JANUARY 2018 M.Sc. THESIS IN ELECTRICAL AND ELECTRONIC ENGINEERING NOOR HUSSEIN JUMAAH

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCE

DEVELOPMENT OF DIGITAL MEDICAL WEIGHT SCALE USING 32-BIT ARM BASED MICRICONTROLLER

M.Sc. THESIS

In

ELECTRICAL AND ELECTRONIC ENGINEERING

BY

NOOR HUSSEIN JUMAAH

JANUARY 2018

Development of Digital Medical Weight Scale Using 32-BIT Arm Based Microcontroller

M.Sc. Thesis

In

Electrical and Electronic Engineering

University of Gaziantep

Supervisor

Prof. Dr. Ergun ERÇELEBİ

By

Noor Hussein JUMAAH

January 2018

REPUBLIC OF TURKEY
UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
ELECTRICAL AND ELECTRONICS ENGINEERING

Name of the thesis: Development of Digital Medical Weight Scale Using 32-Bit Arm Based Microcontroller.
Name of the student: NOOR JUMAAH
Exam Date: 17/01/2018
Approval of Graduate School of Natural and Applied Sciences

Prof. Dr. Ahmet Necmeddin YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Ergun ERÇELEBİ
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Ergun ERÇELEBİ
Supervisor

Examining Committee Members	Signature
Prof. Dr. Ergun ERÇELEBİ	....
Prof. Dr. Ilyas EKER	....
Assoc. Prof. Dr. AHMET METE VURAL	....

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that as required by these rules and conduct. I have fully cited and referenced all material and result that are not orginal to this work

Noor Hussein JUMAAH

ABSTRACT

Development of Digital Medical Weight Scale Using 32-BIT Arm Based Microcontroller

Jumaah, Noor Hussein

M.Sc. Thesis in Electrical and Electronic Engineering

Supervisor: Prof. Dr. Ergun ERÇELEBİ

January 2018

59 Pages

This thesis includes the design and implementation of a modern digital weighing medical scale. The system includes facilities for interactive connection feature with smartphone which makes the scale to be used as daily body fitness and patient weight monitoring system. The weighing scale is of small size, strong, low power consumption and it has been built to be suitable for professional medical environment. Stain was used as an electric transducer to convert the weight into an electrical signal. The strain gauge was applied within Wheatstone bridge. On no load condition the bridge was adjusted to be in balance condition. When a load was placed on the scale, the bridge become resistance of the strain gauge according to the weight placed on the scale. This unbalanced was created output voltage at the output terminals of the bridge a low noise instrumentation amplifier (LNIA),which can amplify low level signals even with existence of high common mode rejection ratio, high input impedance and high gain . By using this amplifier, the common noise and temperature dc drift were cancelled and only the differential signal was amplified with gain of 128db. The output of the amplifier was converted into a digital data using 24analogue to digital converter ADC. A medium density performance line ARM based, 32 bit,72 MHZ microcontroller unit (MCU) was used to control the operation of the weighing scale. The processing the output signal of the ADC was achieved by MCU using a software program which was designed for this purpose. A Standalone liquid crystal diode (LCD) display was used to display the weight value. A Bluetooth radio was implemented to send weight data on line to the smartphones for continuous monitoring of the data bus medical staff. All the purposes several tests were carried out on the system to measure the accuracy and resolution of the scale. The maximum error of the weight scale was 0.3 Kg in 200Kg weight.

Key Words: Medical scale, Strain gauge, Bluetooth Weight scale, Software, Micro controller, Transducer, ARM32.

ÖZET

32-BİTLİK ARM TABANLI MİKRO DENETLEYİCİ KULLANILARAK SAYISAL MEDİKAL TARTININ GELİŞİTİRİLMESİ

Jumaah, Noor Hussein

Yüksek Lisans Elektrik ve Elektronik Mühendisliği Tezi

Tez Danışmanı: Prof. Dr. Ergun ERÇELEBİ

Ocak 2018

59 Sayfa

Bu tez, modern sayısal medikal tartının tasarımını ve uygulanmasını içerir. Geliştirilen sayısal medikal tartı, günlük vücut formu ve hasta ağırlık izleme sistemi olarak kullanılacak tartıyı akıllı telefon ile etkileşimli bağlantı özelliği için olanakları içermektedir. Ayrıca, dijital ölçek, küçük boyutlu, güçlü, düşük güç tüketimi ve profesyonel tıbbi çevre için uygun olarak üretilmiştir. Gerinim ölçer, ağırlığı bir elektrik sinyaline dönüştürmek için bir elektrik dönüştürücü olarak kullanılmıştır. Gerinim ölçer, Wheatstone köprüsü içinde uygulandı. Yükü olmayan koşullarda köprü denge durumuna getirildi. Tartı üzerine bir yük yerleştirildiğinde, köprü ölçeğe yerleştirilen ağırlığa göre gerinim ölçerin direnci haline gelir. Bu dengesiz yük, köprünün çıkış terminallerinde, yüksek ortak mod reddetme oranı, yüksek giriş empedansı ve yüksek kazanımda bile düşük seviyeli sinyalleri yükseltebilen bir düşük gürültü devre amplifikatörü (LNIA) çıkış gerilimi üretir. Bu amplifikatörü kullanarak, ortak gürültü ve sıcaklık DC sürüklenme iptal edildi ve sadece diferansiyel sinyal 128dB kazançla yükseltildi. Amplifikatörün çıktısı, 24 bitlik analogdan dijitale çevirici kullanılarak sayısal bir veriye dönüştürüldü. Tartının çalışması orta yoğunluk performanslı 32-bitli ARM tabanlı mikro denetleyici ile kontrol edildi. ADC'nin çıkış sinyalinin işlenmesi, bu amaçla tasarlanmış bir yazılım programı kullanılarak MCU tarafından gerçekleştirildi. Ağırlık değerini görüntülemek için sıvı kristal ekran (LCD) kullanılmıştır. Ağırlık verilerinin sürekli izlenmesi amacıyla ağırlık verilerini akıllı telefonlara göndermek için bir Bluetooth radyo modülü kullanıldı. Tüm amaçlar için Ölçümün doğruluğunu ve çözünürlüğünü ölçmek için sistem üzerinde çeşitli testler yapılmıştır. Ağırlık ölçeğinin maksimum hatası, 200 Kg ağırlıkta 0.3 Kg.

Anahtar Kelimeler: Sayısal tartı, Gerinim ölçer, 32-bitlik ARM tabanlı mikro denetleyici

ACKNOWLEDGEMENTS

First of all, I thank Allah for having given me the strength to carry on this Project and for blessing me with many great people who have been my greatest support in both my personal and Professional life.

A sincere gratitude and appreciation goes to my supervisor, Prof. Dr. Ergun ERÇELEBİ for his knowledge, advise and support throughout my studies.

A big thnak you to all members of electric electronic engineering group past and present, whom I was fortunate enough to work with.

A speical thanks must g oto my friends in Turkey and Baghdad for their everlasting friendship.

Above all I thank my family (Father, mother, brother and sister wavies brother). A special thanks to my close friend and my cousin for his support me and encouragement to complete my career.

Who are the most important part of my life, who have always being there for me in all difficult circumstances, for their love, moral support, encouragement and continuous prayers, for their faith in my ability during my experience in Turkey.

This thesis dedicated to those most dear to me-my beloved family

Noor Hussein JUMAAH

TO MY FAMILY...

TABLE OF CONTENTS **Pages**

LIST OF FIGURES

Pages

LIST OF TABLES

Pages

LIST OF SYMBOLS / ABBREVIATION

INA	Instrumentation Amplifier
PGA	Programmable Gain Amplifier
CMR	Common-Mode Rejection
GUI	Graphical User Interface
MCU	Microcontroller Unit
PCB	Printed Circuit Board
ADC	Analog to Digital Conventer
UART	Universal Asynchronous Receiver Transmitter
RMS	Root Mean Square
SSP	Synchronous Serial Port
LDO	Low Drop Out
LED	Light Emitting Diode
BPS	Bit Per Second

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Weight scales have been used for quite a while in homes, businesses and medical facilities. With the increase in demand for health-related information, connected weight scales can now send data to smart phones, tablets and the Cloud where it can be utilized by medical providers and other care givers. Connected weight scales are being used with other home-based consumer and medical devices to improve the health and general well-being of many people [1]. The Weighing machine is fairly beneficial device. It assists us checking the personnel weight in addition to another product's weight. Furthermore, weighing machine being used in many commercial, medical and industrial uses. Without a weight machine it is difficult to find out the exact mass of any item. There are two different system types of weight measuring known as the analog and digital weighing machine [2]. The analog one is very mistaken, while the digital weighing machine does not face any problem. It typically shows the exact weight on digital screen with extra information based on weighting device, and it can be interface with the digital world. Digital weighting machine having the following quality measures as accuracy and time complexity exchanges were fair.

The manufacturing development within the nineteenth century brings about a fast development of modern devices and measuring techniques to meet the needs of industrialized manufacturing techniques [3]. This in contrast has needed a parallel growth of new devices and measurement techniques [3]. Recently, the requirement for digital weighing machine is raising every day in most commercial enterprise considering the digital measuring of the weight.

The weighing machine, in most, is simple to use with high range of different applications [3]. Thus, the trends to make use of digital weighing machine rather than the classical weighing system is acquired mainly in the world and therefore the requirement has increase to development wide range of high level of digital weighing machine [4]. Many digital weighing scale models have been provided in many of publications; these models exhibit several unique functionalities. For example, the work done by [5]. He was providing three different projects with uses different scales. He started with the cheap and simple scale which was Figure BB-90 scale that has LCD screen. The aim of his project was going to save the data on an SD memory in addition to place more additional features for the scale. He did that by taking out the original LCD screen and after that added a microcontroller type (LPC2103) with new LCD screen in order to control it. The LPC2103 microcontroller takes data from SD card and performed multi-calculations prior to outputting it on the LCD screen. The improved features included date and time, decrease or increase in weight, in addition to multi-user support [6]. Extra improvement of the scale is by give it Bluetooth connectivity. The scale becomes able to communicate with smartphone via a Bluetooth link. He had used the Smart Weight Chart (Android application) in order to show the data as a graph. The second work of him was identical to the first one but had used different scale. In addition, he manipulated the Bearer scale (BG16) that measures the percentage of muscle weight, the percentage of water and the percentage of the fat [5]. He made the same changes with other scales. Even though the scale has very advanced, it was on the other hand costly and not affordable by many people. The people requirement for to frequently check their weight could not be overemphasized. In the present day, the number of patients with fatness is rising at a serious rate. The stroke problems and risk of heart diseases are also on the growth. Overweight and obese persons are at raised risk for many health conditions and diseases, involves: heart Stroke, high LDL and low HDL cholesterol, high blood pressure, diabetes, plaque in arteries of heart, degenerative joint disease, breast cancer, gall bladder infection and respiratory problems. Since these diseases are weight dependent, the bathroom scales being very necessary for people that not have a bathroom scale inside their home where they usually do not bother to check their weight which can be risky to their health. Many of the weighing machines available in the market are analogue types. The analogue scale even though are somewhat cheap and usually do not need power supply, however, it suffers from inaccurate results, zero error problems, calibration, etc. Additionally the only a few digital weighing machines that can be obtained from market are costly and not economical by most people. Thus, the need for developing and creating a digital weighing scale.

The weighing scales in basic are instruments to evaluate weight. The spring scales or spring balances are compute mass by first through calculating weight and balancing the force caused by gravity as opposed to the force on a spring, where a pair of scales or balance utilizing a balance beam compares masses through balancing the weight due to the mass of an object as opposed to the weight of one or extra known masses. A lot of them can be arranged to be reading in units of force (weight). For example; Newton's rather than the units of mass like kilograms. The pair of scales or balance utilizing a traditional balance beam to do a comparison of masses may read accurately for mass even though moved to a place with several non-zero gravitational field strength. As well, the spring balances which have been designed with force consideration would read accurately for weight in a several non-zero gravitational field strength.

1.2 Objective of the Research

This research includes the design and experimental setup of a modern digital weighing medical scale with an interactive connection feature for a smartphone, to be used as a daily body fitness and patient weight monitoring system. The weighing scale is of small size, strong, with low power consumption and built to be suitable for a professional medical environment. An electric transducer is used to convert the weight features into an electronic signal which is then processed using advanced digital technology.

