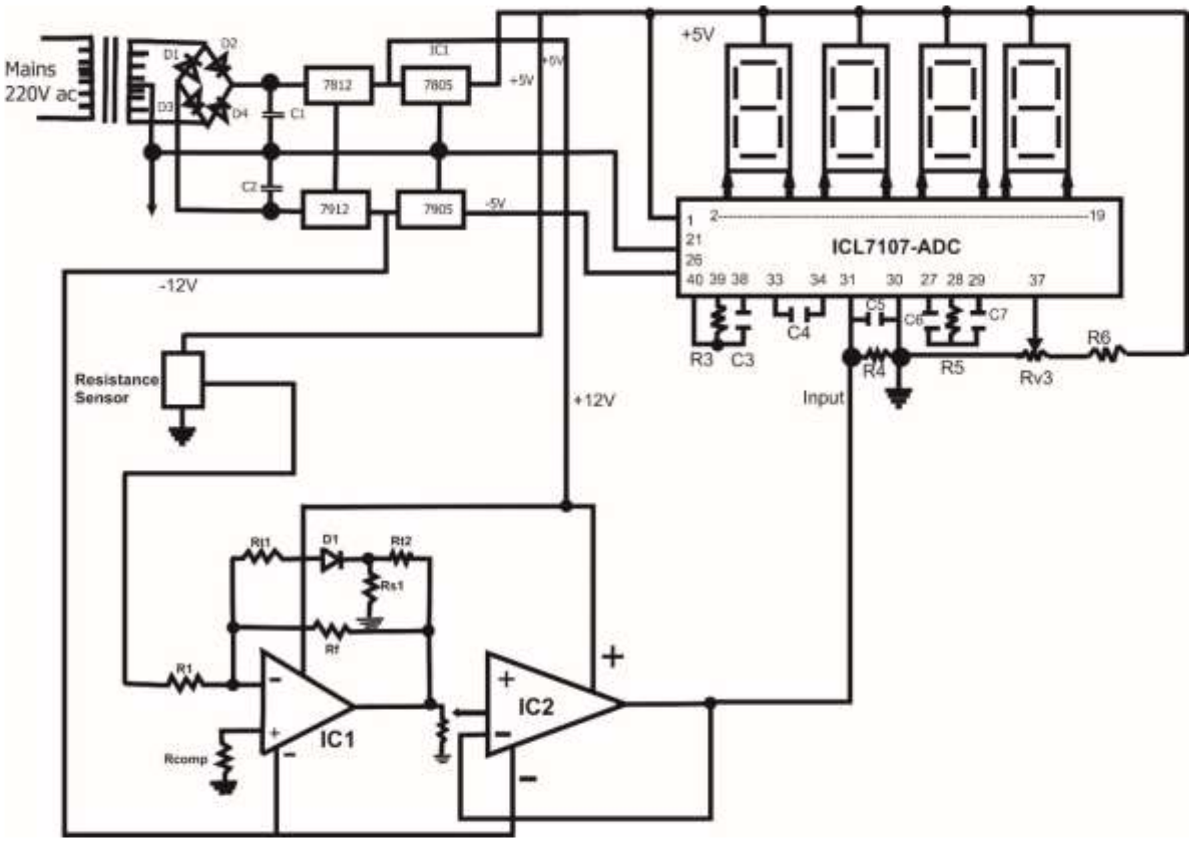

Fig 5.0: Complete Circuit diagram of the Digital Weight Scale

3.0 TESTING AND RESULTS

3.1 Range Testing

This was done to determine the upper and lower limits of the digitized scale. Several standard weighted masses were gradually placed on the weight stand of the scale and the spring screw was adjusted to zero while readings were obtained from the digital readout display to get the appropriate corresponding reading. The upper limits were obtained, as a continuous wardings at a point, the scale readings obtained from the digitized scale remain unchanged due to no further accumulation of more mass to the time scale. This reading was recorded as the upper limit. In adjusting the spring crew, care was taken not damage the elastic limit of the spring. While readings were also taken at no load, and the spring crew was adjusted to zero to obtain the result, as illustrated below:

3.1.1 Range of dynamic load Tests Results

The test results showed in table 1.0 was also carried out (using equation 3) to determine the range at which the dynamic load will be sensed by the resistance sensor which gives the highest amount of input value that can be applied to the sensor without leading to unimaginable error to be recorded. The range was computed to be 0 – 10kg. The upper limit value of 10kg was regarded as the maximum possible weight to the analog weighing scale which was obtained during the conversion of the mechanical extension in the spring to electrical quantity. But with the use of the resistance sensor, which is the sensor that was attached to the spring in the weighing scale that senses the applied force (from the load) and converts it to an extension that is linearly proportional to the applied load. We recalled that in Hook's law, the constant of proportionality is the spring constant value corresponds to the maximum compression obtained by the spring.

