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Software and Hardware Approaches for Mitigating Errors in Weighing Signals Generated by Load Cells

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Abstract: In this paper, handling the error in weighing signal is a very important topic. The load cell sensor produces the weighing signal. Sensor function is transforming the weight of things into a weak electrical signal. The noise from different sources like machines, electromagnetic fields, humidity, power lines and temperature variations produces errors in the weighing signal. As a result, the accuracy of the weight will be affected. The paper used hardware and software techniques to reduce the error in the weighing signal. The software filtering is used to reduce the unwanted effects. The average and standard deviation of the normal distribution signal are used to measure the error value.

Keywords: Weighing signal; NodeMCU-32S; ADC converter; Load cell; Instrumentation amplifier, ADC converter; Iraq.

I. INTRODUCTION

Now, the industry field had developed and produced several products, which need high accuracy in the weight of their components like industries of drug and asphalt [1]. In addition to the weighing signal is used in some control systems [2]. In the marketing sector, a lot of market owners wanted to have a good earning. Where several goods like liquid and solid products are found in pouch, packing bottle, packet or tine [3]. The need to weigh through packing/filling accurately is essentially before sale, as shown in Figure 1 [4]. The in accuracy in the stage of under filling leads to lose the trust between the customers and the market owner. The accuracy of weighing sensor is important factor that controls the accuracy of weighing operation [5].The load cell sensor is used to produce a weighing signal. It contains four strain gauges, they are sensing elements [6]. The strain gauge. Transform the deformation to a voltage signal. The change in the resistance of the strain gauge is proportional to the amount of the applied load as shown in Figure 2 [7]. The signal is producing from the load cell is very weak and measuring in millivolt. This reason made it vulnerable to any outside variation such as temperature, vibration, electromagnetic interferences, humidity and other kinds of noise producing an error in the weighing signal. The ADC deals with the signal in volt, and the weighing signal produced from the load cell sensor is millivolt, so that the need of using an instrumentation amplifier is necessary in this stage, such as AD620, which has well features like high CMRR, high gain and low drift [8].

The next step is that the signal enters the node mcu 32s v1, which includes ADC12bit [9]. Then the produced signal will be in digital form. For removal in the weighing signal many noise effect removing in the weighing signal many noise removal approaches are constructed of two techniques. The first technique is software by using adaptive filtering and average weight factor. The second technique is hardware by using electronic components such as low pass filter. Constructs of a capacitor plus a resistor. This paper is organised as follows: previous work is outlined in Section 2, whereas the following methodology is presented in Section three. The obtained results are presented in Section 4, and the paper's conclusion is in Section 5.

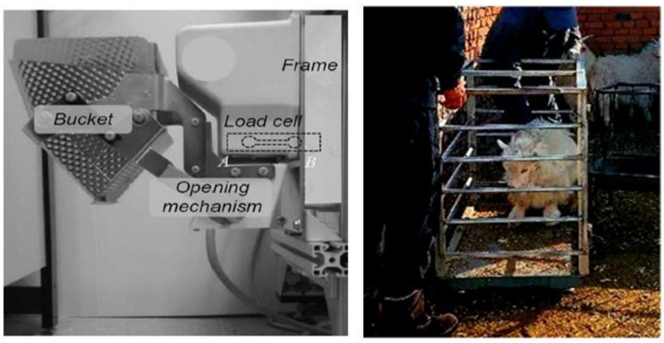

Figure 1: Applications of load cell in the marketing [4][5]

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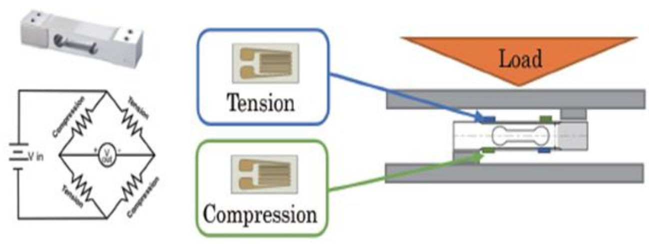

Figure 2: Strain gauge load cell [7]

1.1 Previous Works

The load cell is entering human life in various aspects. Researchers are noticed the error produced with the signal of the load cell. They tried to reduce the error by proposing and presenting some ideas. The most related researches have been reviewed.

In (1994). M.Tariq B. used a digital adaptive FIR filter. The working title was "Improvements in Dynamic weighing performance using robot transport and signal processing techniques" Throughput rate is increased up to 80%[10].