A medium density performance line, that is ARM-based, 32bit, 72MHZ microcontroller unit (MCU) and a low noise on-chip programmable gain amplifier (PGA) with a gain of 128dB is used for the weighing scale application. A standalone liquid crystal diode (LCD) display is used to display the weight value and a Bluetooth radio is applied to send weight data on line to the smartphones for continuous monitoring of the data by medical staff. The signal processing of the system is controlled by software. Different programs have been developed for the LCD display control for the wireless Bluetooth module to communication the scale with smart phones. Also a software program is written for the EEPROM weight readings storage.

1.3 Thesis Organization

This thesis has been organized to five chapters:

Chapter 1 consists of Introduction, objectives of the research and thesis organization.

Chapter 2 provides literature survey which describes some of the related topics to this research.

Chapter 3 describes the design concepts of the digital weighting scale.

Chapter 4 describes the implementation of the hardware and software of the scale.

Chapter 5 consists of results and discussion.

Chapter 6 describes the conclusion and future work related to this research.

Finally, the thesis includes a list of references related to the research.

CHAPTER 2

LITERATURA RESEARCH

2.1 Introduction

There are several types of weighting scales could be found in the literature. Early types of scale were mechanical weight bridge, analogue electronic scales, electromechanical balance and the portable weigh bridge, the portable ramp end scales, Axle scales and different types of digital weighing scales. The early studies of weight scalar have been carried out from 1977 [6]. A high accuracy mechanical scale has been used and improved for use, involves protect the mechanical parts from rust and constructing a jig to convert the beehive weight to the balance. The elaborate vision system has been used to check out the amount of changing in weight. It was one among the previously implementations of noninvasive measurement of weight that is the scale has been built in into the system, instead of attached at specified time periods. The weight scale has become a part of the beehive. The scale had 0.5kg accuracy and it can provide efficient data for the research groups study. The studies have travelled to the recorded and beehive the weight for the hourly basis, throughout the period of three years. Improvements in the development of strain gauges, pressure sensors and load cells made these techniques more attractive for usage in weight measuring uses. The load cells are becoming a common in beehive weighing systems. For application of a robust and single, the load cell is utilized to weigh an entire beehive [7]. The optimal weight that the load cell may be able to accommodate is 200kg, which adheres to the requisites of an average sized beehive. In addition, the jig has been used to convert the weight of the beehive into the load cell allows for regular weight distribution and could handle will need to an imbalance of weight happen in the beehive. One more application of load cells is seen in the Arnia Scale [8]. The theory of the scale is identical to the earlier model, but utilizes a more less design. The system utilizes four load cells, 1 in each corner, in order to balance the weight load. The model has taken into consideration greater ventilation of beehive and then will allow any hive debris to fall straight to the ground and stop a build-up at the beehive base. The total height adds 35mm to the total height of the beehive. The weight scale contains a working capacity of 150kg, measuring weight in increases of 10g. The system of strain gauges provides a layer of complexity for the scale design.

Recently, beehive weight measurement was greatly depended upon the researchers to be going to the place of where put the scale and recorded the value that appears on the mechanical balance manually [6]. The manual recordings are often required an hourly basis, that has been cumbersome and requested additional attention. The modern development of technology has widely minimized the need for location visits. The development of data logger technology has reduced the requirement to manually monitor the hives weight since it can automatically record the variations over time. The accumulated data will then be collected at lower frequent intervals. For totally remote observation, significant advances have been presented to let beekeepers to check on the state of their beehive. Several systems, like Arnia, have built in a wireless component that has the ability to send data to a single hub. After that, the data are then reachable from different devices such as smartphones, tablets, or smart phones [9]. Many of these applications offer the necessary information to stop any sudden bee’s loss in the beehive, as example, through disease or theft. The weighting scales (it usually termed "scales" by Australian and UK English, and its termed "weighing machine" in south Asian English) is the instrument for measuring the mass or weight of an object. The spring scale principles are based on measuring the weight via measuring the distance of spring deflects due to its load. A balance analyzes the torque on the arm because of the sample weight to the arm torque as a result of a standard reference weight utilizing a horizontal lever. In other side, the balances are different from scales, because the balance measures gravitational mass, while the scale measures weight (compression or tension force of constraint given by the scale). Scales are widely-used in many commercial and industrial applications. The specialized bathroom scales and medical scales are utilized to measure the body weight of people. In other hand, the balance scale is simple device that its application probably far predates the evidence. Which has allowed archaeologists to linkes artifacts to scales in order to finding out absolute weight. The balance scale has been used probably to evaluate relative weight long prior to absolute weight. There are various balances types found in the literature as outlined by the mechanism of operation. A brief description has been presented in the following sections for these types.

2.2 Mechanical scale

The initial spring balance was first brought into popular use in the 18th century. Richard Salter, from Bilston, England had begun constructing what is today called a fisherman's scale that used a spring balance to scale weight. The Salter brand was even the earliest company in England to designated bathroom scales. Current home scales have developed from these early industrial representative models. In the present day, the scale is based upon the corresponding spring balance idea.

The spring scale case had manufactured from aluminum or stainless steel. The interior of the scale is consisting from: pins, plastic, gears, and metal springs. The gears are often made from steel, stainless, aluminum, iron, copper, bronze, brass, zinc, nickel, plastic, or silver. The non-slip mat is made from a mix of rubber and poly vinyl chloride [10].

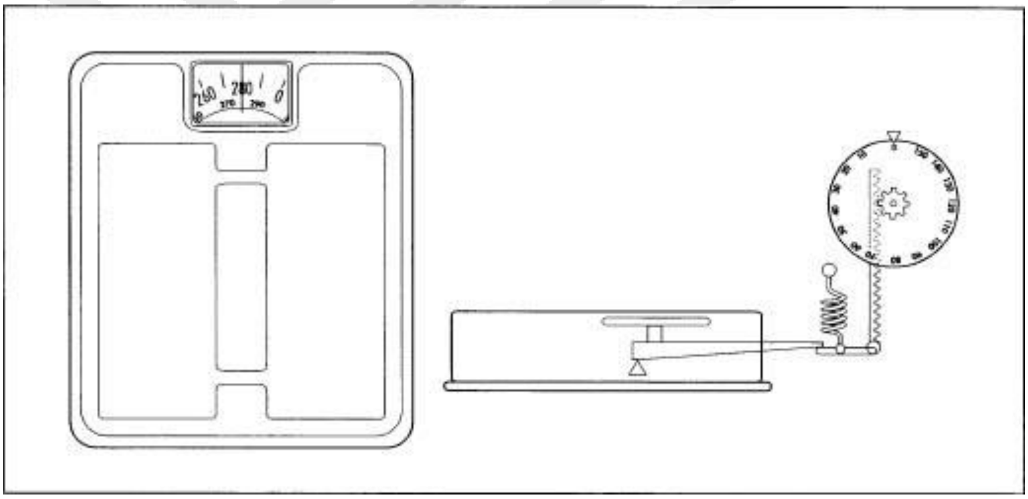


Figure 2.1 Traditional bathroom scale (Mechanical body scale)

2.3 Analog Medical Weighing Scales

Recent analog medical scales utilize sensing devices like piezoelectric sensors or transducer load cell. They don't use a digital processor and their read outs to the consumer are analog therefore, it got this name. The weight scales either have a calibrated rotating dial or a rotatable pointer or graduated dial scale. The functional block diagram of an analog weighing scale is illustrated in Figure 2.3 [10].

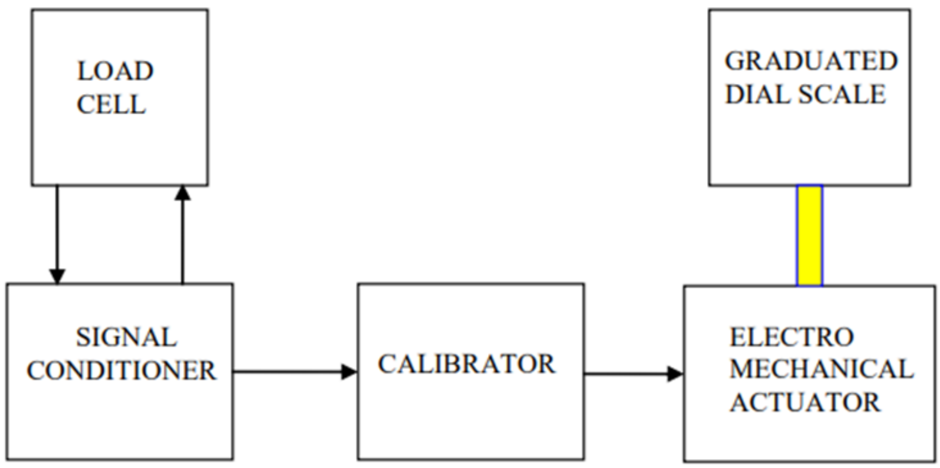


Figure 2.2 The Functional scheme of an Analog Medical Scale

This weighing balance type has a several disadvantages. The First one, the dial has a poor resolution in that little differences in weight among different objects aren't easily detected or measured. The Second disadvantage, the device does not have any memory so that the previous measured weight of an object isn't stored and could only recalled by written the measurements records or by mentally. The third disadvantage is the calibration issue, which has to be done in every time start measurement which makes it cumbersome and tedious. The fourth one is the device that has high electrical power usage particularly because of the electro mechanical actuator who works on heavy current. The last disadvantage is the performance of the machine which is appreciably low as a result of the moving parts of the actuator as well as to the obvious expensive cost maintenance. Also, the calibrator has, often, been replaced by a digital processor circuitry which generates a digital signal in order to driving the actuator which in operates the analog dial. Keeping this kind of dial makes an unaddressed low-resolution problem.

2.4 Digital weighting scale

The digital medical scale is a one of the electronic weighing machine that used to measure various readings involves BMI, muscle mass, body fat, water ratio together with body mass and lean mass. The digital bathroom scale is an intelligent scale that has many features such as fitness tracking, cloud storage, and smartphone integration [12]. The medical weighing scales have been used primarily by lab environments, or by professionals like a doctor or within hospital. With these environments authorized medical scales are needed as it is vital to find out the patient's accurate weight and have the option to monitor this accurately. Additional users involve personal trainers, health spas and gym staff, and even so people within these types tend to just work with non-approved weighing. Digital weight scale systems have been used in different fields including medical, industrial and food samples [13].

Developed a digital weighing scale for finding adulteration and cost standardization. In this work, it has been proposed a system with unique a feature that vision camera with color sensor technology to find out adulteration identification in food sample. From the results obtained, the customer would pay the money only of pure sample that was weigh by load cell without adulterant [14]. Introduced typical idea about selecting load cell for load measurements and explains the new implementing of weight measurements system based upon ADC, Digitizer board and Amplifier. This study has an advantage of high accuracy measuring systems in addition to errorless and simple design. The significant idea of that study is to implement a simple method for load measurement by help of advanced instrumentation and load cell [15]. Discussed the advancement of a load cell depending on the static weighing system. Particularly, the focus is on utilizing digital filtering methods to eliminate the measurement noises out of the highly low frequency noise from the static weighing system. These designed systems had great accuracy with high precision outcome [16]. Has designed a micro controller that based on bagging machine and electronic weighing that operates fast and will make accurate measurement along with packs consecutive weights. It had been ideal for granular materials. This method could have automatically the tare weight from the weight hopper; it is software system had been written in a way that, some hard conditions of the sugar factories had been taken into consideration and it was easy to understand. The system appears to be user friendly and offers the required alarms.The digital medical scale consists of the following main electronic parts:

1-Load cell sensor (strain gauge)

A load cell is a transducer that has the ability to translate pressure (force) to the electrical signal, Load cell it's the sensing unit of weight scale translate the patient weight to the electrical signal, A strain gauge is an equipment that used to measures the changes in electrical resistance with proportional of and response to strain (force, pressure, etc.) that applied to the device [17].

One of the most regular strain gauge is constructed of foil or very fine wire, arrange in a grid pattern in such a way that the linear change in electrical resistance happen when strain is applied in one certain direction, most usually found with a base resistance of 120 Ω, 350 Ω, and 1,000Ω [18].

2-Low noise instrumentation amplifier (LNIA)

The LNIA is an analog subsystem which can amplify low-level signals even with existence of high common mode noise. The LNIA is optimized for DC signals and are generally characterized by high common mode rejection ratio, high input impedance, and high gain. The most often used instrumentation amplifiers involve 2 or 3 operational amplifiers and many precisely matched resistors. The utilization of multiple operational amplifiers enhances both accuracy and gain linearity. In these devices, the common mode rejection ratio (or CMRR) is relatively equal to 1 / 2 the resistor mismatch and the gain. The common mode error or output is mounted by the resistor mismatch and it independent of both output signal and gain. The Instrumentation amplifiers which consist of only single operational amplifiers have also been available, but do not gain the low bias currents and low drift of more advanced devices.