Table 1.0: The Results of Dynamic Load Test Range

Minimum Scale Value	Maximum Scale Value
0.00kg	10.00kg

$$Range = R_{Ahighestvalue} + R_{Alowestvalue} \qquad (3)$$

3.2 Accuracy Testing

During the accuracy testing a standard weighing scale was used and it's standard reading obtained was used to compare the one obtained from the designed and constructed digitalized scale. Each weighing object was weighed with the analogue scale and that of its corresponding designed digitized scale and their various readings noted. The readings obtained was then tabulated. The mean difference between the analogue scale readings R_A and that of the digitized scale (R_D) was also calculated. The mean difference (R_m) was calculated using:

$$R_m = \frac{\sum (R_A - R_D)}{N} \qquad (4)$$

Where N = number of readings taken

A simple product moment correlations coefficient was utilized to show the relationship between two readings. The product moment correlation coefficient was resolved using equation 2 below.

$$r = \frac{\sum (R_A - R_{\overline{AM}})(R_D - R_{\overline{DM}})}{\sqrt{\sum (R_A - R_{\overline{AM}})^2 \sum (R_D - R_{\overline{DM}})^2}} \quad (5)$$

R_{AM} = mean of the values of R_A variable given as R_{AM} =

$$R_{AM} = \text{ mean of the values of } R_A \text{variable given as } R_{AM} = \frac{\sum R_A}{N} \quad (6)$$

R_{DM} = mean of the values of R_D variable given as R_{DM} =

$$R_{DM} = \frac{\sum R_D}{N} \quad (7)$$

N = number of values

3.2.1 Accuracy Test Result

At the end of the accuracy test performed, that of the readings of the analogue weighing machine was compared to that of the digitized modified weighing machine. The result in table 3.0 below and was plotted using excel Microsoft package in Figure 6.0. The mean difference was computed using equation 4 and was found to be 0.16667kg

Table 2.0: The result of the accuracy test

S/N	Readings of the Digitized weighing scale R_D (Kg)	Analogue weighing scale R_A (Kg)	Difference (Kg) ($R_A – R_D$)
1.	0.00	0.00	0.00
2.	0.50	0.70	0.20
3.	1.00	1.00	0.00
4.	1.50	1.50	0.00
5.	2.00	1.90	-0.10
6.	2.50	2.40	-0.10
7.	3.00	3.10	0.10
8.	3.50	3.80	0.30
9.	4.00	4.40	0.40
10.	4.50	4.80	0.30
11.	5.00	5.20	0.20
12.	5.50	5.60	0.10
13.	6.00	6.30	0.30
14.	6.50	6.60	0.10
15.	7.00	7.30	0.30
16.	7.50	7.80	0.30
17.	8.00	8.30	0.30
18.	8.50	8.70	0.20
19.	9.00	9.30	0.30
20.	9.50	9.70	0.20
21.	10.00	10.10	0.10
		Σ	3.5

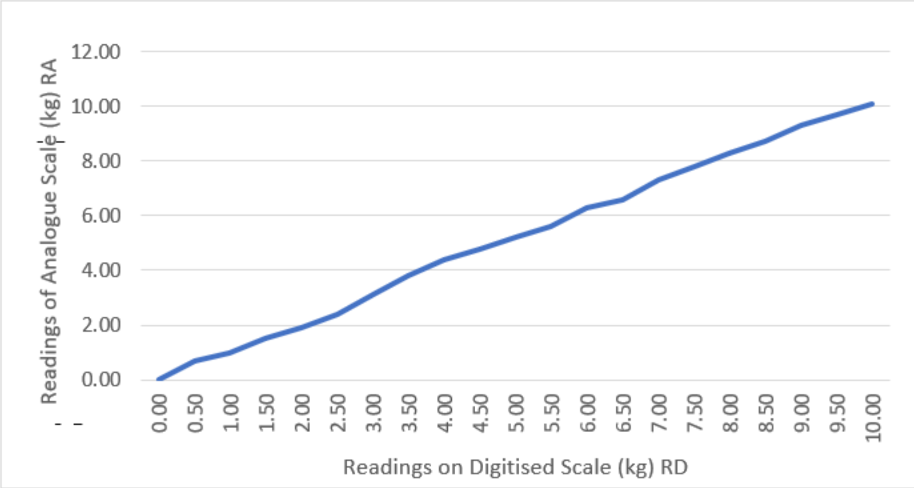

Fig 6.0: Graph of the analogue readings against digitized readings (R_D)