Jacek Leski (2002) has proposed another approach in addition to the weighing in average method used in the past. The robust E-insensitive weighted average is based on criterion function minimisation to reduce the impulsive noise in weighing signal [12].

In (2001). Mathew G. Pellertier has proposed a new method to reduce the impulse noise in weighing signal by using the accelerometer to get the impulse noise response used in an adaptive noise cancellation signal processing technique to remove impulse noise [11].

M. Jafari Panah et al. (2003) have suggested an analogous adaptive approach for the response correction of the load cell. The output of the load cell is oscillatory. In the proposed method, the compensation filter will track the variation in the output of the load cell. Consequently, the adaptive approach will smooth the weighing signal output from the load cell [13].

Jacek Senkara and Hongyah Zhang (2005) have presented adaptive noise cancellation manner depending on subtracting noise from weighing signal. This leads to an enhancement of the SNR, but the signal produced is very weak. This approach of subtracting and filtering is controlled by the adaptive operation to achieve a controller system performance [14].

In (2007). P. BurNos and etal. They designed the MS_WIM system. Working title was" Accurate weighing of Moving Vehicles". The error was 4%[15].

In (2010). Yan Z. and Huake F. proposed a new approach to reduce the error in weighing signals. The working title was "Dynamic weighing signal processing by system Identification". The first stage uses a wavelet transform to filter high-frequency noise. The second stage uses a genetic algorithm to filter the dynamic load that is combined with a weighing signal. The third stage uses ARX scheme. The accuracy result was 4.61% [16].

In (2012). Mutian Z. Working title was" Weighing Strategy Based on Dynamic Signal Processing Technology". Changing the parameters of the optimal filter could reduce the error in the weighing signal by 9%[17].

In (2013). Hui_mei H and etal. Have modified AR model to reduce the error in the weighing signal. The working title was"An intelligent signal processing method for high-speed weighing system". The error was 0.49% [18].

At the same year, Yin R. and Yang J. They are proposed a dynamic voltage compensation method to reduce the error. Working title “A dynamic voltage compensation method for improving weighing accuracy ".The error was 2.2%[19].

In (2014). Sakkarin S. and et al. They used Kalman filtering to predict the optimal weight of the load. The working title was " Estimating an optimal weight set point to LESSEN errors in filling weighing system based on Kalman filtering". The error was 4.42% [20].

In (2015). A. paw lowski and et al, they are proposed a new method to reduce the error in weighing signals. The working title was “Fast non-stationary filtering for adaptive weighing system". By reducing the time required to get the steady state of the load cell signal. This approach improved the accuracy of the weighing system [21].

In (2016). Maciej N. proposed a new method to reduce the error in weighing signals. By using a filtering scheme based on the (FIR) model. The working title was "High_precision FIR_ model_Based Dynamic weighing system". The accuracy is enhanced by this model four times [22].

In (2018). Duc Chage_dong with the working title of "Theoretical Analysis of low frequency Dynamic load and a Research on the algorithm for weighing accuracy improvement". They proposed the mathematical model of a moving average filter and the B_spline least squares method, and the error was

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5% [23].

In (2021). Abdelkader F. and Fakhrulddin H, they are used a software filter to reduce the noise from the weighing signal. The working title was" Handling the error in weighing signal". The error was 4.16%[19].

In (2023). Zhiwen He and et al. they proposed the Kalman_EEMD algorithm. Working title was "Study of Channel _Type Dynamic Weighing System for Goat Herds". The average error was 4.64%[24].

1.1.1 Load cell

It is a type of conversion device that can convert the applied force, such as pressure, tension, and compression, into an electrical signal or measurable voltage. It provides a weak voltage measured in millivolts (mV). The signal strength is proportional to the applied force. The accuracy of the load cell is very high. For this reason, it is currently used in the installation of electronic weighing devices [25].

1.1.2 Load cell's applications

The load cell is used in various applications such as industry, automotive, medical applications, and agriculture.

1. Crash barrier
2. Material testing
3. Truck scale application
4. Force dynamometer
5. Crane load monitoring
6. Road vehicle weighing devices

1.1.3 Types of load cell

The type of load cell is determined by the type of applied load, such as tension, bending, or compression etc. The specifications of the selected load cell depend on the weighing application setup, including the load cell capacity, maximum, and minimum load. In addition to environmental conditions such as humidity, vibration, and temperature, as well as the signal-to-noise ratio (SNR). These conditions must be considered when selecting the type of load cell. Among these types are pneumatic, hydraulic, and strain gauge load cells. As shown in figure (3).The last type, strain gauge load cell, is used in most applications due to its high accuracy [26].