3- Analog to Digital Converter (ADC)

ADC is a unit that can convert an analog signal to digital signals. The analog information is transmitted by instrumentation amplifier and the output of ADC is send to the MCU as digital serial information.

4- MCU (Microcontroller Unit)

Microcontroller unit is the processing unit in medical scale translates the serial digital data that comes from ADC to the display, also called core unit.

5-LCD (liquid crystal display)

LCD is the display visual unit that shows the weight information in human format.

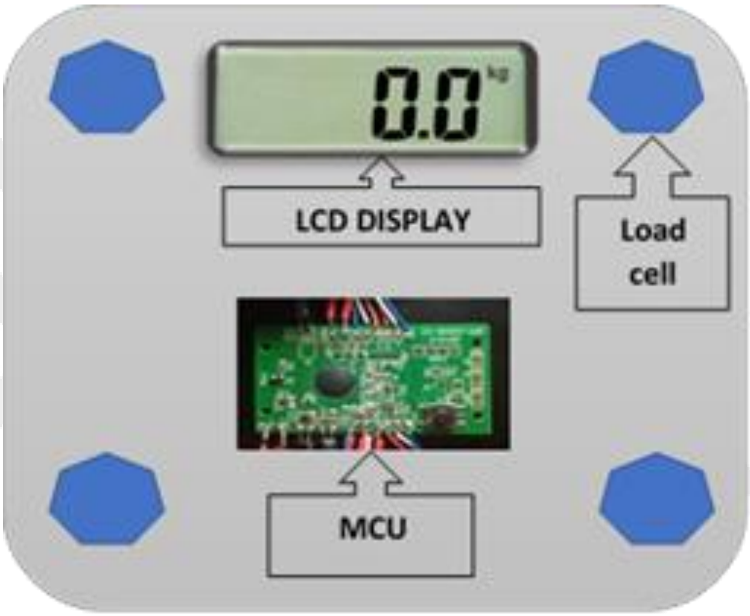


Figure 2.3 Digital Medical Scale Electronic main part

CHAPTER 3

THE DESIGN CONCEPT OF THE WEIGHT SCALE

3.1 Introduction

This chapter gives the design concept of the digital weight scale. The first part of the weigh scale includes the principles of designing the wheatstone bridge which is used as a transducer to convert the applied load on the scale to an electrical signal. The theory of operation of the bridge includes the conversion of the variation of the strain gauge resistance because of change of the applied load on the scale to a voltage at the output of the bridge.

The chapter also gives the design principles and operation of the most important and modern parameters of the system. These parameters are applied in designing the digital weight scale system.

These parameters include instrumentation differential amplifier, filter, ADC dynamic range, gain error drift, noise free, system gain and update rate. The other parts of the system high efficient micro controller unit MCU used to operate and control overall system with a computer program developed specially to control and display the weight data on LCD display. The displayed data could also be sent through a Bluetooth technique to a smart phone to follow up the weight data of the patients for body fitness.

3.2 Block Diagram of the Proposed Digital Weight Scale System

The following sections clarify the design and operation principles of the important parameters of the weight scale system.

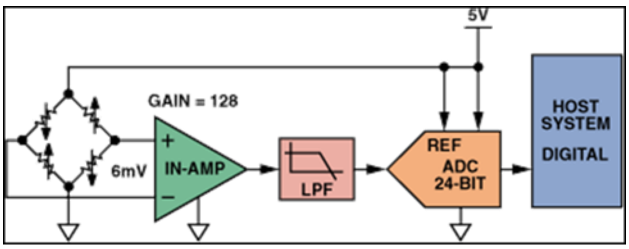


Figure 3.1 Typical Weight Scale System Block Diagram

3.2.1 Load-Cell Sensor

The most regular weigh scale setup is to utilize a bridge class load-cell sensor, that has voltage output which directly proportional to the weight applied on it. A common load-cell bridge has illustrated in Figure 3.2. As shown in Figure, it is four resistor bridge circuit that has at least two varying arms, As the resistance variations with weight placed, it makes a differential voltage in a common-mode level of 2.5V (one half the supplies voltage). A regular bridge is having a resistor of the order of 300Ω. The load cell is naturally monotonic. The key parameters of it are the drift, the total error, and the sensitivity [7].

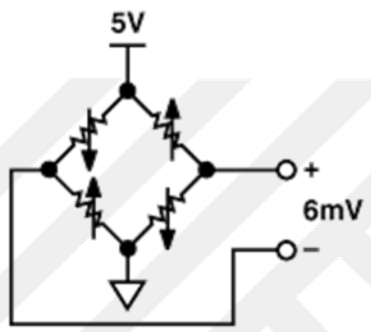


Figure 3.2 Basic Circuit of Load Cell.

There are three categories of load cell: the strain gauge transducer, oscillating string transducer that measures variations in frequency and the magnetic transducer that measures variation in magnetic permeability.

3.2.2 Strain Gauge Basics

A strain gage is an electrical resistance which varies in proportion depends on the strain amount in device. The strain gauges (variable resistance transducers) passive transducer which is used to measure strain produced by a force by the changes in electrical resistance in wires [19]. The spring element or sensing is the key structural element of the load cell. The sensing is manufactured in such a way that it creates a strain, which is directly proportionate to the load placed. The sensing elements are often made from: beryllium copper alloys, high strength alloy steels, heat-treated aluminum alloys or precipitation-hardened stainless steels [7].

Different Types Strain Gauges:

- Wire Strain Gauge
- Foil Stain Gauge
- Semiconductor Strain Gauge

The resistance wire gauges have two basic forms un bonded and bonded.

In the unbounded type a fine wire resistance strain gauge is stretched around the insulated pins. The advantages of Un bonded strain gauge is that the range of this gauge is +/- 0.15% strain and has a very high accuracy but the limitation of un bonded strain gauges occupies more space [11].

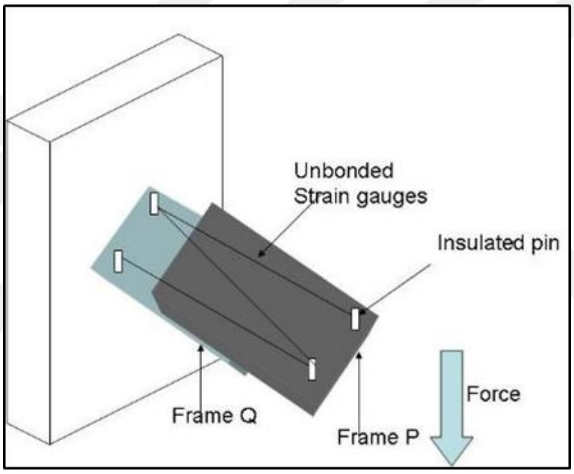


Figure 3.3 The Unbounded Strain Gauge

By connecting strain gauges to the precisely machined part, the force applied could be determined in terms of resistance change. Usually, the strain gauges are 4 or a multiple of four, which are linked to Wheatstone bridge configuration to make a very little change in resistance towards a usable electrical signal. The passive components like resistors and temperature depending wires has been used to calibrate and compensate the output signal of the bridge [7].

3.2.3 Bending load cells

It is where the sensing elements may subject to bending. There are broadly used in various designs for commercial transducers. They provide high levels of strain at relatively low forces. Additionally, in case that beam of symmetrical cross-section in about the bending axis, there are often two surfaces are subjected to identical strains of opposite sign. This presents a convenient means of implementing the temperature compensation and the full bridge circuit which is relatively easy. The gauges are cemented straight in to the structural member surface under test ın order that changes in length are determined by changes in the gauge resistance. The degree of the change in resistance is determined from the following formula.

$$R = \rho \frac{L}{A} \tag{3.1}$$

Where:

A: cross-sectional area

L: total length

P: the foil strain gauge resistivity.

By taking the strain logarithm and the differentiate both sides, then the equation being as in follows:

$$log\, R = \, log\, L \, + \, log\, \rho - log\, A \tag{3.2}$$

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta A}{A} \tag{3.3}$$

By introducing the Poisson’s ratio, σ, of the gauge material, which is:

$$\frac{\Delta A}{A} = \frac{2\sigma \Delta L}{L} \tag{3.4}$$

By apply equations 3.3 and 3.4, equation (3.5) is yielded:

$$\frac{\Delta R}{R} = \left(\frac{\Delta L}{L}\right)(1 + 2\sigma) + \frac{\Delta \rho}{\rho} \tag{3.5}$$

At last, by applying equation 3.5 in gauge factor (k) equation $k = \left(\frac{\Delta R}{R}\right)\frac{\Delta L}{L}$, then the gauge factor equation being as in follows:

$$k = (1 + 2\sigma)\left(\frac{L}{\rho}\right) + \left(\frac{\partial \rho}{\partial L}\right) \tag{3.6}$$

Regarding equation 3.5, the resistance change is happening from changes in the gauge dimensions due to mechanical strain and also the probability of changes in resistivity. The bridge circuits are widely used to evaluate the changes in the strain gauges resistance due to that the small resistance changes could be measured and involves two identical strain gauges within an adjacent arm of the bridge. the one gauge has subjected to a mechanical strain while the other is separated from the strain, but it positioned were its temperature environment is similar to that of the strain detector. Hence, any changes in temperature would influence each gauge evenly and the bridge will remain balanced.

3.2.4 Instrumentation amplifier

Using of instrumentation amplifiers (INAs) in this research is to condition the small signals in the existence of DC potentials and large regular-mode voltages. The architecture of INA that on chip with 24-bit ADC is 3 op-amp INA carries out this function with the input stage producing a high input impedance without the common mode voltage and output stage filters and it will delivers the differential voltage. Big impedance along with high common-mode rejection is a key to the load cell strain gauge of medical weigh scale [20].

INAs are application amplifiers to condition small signals. Their high impedance together with high common-mode rejection is ideal for load cell strain gauge applications. the non-inverting inputs of the input stage is achieved high input impedance, without needs to resort to any feedback tricks.

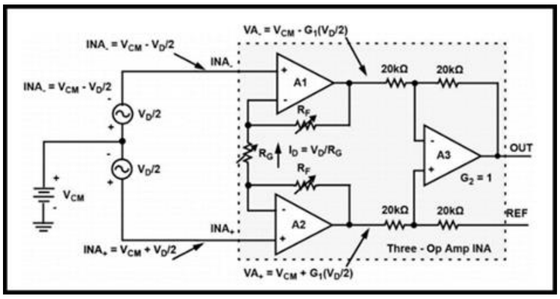


Figure 3.4 Block Diagram of a Three-op amp INA on HX711 chip

$$\text{INA}_{+} = V_{CM} + \frac{V_D}{2} \tag{3.7}$$

$$\text{INA}_{-} = V_{CM} - \frac{V_D}{2} \tag{3.8}$$

$$\text{I}_\text{D} = \frac{(\text{INA}_{+} + \text{INA}_{-})}{R_G} = \frac{V_D}{R_G} \tag{3.9}$$

The output voltages of A1 and A2 can be calculated from following equation:

$$\text{VA}_{-} = V_{CM} - \frac{V_D}{2} - \ I_D R_F \qquad \text{VA}_{+} = V_{CM} + \frac{V_D}{2} + \ I_D R_F \tag{3.10}$$

By substituting Equation 3.9 into Equation 3.10 yields:

$$\text{VA}_{-} = V_{CM} - \frac{V_D}{2}\ G_1 \quad \text{VA}_{+} = V_{CM} + \frac{V_D}{2}\ G_1 \tag{3.11}$$

Where $G_1 = 1 + 2\frac{R_F}{R_G}$ (3.12)

The action of the INA to remove common mode signals from the desired load cell strain gauge differential signal, the differential component (VD/2) that amplified by the gain (G1), while the common-mode voltage VCM (VCM in this research (AGND+1.2) maximum and (AVDD-1.3) minimum) passes the input stage with unity gain and is subsequently cancelled out by the common mode rejection of amplifier A3 which is exactly the result we want. The input rejection mode in this research is 100db at 128 INA gain achieved from HX711 chip INA unit.

The input offset voltage of all amplifiers, will vary over time and temperature. The terms of input offset drift through temperature is volts per degree Celsius. This offset drift could be challenging in high accuracy applications and are not able to be calibrated out during early manufacturing.