From the above graph, although both started at the origin, as the loading progresses, we observed some variation in the readings obtained from both scales. It was also discovered that the various readings that was obtained with the analogue weighing scale was little higher than that obtained from the corresponding digital weighing scale. For example, the situation whereby, the modified scale recorded 0.5kg as against the 0.7kg is obtained from the corresponding analogue scale, when calibrated standard weight of 0.5kg is used as test mass for both scales. Also from the above test result, it shows that both the analogue readings and the digitized readings started from the origin, which implies that both them are accurate. Although it might see from the mean difference shown more of negative values. This is why the graph of the digitized scale readings is seen to shift upwards from that of the analogue scale as shown in fig (5.0) above, which means that in most cases, the value of the readings by the digitized weighing scale is always less than that by the analogue type. The highest difference recorded was 0.40kg while the lowest value was – 0.10kg. The mean difference was obtained as 0-0. 167kg and which implies that if 0.167 is added to all readings of the digitized scale. It gives more accurate result. So therefore, $R_D = W_A + (0.167)$.

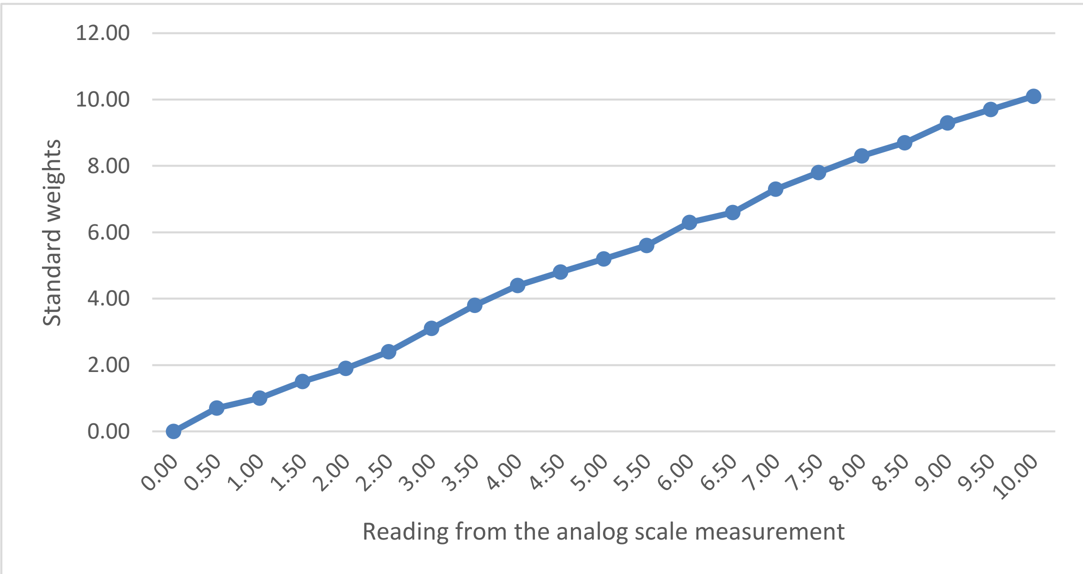

Figure 7.0a: Reading from the analog scale measurement

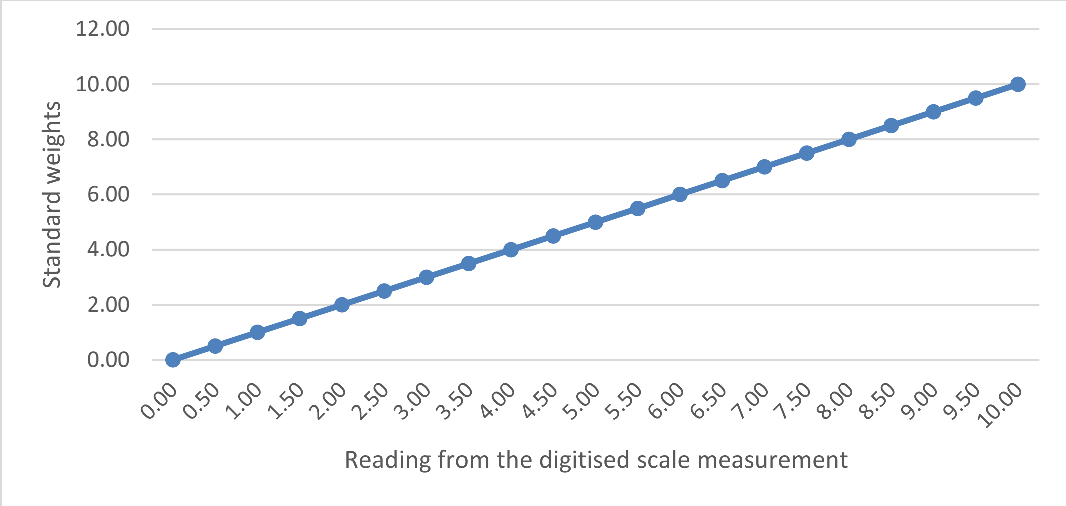

Figure 7.0b: Reading from the digital scale measurement

Figures 7a and 7b are graphs showing the Comparisons of the modified digital weighing scale and the analogue weighing scale to a standard weight. From the mentioned graphs, the readings from the two measuring scales were plotted and when compared individually using a standard weight. It was observed that although at the beginning of the measurement at no load (weight), both scales did not record any reading that’s 0-00kg, but as the loading progresses using the standard weights, we discovered that some points fall apart or was not aligning other ones as seen in Figure 7.0b, this occurred as a result error emanated from analogue weighing scale measurement. But as seen in Figure 7.0b that all the points are aligned accordingly to show the appropriate linearity that is all the exact points was aligned and no error resulted. The correlation coefficient was computed to be 1.06044255.

The product moment correlation coefficient is 1.0604 as in Table 3.0, which shows that there is a perfect correlation relationship between the results of the weighing scales, which connotes that the readings form the digitized scale is reliable.

3.3 Validation of the Modified digital weighing scale