Pneumatic load cell

Hydraulic load cell

Strain gauge load cells

Figure 3: Load cell types [26]

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1.1.4 Instrumentation amplifier

The instrumentation amplifier is used for controlling and monitoring physical quantities in industrial processes, such as controlling and measuring humidity, light intensity, temperature, etc. The main function of the instrumentation amplifier is to accurately amplify the low-voltage signal coming from the sensor. There are several applications that use an instrumentation amplifier where high input impedance, time drifts, low noise, low thermal and accurate closed-loop gains are requested. AD521 and AD624 are kinds of instrumentation amplifier ICs. They are produced by the Analog Devices Company. The features they have are [27]:

1. High CMRR
2. High gain
3. Low DC offset
4. They have low output impedance.

1.1.5 Analog to digital converter

Current signals interact with electronic voltage as analog signals. Analog signals must be converted to digital before entering the computer. For this reason, the analog-to-digital converter (ADC) is used to facilitate their processing via the computer. Additionally, the analog-to-digital converter is present in digital electronic devices and is of interest to digital electronic device designers [28]. It is commonly abbreviated as ADC. Types of ADC are:

1. Flash ADC
2. Dual–Slope ADC
3. Successive Approximation ADC

1.1.6 Node MCU 32s

Is an open-source platform that is a simple I/O board, as shown in Figure 4. It is an ESP core chip-based microcontroller board. It has 38 input /output pins, a two-channel analog input is A/D (12-bit), supports interface and UART. Also, it involves a supporting circuit for the board. It can be programmed by using a programming language like Python, MATLAB, and c++ [29]. It has the ability to process a single bit without affecting others in the word byte. The purpose of designing a board is for embedded applications in which is automatically manage and control the system. As well as, it can convert the signal from analog to digital or vice versa. Now, it is used in medical devices, printers, automatic home devices and other devices. The features that it has are:

1) Frequency range for the Wi-Fi (2.4GHz_2.5GHz).
2) It is supported for RTOS, because it has a clock frequency range(80MHz_240MHz).
3) Built in 2-channel 12-bit ADC from success approximation type.
4) Speed up to 150Mbps.
5) Memory: 520kiB SRAM.

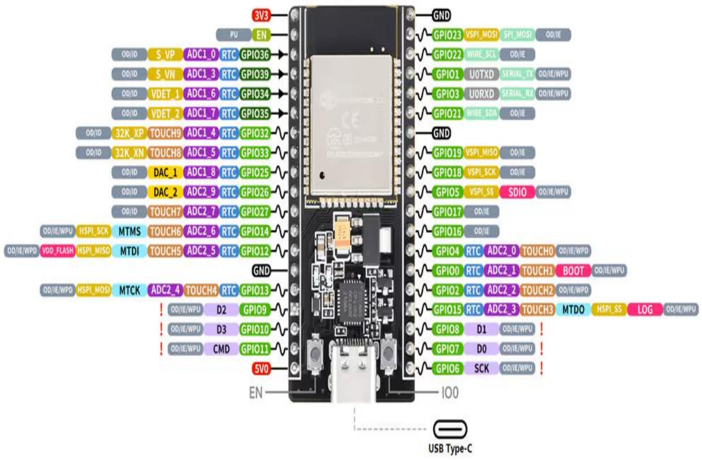

Figure 4: Node MCU 32s pine diagram [10]

1.1.7 The filtering

It is the process of eliminating unwanted external electromechanical signals that come from nearby machines and interfere with the weight signal. The filter is an electronic circuit whose function is to allow a specific range of frequencies to pass through while blocking signals with other frequencies. It consists of a resistor and a capacitor, as shown in Figure 5. It is of the Low Pass Filter (L.P.F.) type, allowing low-frequency signals to pass through while blocking high-frequency signals [30].