The input offset drift in this research of HX711 chip is 0.2 mv at 128 INA gain and the input offset temperature drift is $\pm 6nv/°C$ at gain equal to 128. Beside the drift over temperature, the offset voltage of the amplifier's input can drift through time and can make significant errors through the life of the product. The Zero-drift amplifiers inherently minimize both the drift over temperature and time by continually self-correcting the offset voltage [8].

3.3 Advantages of a Programmable Gain Amplifier

The challenges to made a accurate differential amplifier by used discrete parts and got a gain accuracy or a good CMR performance and got matching of four external resistors that have been used to set up the op amp to a differential amplifier. Additional analysis explains that resistor tolerances could cause the CMR to vary from high limits of op amp to low as (-24,dBm) While integrated solutions boost on-chip resistor matching, generally there is remain issue for absolute matching with external resistors utilized to placed amplifier gain. This due to the tolerance between external resistor values and on-chip precision resistor values which can vary in about 30%. theother source of error is the thermal performance difference in between external and internal resistors; it is simple for the external and internal resistors to have reverse temperature coefficients. The programmable gain amplifier (PGIA) had solved this problem by having each of the resistors on board. This type of amplifier has a gain error (see Equation 3.12) less than 1% and offering regular trim capabilities of the order of ± 0.05% and ± 0.4% maximum across temperature [9].

$$GAIN_{ERROR} = \frac{GAIN_{EXPECTED} - GAIN_{MEASURED}}{GAIN_{MEASURED}} \quad (3.13)$$

3.3.1 ADC (Analog to Digital Converter)

ADC is an electronic integrated circuit that can transforms a signal from analog to digital form [22]. This could also be referred to as a quantizes. The basic ADC function is shown in Figure 3.4.

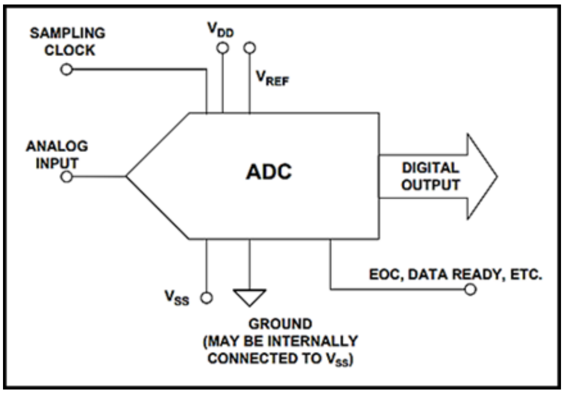


Figure 3.5 Basic ADC Function

The efficiency of how ADC digital number value approximates the analog value it dependence on the ADC resolution. The digital output of the ADC is binary number and the STM32 MCU translating and converting this binary to number in base10 or human format on monitor or display. The resolution of an ADC is specified in bits and determines how many distinct output codes (2^n) the converter can produce. For example, in this research a 24-bit ADC produces (2^24), or 16,777,216 output codes.

Thus, a 24bit ADC with a 5Vdc maximum input will resolve the measurement to the 5Vdc/16,777,216 = 0.29802µ V d c.

The accuracy of the ADC will determine how actual digital output is closed to digital output that expected theoretically for a given analog input.

The ADC resolution is generally chosen with respect to the full-range reading of ADC with avoid the respect for the measured value with any instant [9].

The resolution can be used to describe the general performance of an ADC while the effective resolution describes the useful bits from an Analog to Digital conversion with respect with the input noise. Effective Number Of Bits (ENOB) is often used to specify ADC effective resolution. ENOB is NOT the same as the actual resolution of the ADC [9, 10].

3.3.2 ADC Selection

The best ADC architecture that used for weigh scale requirements is sigma delta, because its high linearity and low noise at low update rates. Another benefit is that digital filtering and the noise shaping are carried out on-chip. The utilization in the high-frequency modulator forms the quantization noise making sure that the noise is pushed against one half of the modulator frequency. The digital will then make band-limits the response to a considerably lower frequency. This greatly minimizes the requirement for complex post-processing of the ADC data by the user [10, 12].

The ADC will need also to have a low-noise PGA along with high internal gain in order to magnify the small output signal out of the load cell. An integrated PGA could be optimized to provide low temperature drift, in comparison to a discrete amplifier of external gain resistors. Equipped with discrete settings, any errors caused by temperature drift can get amplified by using the gain stage. The HX711 Load Cell Amplifier type is mainly designed for applications of weigh-scale, it has a good noise specification about (50nV/rms) and have front-end gain stage of (128) maximum gain. The load cell can be straight interfaced to this ADC [9]. The block diagram of 24-bit HX711 ADC is shown in figure 3.5

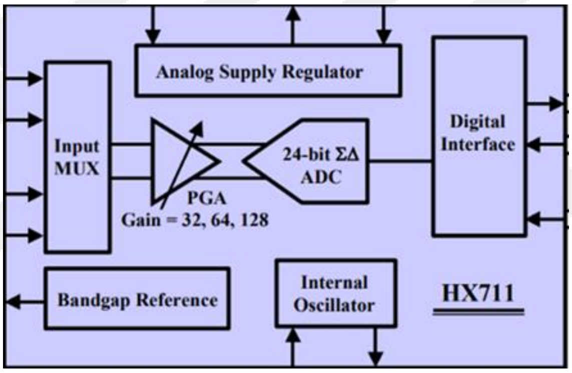


Figure 3.6 Typical HX711 weight scale ADC block diagram

3.4 The ARM Cortex-M3 Microcontroller

3.4.1 Introduction to Cortex-M3 Processor

The ARM Cortex M3 processor, is the first generation of the Cortex processors produced by ARM in 2006, it was mainly designed to work with the 32-bit microcontroller market. The Cortex M3 processor gives an excellent performance at low gate count and has many new features that previously available just in high-end processors[6].

Architecture of Harvard bus

- Three stage pipelines along with branch speculation
- Integrated bus matrix
- Nested vectored interrupt which is configurable
- NVIC controller
- Advanced configurable debug and trace
- Optional Components
- Requirements:
    - Wake-up Interrupt Controller (WIC)
    - Embedded Trace Microcells (ETM)
    - Memory Protection Unit (MPU)
    - Fault Robust Interface

The architecture of the ARM Cortex-M3 is shown in figure 3.7 below

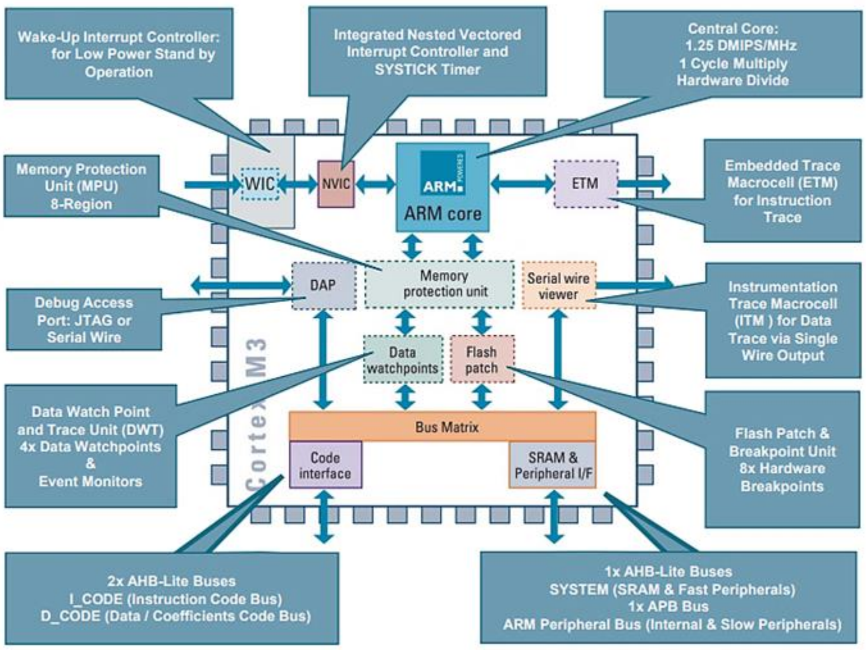


Figure 3.7 ARM Cortex-M3 architecture

High Performance

- High efficiency processor core – 1.25 DMIPS/MHz
- Advanced instructions for data manipulation
- Bit Field Manipulation
- Hardware Division
- Single Cycle Multiply
- Exceptional performance at low frequency

The comparison in performance between ARM family processors shown in figure 3.8

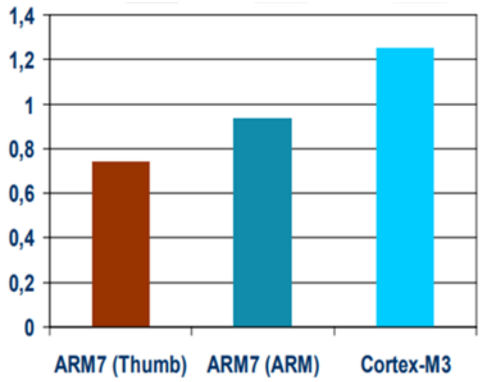


Figure 3.8 Relative DMIPS/MHz

Excellent Code Density

- Thumb2 Instruction Set Architecture (ISA)
- Optimized applications for performance and code size
    - 32-Bit code performance
    - 16-Bit code density
- No interworking required between code objects

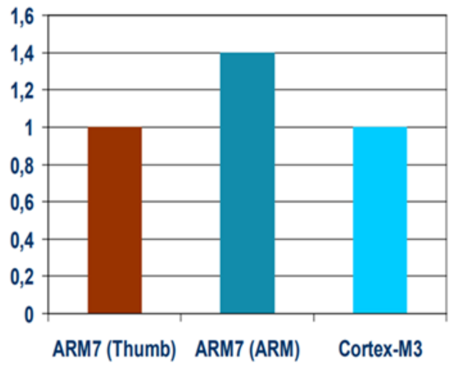


Figure 3.9 Relative Code Size

• Cortex-M3 features architected which supports the sleep states

- Involves a Wake-Up Interrupt Controller (WIC), which is very low gate count
- Allow standby operation with ultra-low-power
- Essential for expanded life battery depending applications

3.4.2 STM32F103 Microcontroller

The STM32F103 is a family of micro-controllers [25, 26]. The STM32F103 microcontrollers are based upon the Cortex-M3. The STM32F103 is a high-performance ARM CortexM3 32bit RISC core operating at a 72MHz frequency, high-speed embedded memories (which is the Flash memory up to 128Kbytes and an SRAM up to 20Kbytes), and a range of I/Os and also have peripherals that connected to two APB buses. The STM32F103 offer two 12bit ADCs, three general purpose 16bit timers plus one PWM timer, in addition to advanced and standard communication interfaces: up to 2 SPIs and I2Cs, 3 USARTs, CAN and USB[6]. The STM32F103 comes with six different packages types from 36 pins to 100 pins.

Table 3.1 STM32F103xx device features and peripheral counts

Peripheral		STM32F103Tx		STM32F103Cx		STM32F103Rx		STM32F103Vx	
Flash - Kbytes		64	128	64	128	64	128	64	128
SRAM - Kbytes		20		20		20		20	
Timers	General-purpose	3		3		3		3	
	Advanced-control	1		1		1		1	
Communication	SPI	1		2		2		2	
	I^2C	1		2		2		2	
	USART	2		3		3		3	
	USB	1		1		1		1	
	CAN	1		1		1		1	
GPIOs		26		37		51		80	
12-bit synchronized ADC Number of channels		2 10 channels		2 10 channels		2 16 channels(1)		2 16 channels	
CPU frequency		72 MHz							
Operating voltage		2.0 to 3.6 V							
Operating temperatures		Ambient temperatures: -40 to +85 °C / -40 to +105 °C Junction temperature: -40 to + 125 °C							
Packages		VFQFPN36		LQFP48, UFQFPN48		LQFP64, TFBGA64		LQFP100, LFBGA100, UFBGA100	

1. On the TFBGA64 package only 15 channels are available (one analog input pin has been replaced by 'Vref+').

3.5 Bluetooth radio model

The HC-05 module is the serial port protocol (SSP) Bluetooth that is easy to use. The CSR Bluecore 04-Externa single chip Bluetooth system has a CMOS technology and with an Adaptive Frequency Hopping Feature (AFH). This feature gives a very highly immune and secured transmission system to protect against noise and jamming signals [27].

The Bluetooth module is used to transport weight data from the medical scale to the smartphone.

Figure 5 shows the HC-05 Bluetooth radio module.