At the completion of design and construction of the system (Digitised Weighing Scale), there was need to validate its outcome that was obtained to that from the previous research work, to ascertain the level of accuracy when compared with each other. The research work of Fagbemi et al., 2014, was used to in achieving this task. Although the former employed the resistance sensor while the latter used the microcontroller. When their various results were compared, we obtained the table below:

Table 3.0 Comparison with other research work

	Mean difference	**Product of correlation**	**Range**
Fagbemi et al. 2014	1.44kg	0.9998	0-118kg
Modified digitized weighing scale	0.16667kg	1.0604	0-10kg

From the above table 3.0, we discovered that the modified weighing scale was more accurate with a product correlation that was perfect (1.0) and a corresponding less mean difference of 0.1667 been compared to that of Fagbemi et al., 2014, which recorded 0.9998 and 1.44kg respectively. This is because the latter also has a correlation error of 0.0002. This shows that the reading that was obtained from the modified weighing scale was more reliable reading without any error recorded. Which implies that the modified weighing scale that was designed and constructed in this researched work is preferred, which can guarantee perfect result that is trustworthy.

4.0 CONCLUSION

For a digital computation of measurement, a digitized weighing scale was designed and constructed, and its functionality of the different components was presented. The system was designed to digitally display weight measurements. The device produced consist of a weight scale that read about 0 to 10kg of the mechanical weight. The system was designed to be able to measure the weights using electric and electronics means and which replaced the mechanical scale with this display. It also uses the resistance sensor to convert the different weights to proportional voltages, which is processed using the signal conditioning and the input scaling circuits respectively, which the output is then converted to digital using dedicated ADC chip ICL 7107. The device display was calibrated to read in kg. This development can be further innovated by making use of; microprocessor-controlled unit, such that it can interface with a computer for measurement and data analysis; Dedicated integrated circuit for some design stages to reduce component parts; Liquid crystal display (LCD), because of its low power consumption capabilities. Though not readily available, there are units that can display other colours like LEDs and lastly the use of better circuits that can work with less distortions and accuracy.

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