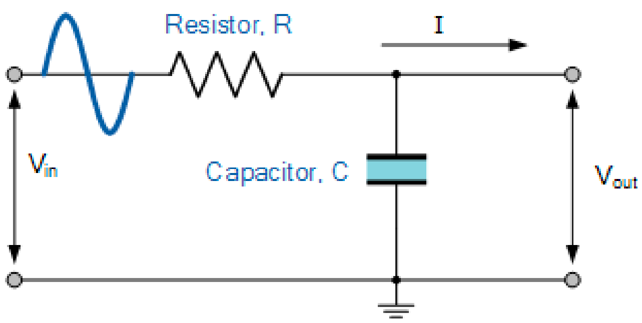

Figure 5: Low Pass Filter [31]

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II. THE PROPOSED METHODOLOGY

The electronic weighing system mainly consists of the load cell, instrumentation amplifier and the analog to digital converter as shown in Figure 3. The load cell is tested first. The instrumentation amplifier is designed to have a suitable gain. The analog to digital converter has a resolution of 12 bit. Software is written to operate the system using C language.

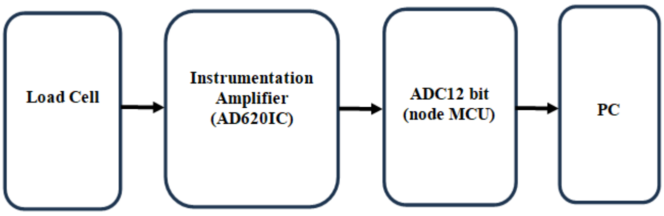

Figure 6: Proposed weighting system

2.1 Load cell test

The first examination, the load cell linearity, is tested by using a voltmeter with three digits after dot as shown in Figure 4.

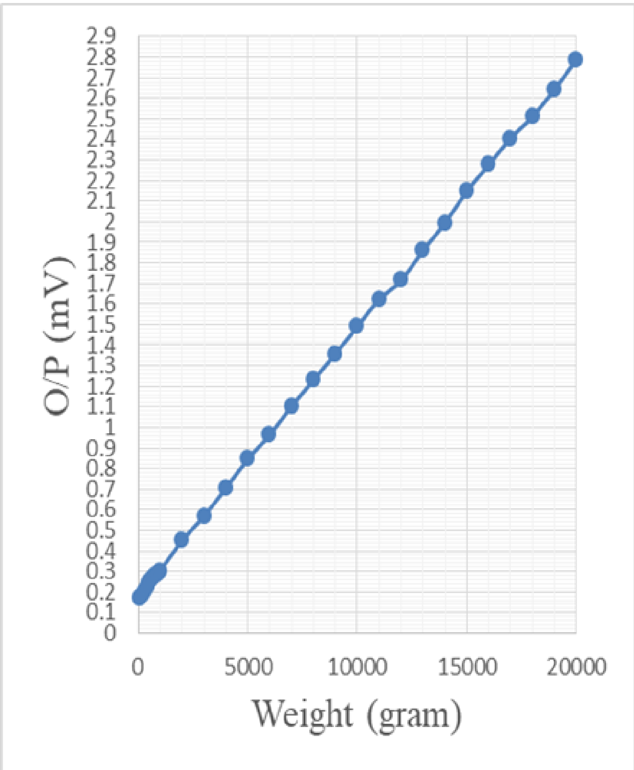

Figure 7: Load cell output with a digit's voltmeter

From the figure above, the linearity of the load cell is confirmed.

2.2 Adaptive filter

The average function will receive the readings and the number of readings and calculate the average for them and return the result to the main software, see algorithm 1.

Algorithm 1 Pseudo code of the average function.

```
START
  Int counter = 0
  Int sum = 0
  Int SensorValue = 0
  Int Average = 0
  Int n = No_of_readings
  WHILE counter < n DO
    SensorValue = Output_of_A/D
    sum = sum + SensorValue
    counter = counter + 1
    Delay(5 milliseconds)
  END WHILE
  Average = sum / n
  RETURN Average
END
```

The adaptive filter is introduced to exclude unwanted signals due to its high absolute error. It will call the average function to calculate the average for the number of samples. The average is used to determine the limits of the adaptive filter, i.e. the middle range, upper limit and lower limit. Then, it starts to read the number of readings from the load cell. In case this reading lies within the boundaries of the adaptive filter, it will be accepted; otherwise, it will be rejected. Following that, it will calculate the average for the readings after the adaptive filter as well as the average of readings before the adaptive filter, see algorithm 2.