Figure 6 shows the UART interface between the Bluetooth module and STM32 MC

Figure 3.10 HC-05 Bluetooth radio module

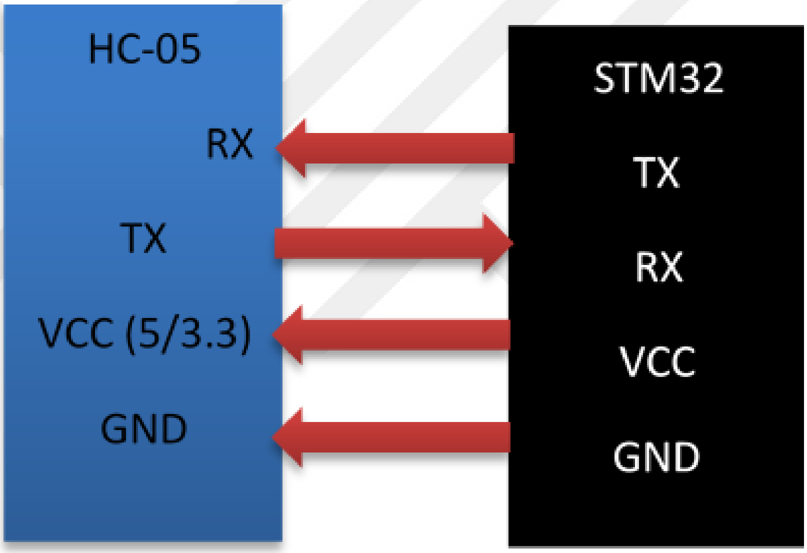


Figure 3.11 UART interface between Bluetooth module and STM32 MCU.

3.6 The open-source Arduino Software

IDE is the software application that makes it easy to code an algorithm and upload it to the board [28]. The software runs on different operation system such as Windows, Mac OS X, and Linux. The sentence structure, or the words and structure of the code, is like Java, C or C++ [29]. The Arduino software (both versions 1.6.12 and 1.6.13) includes a driver for the STM32 board.

Figure 3.12 shows the STM32 firmware block diagram of the algorithm used to design the software system.

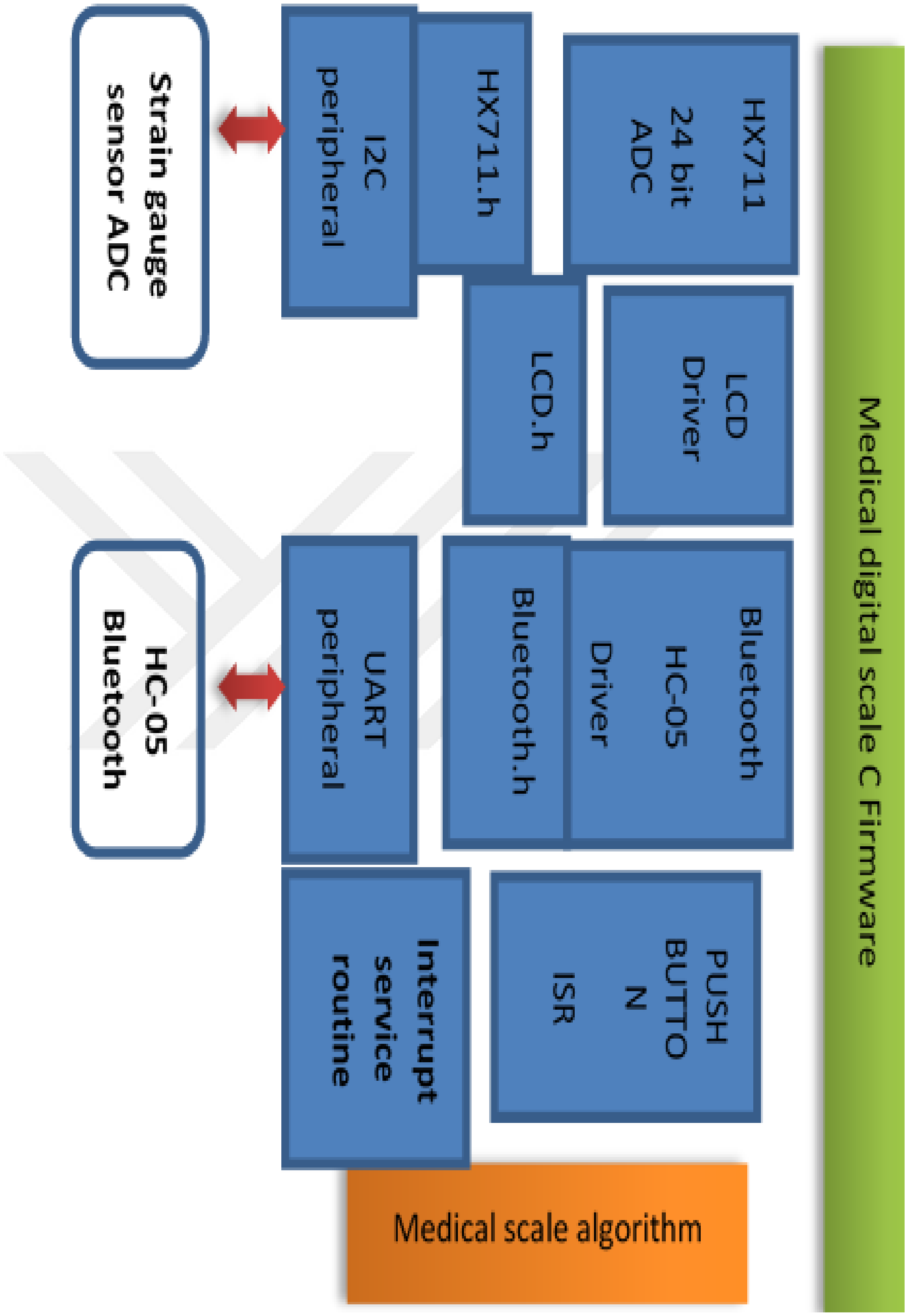


Figure 3.12 STM32 firmware block diagram

CHAPTER 4

HARDWARE AND SOFTWARE IMPLEMENTATION OF DIGITAL WEIGHT SCALE SYSTEM

4.1 Digital Weight Scale System Design

The demand of high performance of modern digital medical weight scale in these days has increased and become very important. The traditional weight scales design and components does not meet the requirements of these times and days. The modern requirements of these days are high accuracy weight scales, low power, high resolution, easy to use, light weight portable scale and an interactive with smart phones and tablet. And according to these requirements above this research designed the digital medical weight scale and implemented. The block diagram of digital weight scale is show in figure 4.1 The schematic diagram of the overall on weight scale system in based shown in figure 4.2

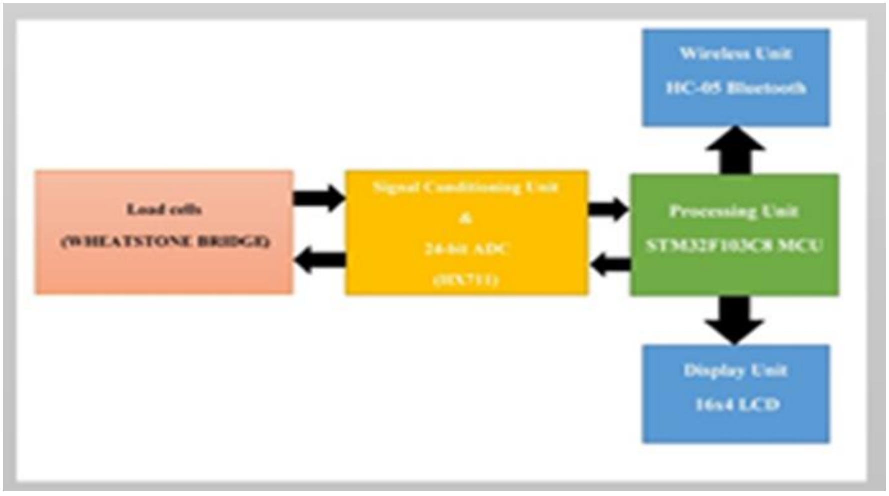


Figure 4.1 Digital weight scale

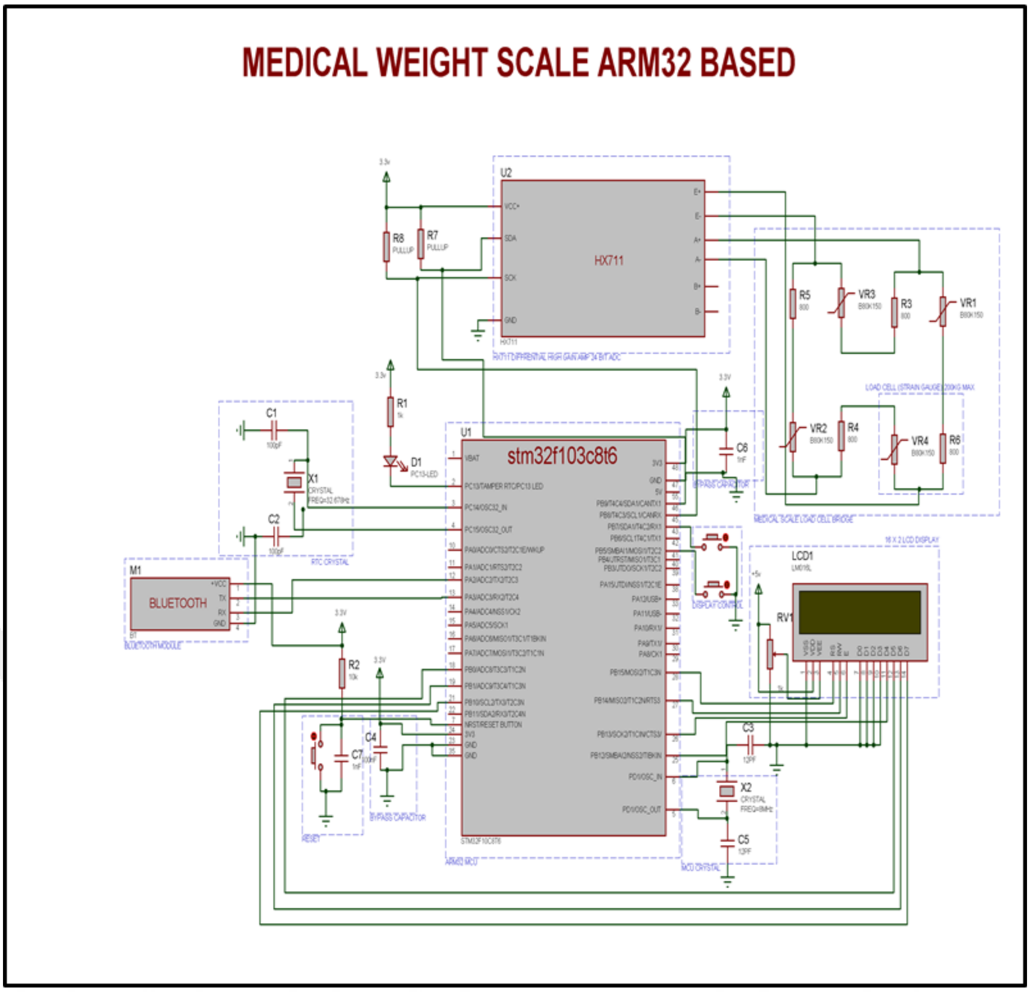


Figure 4.2 Digital medical weight scale hardware schematic diagram.

When designing a digital weight scale that reads and shows the body mass index (BMI) for the fitness or weight to digital electronic data. This data was then read by a microcontroller which translates it to visual data, so it could be displayed on LCD screen or sent to smart phone the transducer used to convert the patients weight to physical electronic signal which is called a load cell or strain gauge.

4.1.1 Mounting the load cells

According to the mechanical and theoretical design requirements such as four load cell sensors Wheatstone bridge and the balance of human body force on the scale to get load cell reading accuracy, the design required mount the four load cells in the corners of weight scale platform plate to offers higher strain levels with relatively low forces. The size dimension of weight scale platform is 30cm and the platform area is 900cm^2 and the position of each load sensor is 1cm from to edge and 1.5cm from side edge.