Algorithm 2 Pseudo code of adaptive filter.

```
START
  Average = call average function
  Int upper_weight = 0
  Int lower_weight = 0
  Int counter = 0
  Int sensor_value = 0
  Int sum = 0
  Int n = No_of_readings
  Int nr = 0
  upper_weight = 1.1 * Average
  lower_weight = 0.9 * Average
```

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```
 WHILE counter < n DO
  sensor_value = output_of_AD
  IF lower_weight <= sensor_value <= upper_weight THEN
   sum = sum + sensor_value
   nr = nr + 1
  ELSE
   Reject sensor_value
  END IF
  counter = counter + 1
 END WHILE
 Average = sum/nr
 RETURN Average
END
```

2.3 Hardware filtering

The building of the Low Pass Filter (LPF) which is used in hardware filtering is done by using a resistor and capacitor. The LPF removes the highest amount of noise from the weighting signal at highest frequency.

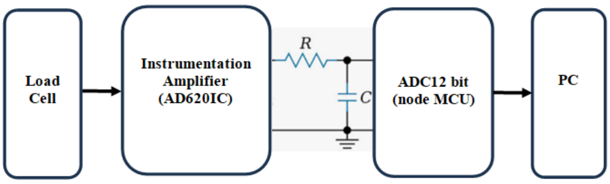

Figure 8: LPF within the system

III. RESULTS

3.1 Sigma variation

The value of sigma is examined as a function of the number of readings. The load is fixed (at 7000g) and the number of readings is varied.

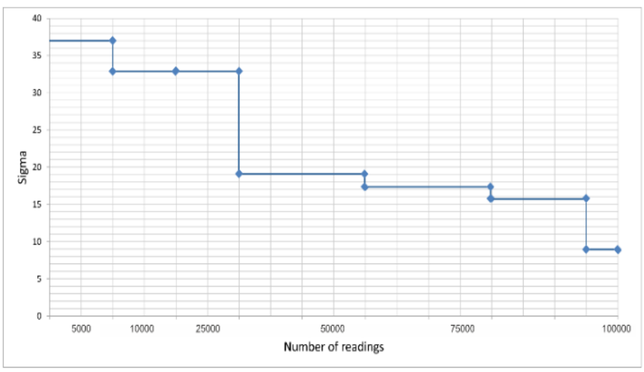

Figure 9: Effect of the number of readings on sigma at 7000g

The variation of sigma is illustrated in Figure 8, ranged from 5000 to 100000 readings. The decrease of sigma means the effect of error that resulted from noise is decreased.

3.2 Error variation

The value of the error is examined as a function of the number of readings. The load is fixed (at 7000g) and the number of readings is varied. Figure 9 confirms that computing the average of more readings produces a smaller weight error.

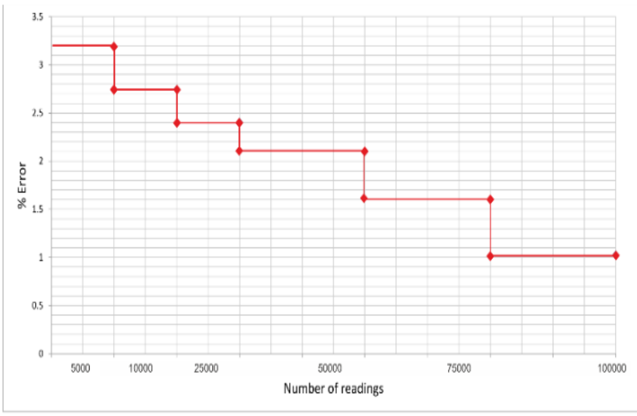

Figure 10: Effect of number of readings on % Error at 7000g

3.3 Adaptive filtering

Table 1: 4kg test using adaptive filtering

	Average	Sigma	Weight (gram)	Combined error	Sigma improvement (%)	No. of readings
Pre-filtering	642.534	8.820	3994.01	± 0.15%	----------	100000
Post-filtering	642.539	6.960	3994.01	± 0.15%	21.079	100000

The combined error is calculated, which is 0.15% from the weight 3994.01g, sigma improvement is 21.079% as shown in Table 1, Figures 10 and 11.

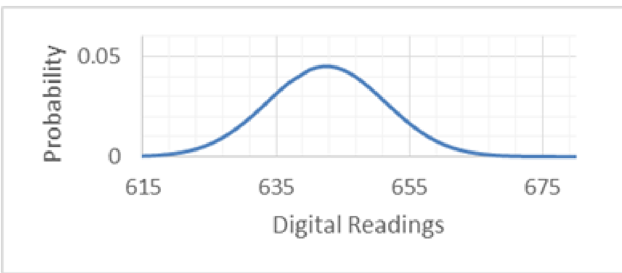

Figure 11: 4kg before adaptive filter

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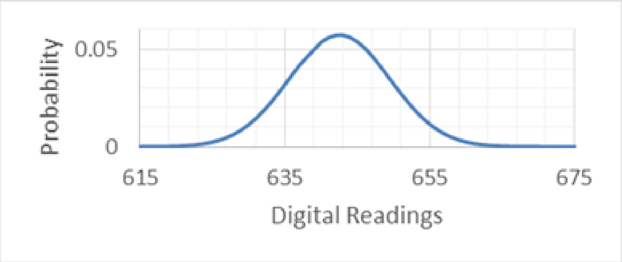