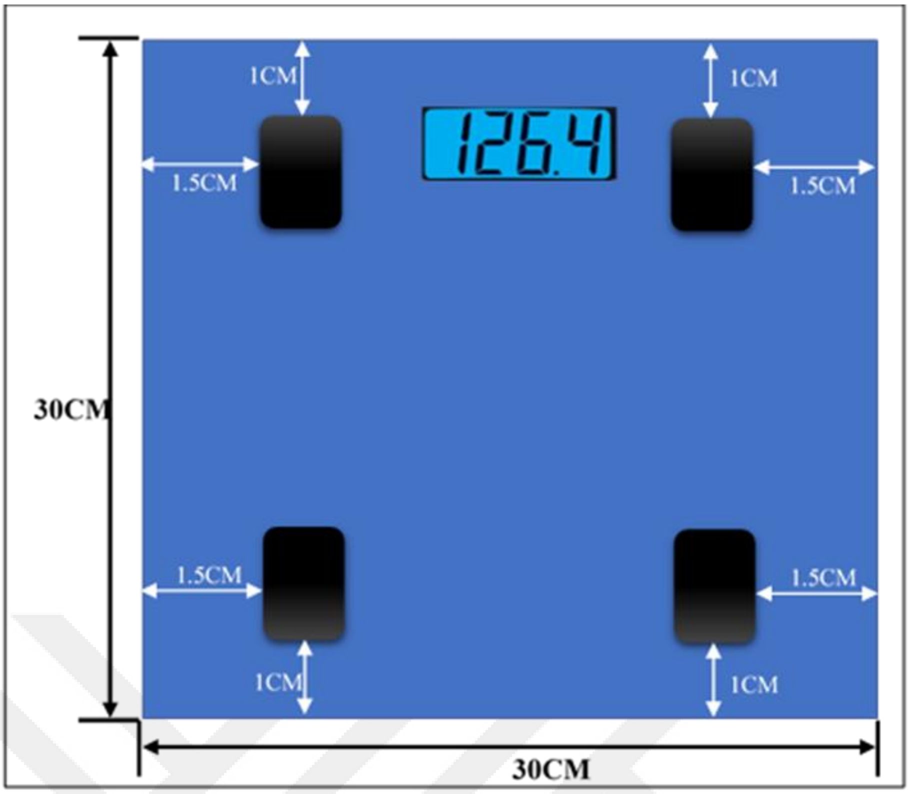


Figure 4.3 Load cells mount diagram

4.1.2 Load cells bridge circuitry

The principle of load cells bridge electrical connection is Wheatstone bridge. According to the theory analysis of Wheatstone circuit in chapter three the load cells connected, each single strain gauge sensor has three wires with colors white, red, blue and figure 4.4 shows the single strain gauge wires. So, these colors not standard color coding every manufacture produces the strain gauge with different wire color code. After test the strain gauge terminals by digital multimeter (DMM) for all sensors the connection with each other done. The connection of the load cell sensors in Wheatstone bridge can be illustrated in figure 4.5 The HX711 has on-chip power regulator thus, this bridge not need external stable power regulator. The sensitivity of this circuit (the full-load output ratio to the excitation voltage) is 2mV/V. With 5V excitation voltage and sensitivity 2mV/V the bridge output voltage is 10mV.

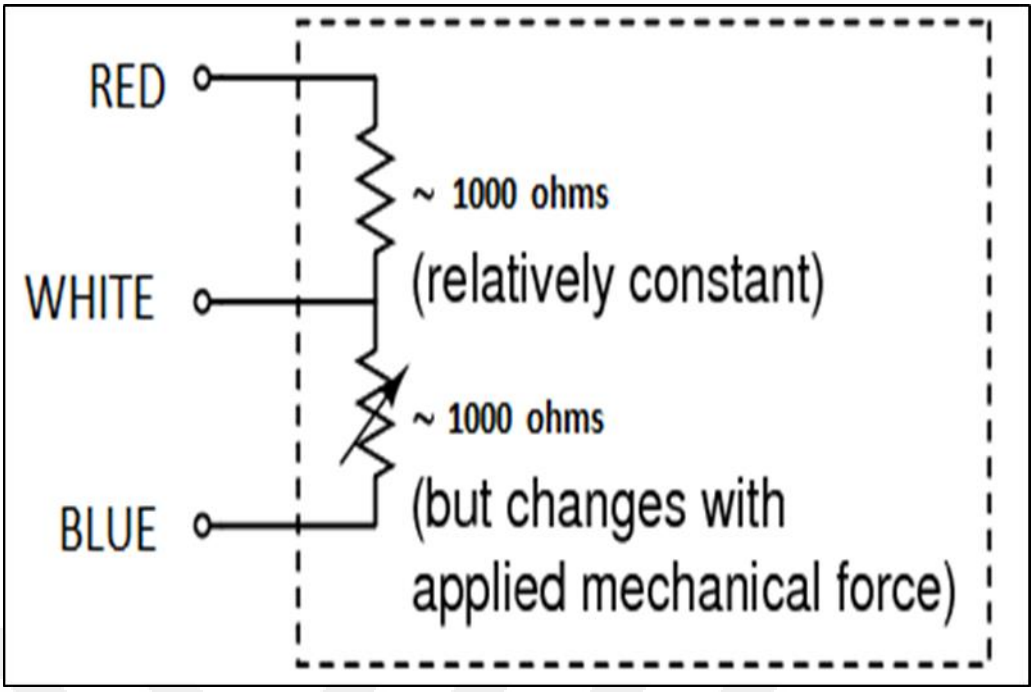


Figure 4.4 Single strain gauge wire terminal

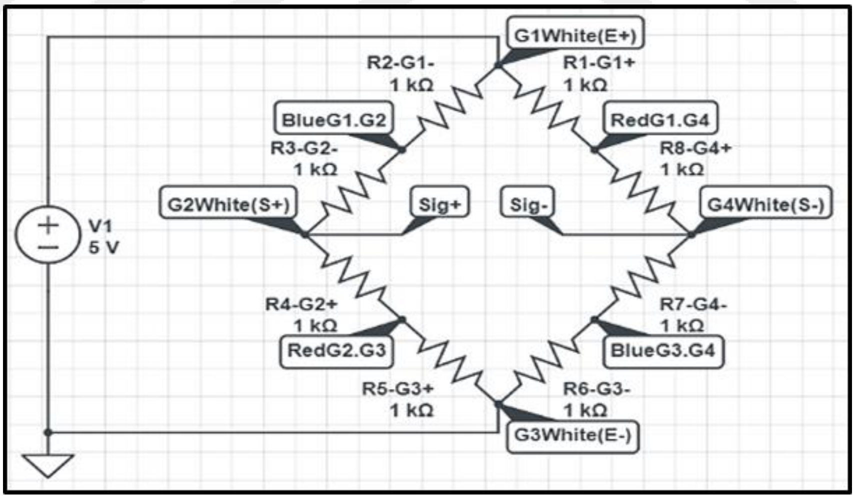


Figure 4.5 Wheatstone bridge strain gauge connection diagram

4.2 Designing the PGA and ADC circuitry

4.2.1 Programmable Gain Amplifier circuit

The PGA and ADC circuit of this research are single chip PGA and 24-bit ADC (HX711) technology based on Avia Semiconductor's patented. The output terminal of the Wheatstone bridge load cells (resistive bridge) (S+, S-) connected directly to the PGA differential input of HX711 (INA+, INA-) without any external component and with 128 gain because the resistive bridge connected to channel A differential input and this gives the design low noise and small size performance. The power supply range of this circuit is (2.7-5.5) volt dc. This circuit provides stable power supply voltage to load cell bridge through on chip power supply regulator. The schematic diagram of INA and ADC of this research is shown in figure 4.6. The ADC circuit provides the conversion weight value to the STM32 MCU through simple digital Synchronous serial interface (SSP) by two pins (DOUT, PD_SCK) with selectable bit rate 10SPS and 80SPS.

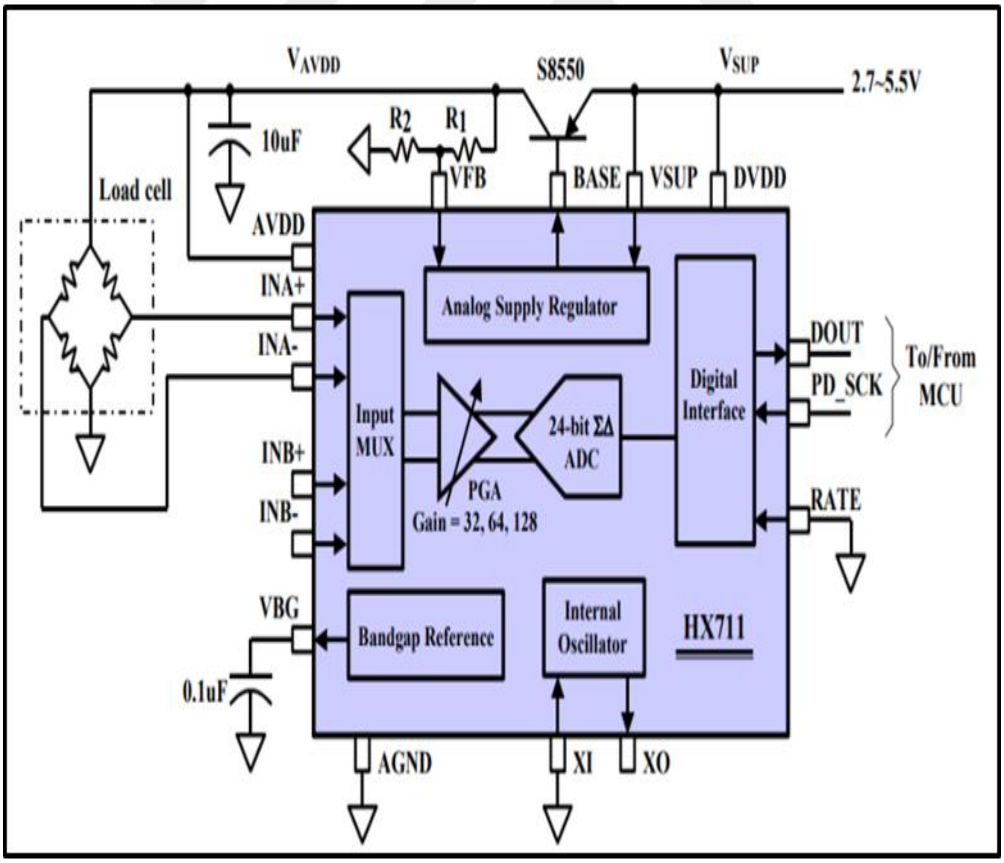


Figure 4.6 INA and 24-bit ADC Schematic diagram

4.2.2 The PGA and ADC circuit features

- Two input channels with selectable differential.
- ADC analog power supply with built-in power supply regulator for load cell.
- Built-in power-on-reset.
- Built-in active low noise PGA that have a selectable gain of 32, 64 and 128
- Built-in oscillator without need to external component, which have an optional external crystal.
- Simple serial interface and digital control, which have pin-driven controls with no needed for programming
- Selectable output data rate of 10 SPS or 80 SPS.
- Simultaneous supply rejection of 50 Hz and 60Hz.
- Supply voltage operate in range between 2.6 ~ 5.5V.
- Current consumption involves built in analog power supply regulator. It is normal operation is less than 1.5mA and the power down less than 1uA
- The operation temperature is in range between -40 up to +85℃

4.2.3 The 24-Bit ADC (HX711) Pin Description

Table 4.1 HX711 Pin Description

Pin #	Name	Function	Description
1	VSUP	Power	Regulator supply: 2.7 ~ 5.5V
2	BASE	Analog Output	Regulator control output
3	AVDD	Power	Analog supply: 2.6 ~ 5.5V
4	VFB	Analog Input	Regulator control input
5	AGND	Ground	Analog Ground
6	VBG	Analog Output	Reference bypass output
7	INA-	Analog Input	Channel A negative input
8	INA+	Analog Input	Channel A positive input
9	INB-	Analog Input	Channel B negative input
10	INB+	Analog Input	Channel B positive input
11	PD_SCK	Digital Input	Power down control (high active) and serial clock input
12	DOUT	Digital Output	Serial data output
13	XO	Digital I/O	Crystal I/O
14	XI	Digital Input	Crystal I/O or external clock input, 0: use on-chip oscillator
15	RATE	Digital Input	Output data rate control, 0: 10Hz; 1: 80Hz
16	DVDD	Power	Digital supply: 2.6 ~ 5.5V

4.2.4 The 24-Bit ADC (HX711) Module Circuit diagram

The 24-Bit ADC (HX711) Module Circuit and connection diagram are shown in Figures 4.7 and 4.8

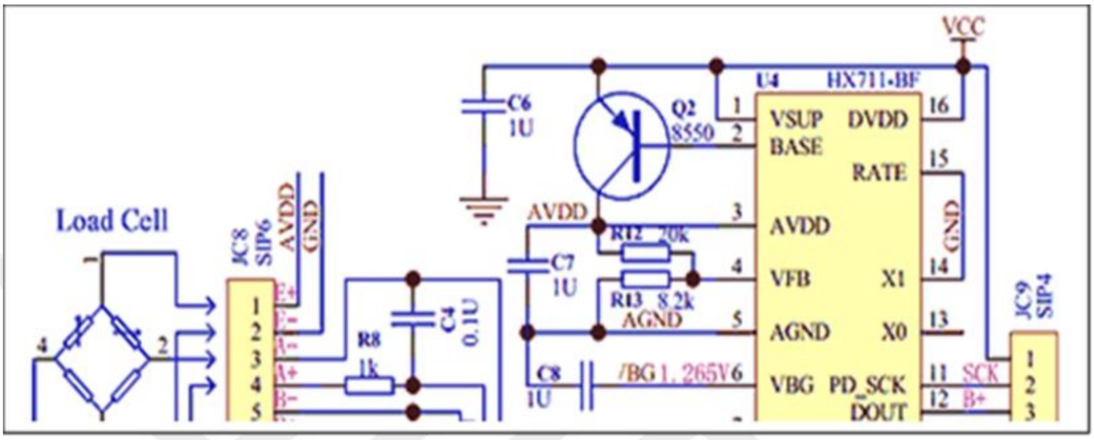


Figure 4.7 Module Circuit of HX711.

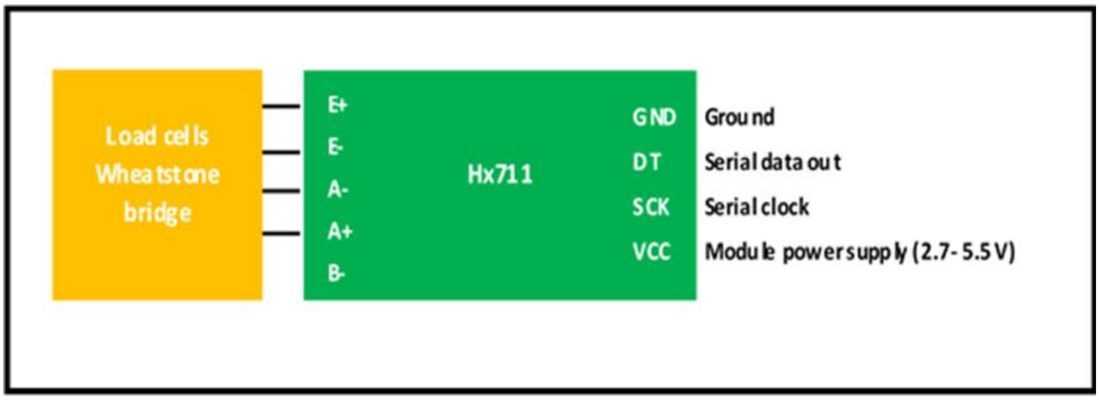


Figure 4.8 Load cell with HX711 connection diagram

4.3 The Analog to Digital converter unit

The analog to digital 24bit chip receives the analog adjusted load cell bridge signal and converts it to an equivalent 24bit binary and it's in 2's complement data format. The output data rate of the ADC related to the RATE pin when this pin pulls to high level the output data rate is 80SPS and where this pin pulls down to low level the output data rate is 10SPS. In this research the output data rate is 10SPS configuration. The procedure of analog load cell differential signal to digital conversion start When HX711 is powered up, built-in power on rest circuitry that can using to reset the chip. And the chip working mode control is through PD_SCK pin, when this pin is low state the chip in normal working mode and when this pin is high state the chip in power down mode. After the rest of on chip power on rest the STM32 MCU return the chip rest to verify the conversion work then when serial data output pin (DOUT) state is low that mean the 24-bit ADC is ready to convert and the STM32 microcontroller read this state always before generate the clock pulses, After STM32 microcontroller gets DOUT state low and PD_SCK in low state it generates 25 positive clock pulses and sends it over clock pin (PD_SCK) to shift out the conversion data on DOUT pin and each pulse shift out 1bit, that start with the MSB bit at first, and continues until all 24bits are shifted out. To make the ADC work in 128 gain the clock pulses should be 25 pulses 24 pulses to shift out the 24 bit of conversion vale and the 25th pulse at PD_SCK input have to pull DOUT pin back to high as shown in figure 4.9

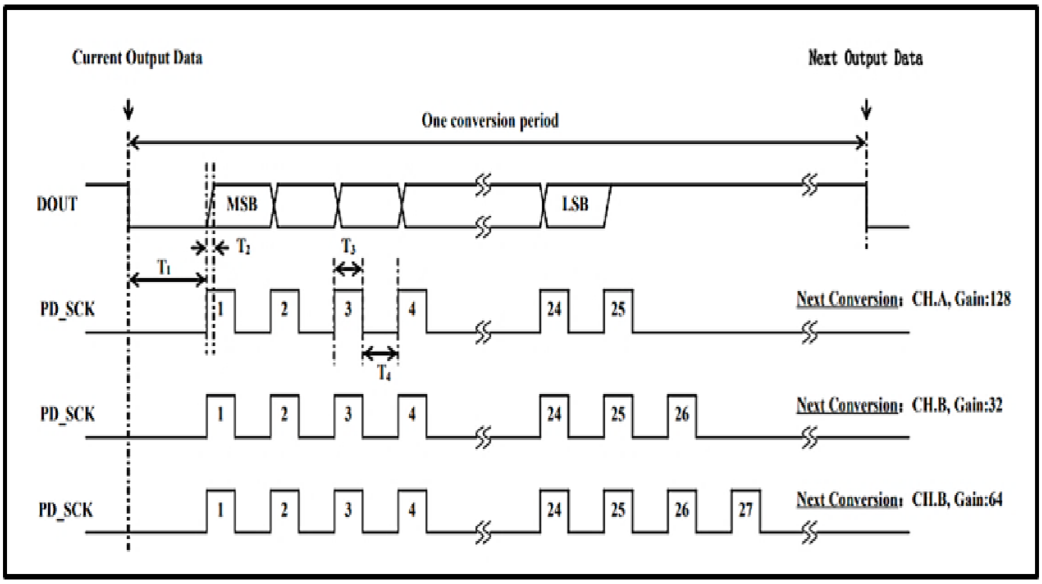


Figure 4.9 Output data, the gain and input selection timing control

The STM32 MCU rests the HX711 chip by changing the input PD_SCK pin from low to high for longer than 60 μs, then the HX711 enters in power down mode after that the STM32 MCU pulls down the PD_SCK pin to low state to return the chip to working mode. After a rest or power down event, the input selection has default to Channel A with a 128 gain.

4.4 Designing the microcontroller circuitry

The microcontroller circuit was designed according to the weight scale system requirement like receive ADC data, display the weight values on LCD, send/receive data to/from Bluetooth wireless radio and read keypad state. The schematic diagram of the microcontroller circuit has designed using Proteus 8 suite software. Figure 4.10 shows the digital STM32 microcontroller schematic diagram.

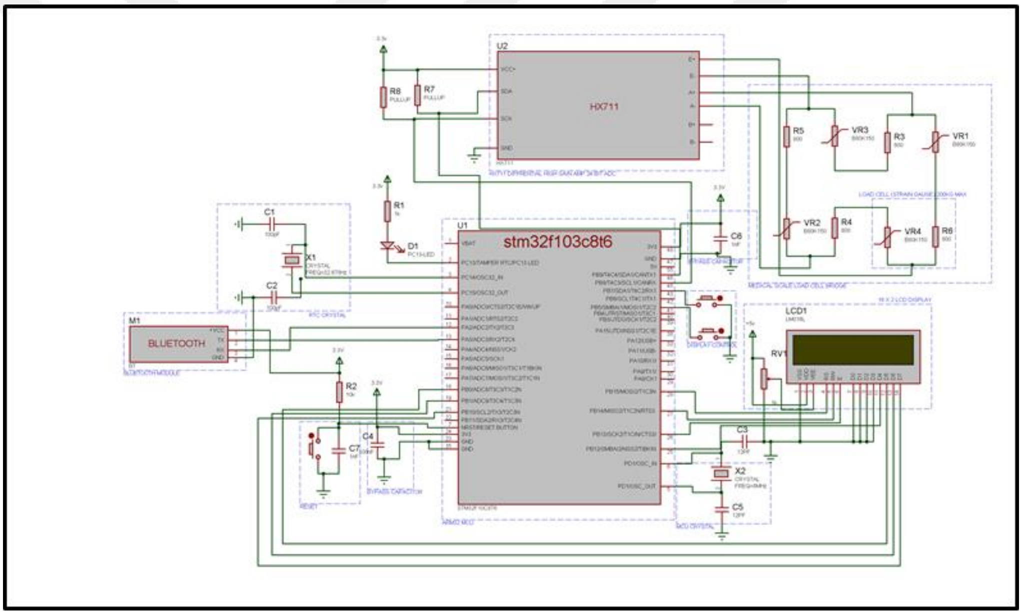


Figure 4.10 digital stm32 microcontroller schematic diagram

The STM32 MCU circuit consists of oscillator circuit, rest circuit, boot, led indicator, step-down regulator, header connector, J-Link header and USB micro connector. Figure 4.11 shows the STM32 MCU schematic diagram of breakout board. The STM32 MCU oscillator circuit is constructed from 8MHZ crystal oscillator and two 20PF load capacitors connected in parallel with crystal pins and the second pins of capacitors connected to ground, these capacitors important for resonance frequency matching. And real-time clock (RTC) crystal 32.678KHZ to generate time pulses to

STM32 MCU with two 20PF load capacitors also connected in parallel on crystal pins and the other pins connected to ground. The crystal oscillator circuit function is to generate clock pulses required for the synchronization of all the internal operations. The oscillator circuit is shown in figure 4.12

The rest circuit consists of 10KΩ resistor connected to 3.3V VCC from first pin and in series with 1µF capacitor from second pin and push button switch in parallel with the capacitor to the ground. Figure 4.13 shows the rest circuit.

The rest circuit function is to restart the STM32 MCU operation manually by switch and automatic by RC circuit. The boot circuit has been constructed from 3x2 header jumper with pull up and pull down resistor to pull up and pull down the BOOT1 and BOOT0 pins. In order to put the STM32 MCU in programming mode it should put the jumper of boot1 in high state and put thee jumper of boot0 to low state. For operation mode the boot1, boot0 should put it on low state. The function of BOOT header to control the STM32 modes manually.

The step-down regulator steps down the USB power voltage from 5V to 3.3V to supply the STM32 MCU. The step-down regulator is keeping the input and out voltage of circuit stable, it constructed from RT9193 chip that constructed from low drop out (LDO), ultra-low noise and two coupling capacitor filter 1µF to. The maximum output power rate of step down regulator circuit is 300ma and 3.3V. The LDO regulator circuit is shown in figure 4.14

The (Light emitting diode) led indicator circuit consists of two led parts and 510Ω current limiter resistors to protect the diode from damage. The first led is connected between 3.3V VCC and ground to light up when MCU circuit get supply. The second led is connected to the pin 13 (PC13) of port C and this led is active low. Figure 4.15 shows the LED circuit.

The J-Link header is 4x1 through hole header for STM32 programming connection. The first pin of J-Link is 3.3V VCC and the second pin is SWDIO serial data input/output program pin. The third pin is SWDCK serial clock program pin. The last pin is GND ground. Figure 4.16 shows the J-Link details.