Figure 12: 4kg after the adaptive filter

3.4 Hardware filtering

Table 2: 4kg test using LPF

	Average	Sigma	Weight(g)	Combined error	Sigma improvement %	No. of readings
Pre-filtering	643.180	8.173	4000.23	+/- 0.0057%	---------	80000
Post-filtering	643.195	6.031	4000.23	+/- 0.0057%	26.205%	80000

The combined error is calculated, which is 0.0057% from the weight 4000.23g, sigma improvement is 26.205% as shown in Table 2, and Figures 12 and 13.

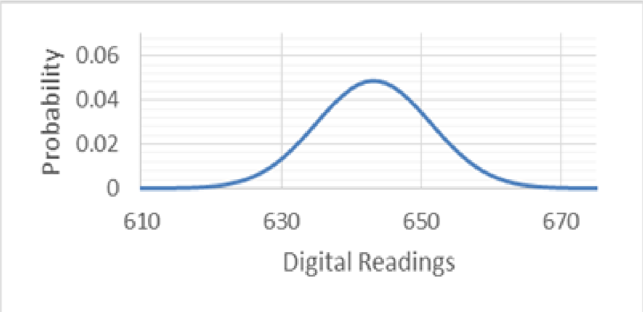

Figure 13: 4kg before the LPF filter

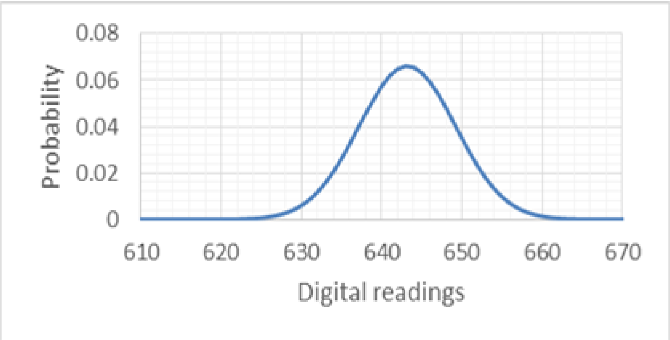

Figure 14: 4kg after L.P.F filter

Table 3: Comparison with other works

Seq.	The previous work	Available result (error)
1	[15]	4%
2	[16]	4.61%
3	[17]	9%
4	[19]	4.16%
5	[20]	4.42%
6	[23]	5%
7	[3]	4.16%
8	[24]	4.64%
9	The proposed system	0.15%-0.0057%

IV. CONCLUSION

Methods and techniques for removing the error in the weighting signal produced by a load cell are proposed. To achieve that, a system is designed and implemented. It has the following features: Resolution equals 0.00024414 of the used 12-bit ADC. And the accuracy is 0.80586 mv or 0.40293 mv. Minimum detectable load is 8g. AN analog signal range produced from the load cell (0.304 to 1.491) mv. In this proposed system the 4kg is used as an example in two techniques. The first one is software by using an adaptive filter. The result was the weight 3994.01g, sigma improvement is 21.079%, and the combined error is calculated, which is 0.15%. The second one is hardware by using L.P.F. The result was the weight 4000.23g, sigma improvement is 26.205%, and the combined error is calculated, which is 0.0057%. Whereas the number of readings used was 80000, it means the time required to reach the accurate weight for the load is reduced by 20% of the first technique.

Future work

The following points can be considered as future work.

1. Design an electronic weighing balance for a range of 0.1kg_1kg.
2. Replace the existing serial communication with parallel communication to speed up the measurement process.
3. To increase the electrical isolation, a photo coupler is to be added to the proposed system to prevent noise from getting into the electronic circuit.

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