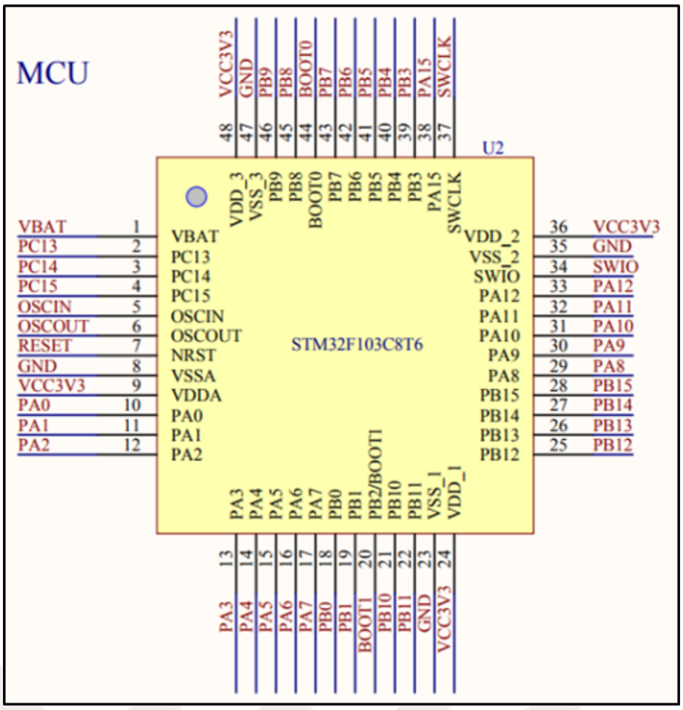


Figure 4.11 STM32 MCU breakout schematic

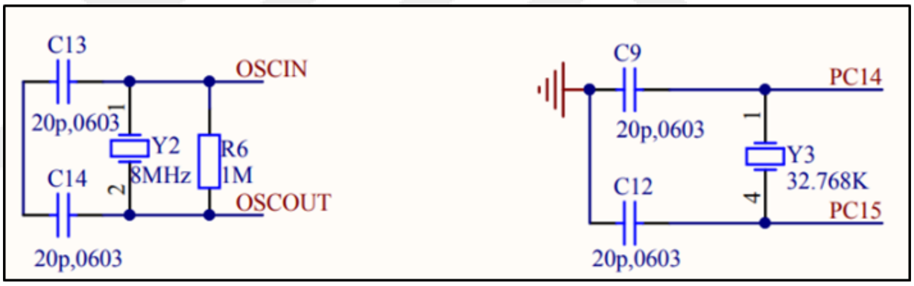


Figure 4.12 Schematic of Crystal Oscillator

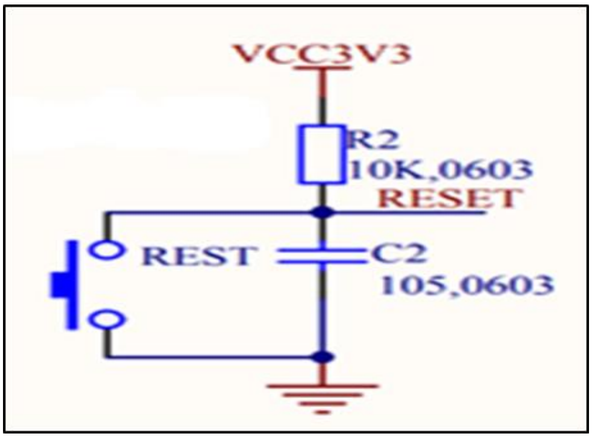


Figure 4.13 Reset circuit

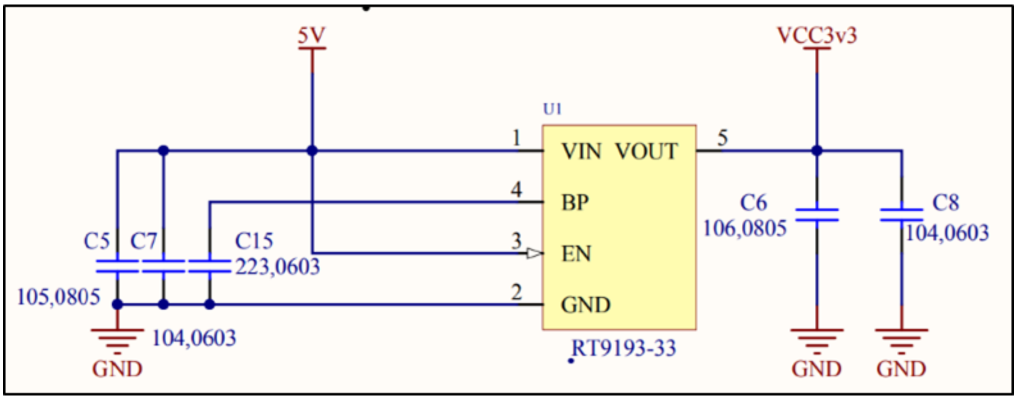


Figure 4.14 Low Drop Out voltage regülatör

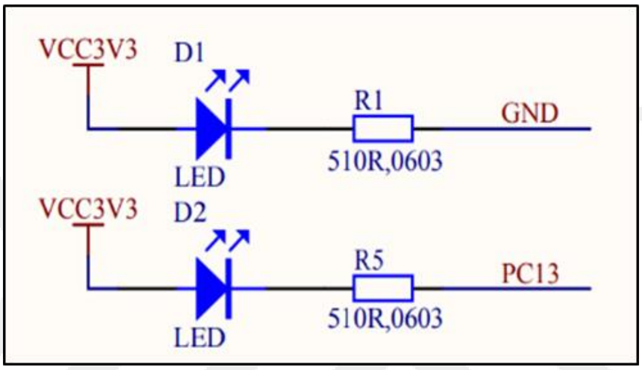


Figure 4.15 LED indicator circuit

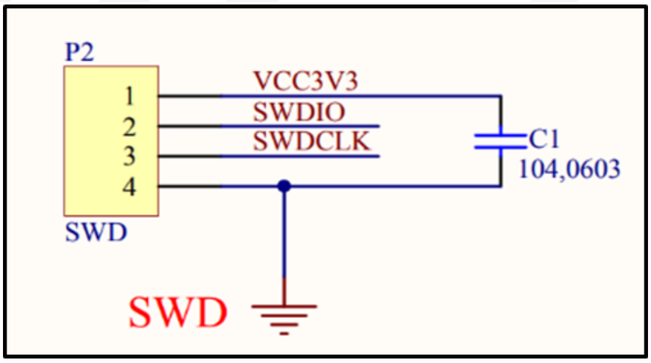


Figure 4.16 J-Link program header

The STM32 MCU is connected with HX711 ADC through the I2C1 hardware module pins. The DOUT pin of HX711 is connected to SDA (PB8) of STM32 MCU and pin PD_SCK of HX711 is connected to SCL (PB9) of STM32 MCU. The synchronous serial protocol is used between STM32 MCU and HX711 ADC.

The 16x4 LCD is connected with STM32 MCU in 4-Bit parallel mode and the pins assignment is shown in the table 4.2

Table 4.2 LCD STM32 pins assignment

#LCD PIN	FUNCTION	STM32 MCU PIN
1	VSS (GND)	GND
2	VCC(5V)	------
3	Contrast Adjustment	------
4	RS	PA0
5	R/W	PA6
6	EN	PA1
7	DB0	GND
8	DB1	GND
9	DB2	GND
10	DB3	GND
11	DB4	PA2
12	DB5	PA3
13	DB6	PA4
14	DB7	PA5
15	BK led A (+)	VCC
16	BK led K (-)	GND

The hardware interface of HC-05 Bluetooth module is asynchronous serial interface through full duplex communications pins transmit and receive pins. The STM32 MCU sends the RS232 data protocol over hardware serial module PA9 and receives the RS232 data protocol over hardware serial module PA10 with baud rate 9600 Bit Per Second(bps). Figure 4.17 shows the HC-05 Bluetooth module STM32 MCU connection diagram.

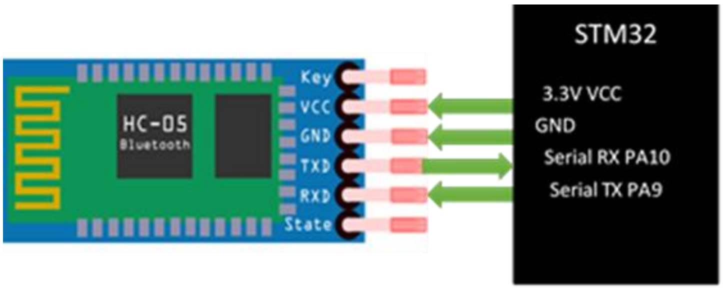


Figure 4.17 HC-05 Bluetooth module STM32 MCU connection

The keypad consists of two push buttons switch with pull ups resisters. One switch for save weight values and the second for display storage weight values.

4.5 System Software Design

The system firmware was written in simple C++ language using Arduino IDE compilation software and Maple mini boot loader and driver. The software design of weight scale system has beenmade through Arduino basic structure. The basic structure of Arduino programming language the entire code is given in appendix D. The main firmware program of weight system is consisting of two main structure of functions setup and loop. These two required parts or functions enclose blocks of statements as shown below.

Variable declaration

void setup ( )

{

Statements;

}

void loop ( )

{

Statements;

The variable declarations should be progress of setup ( ) function at the beginning of program. The setup ( ) function is preparation function and should follow the variables declarations and setup ( ) function is run only once. It has been used to set the hardware modes such as setup pin mode or initialize serial communication. The setup ( ) function will requested as program starts.

The loop ( ) function is execution function and its necessary for program to work. It's the core of Arduino program and should be come after setup ( ) function and follows next and includes the code to be executed continuously.

The whole system software consisting of HX711 driver header file, EEPROM header file, LCD, and HC-05 Bluetooth module driver header file. Figure 4.19 shows the medical weight scale software block diagram.

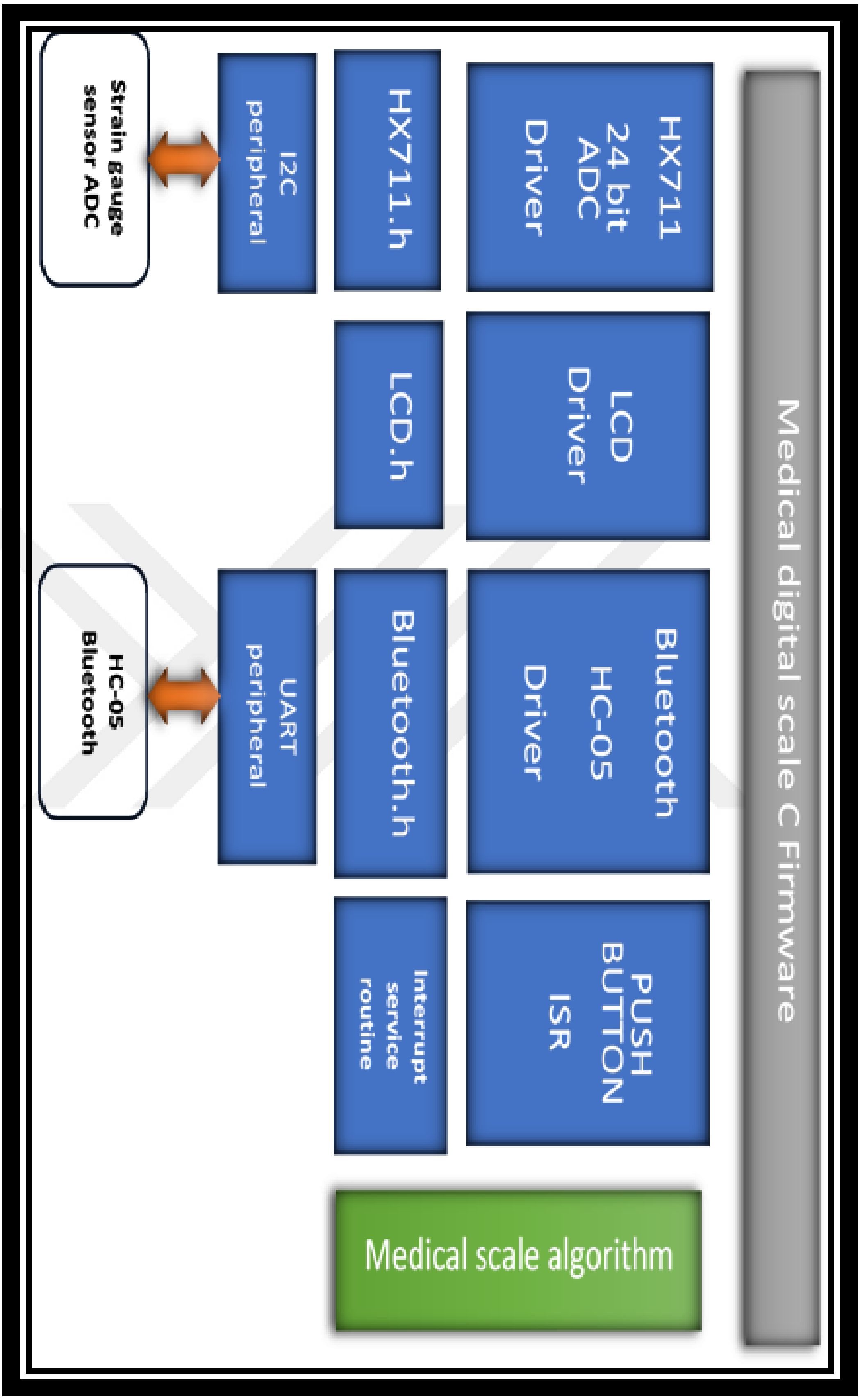


Figure 4.18 STM32 MCU weight scale software diagram

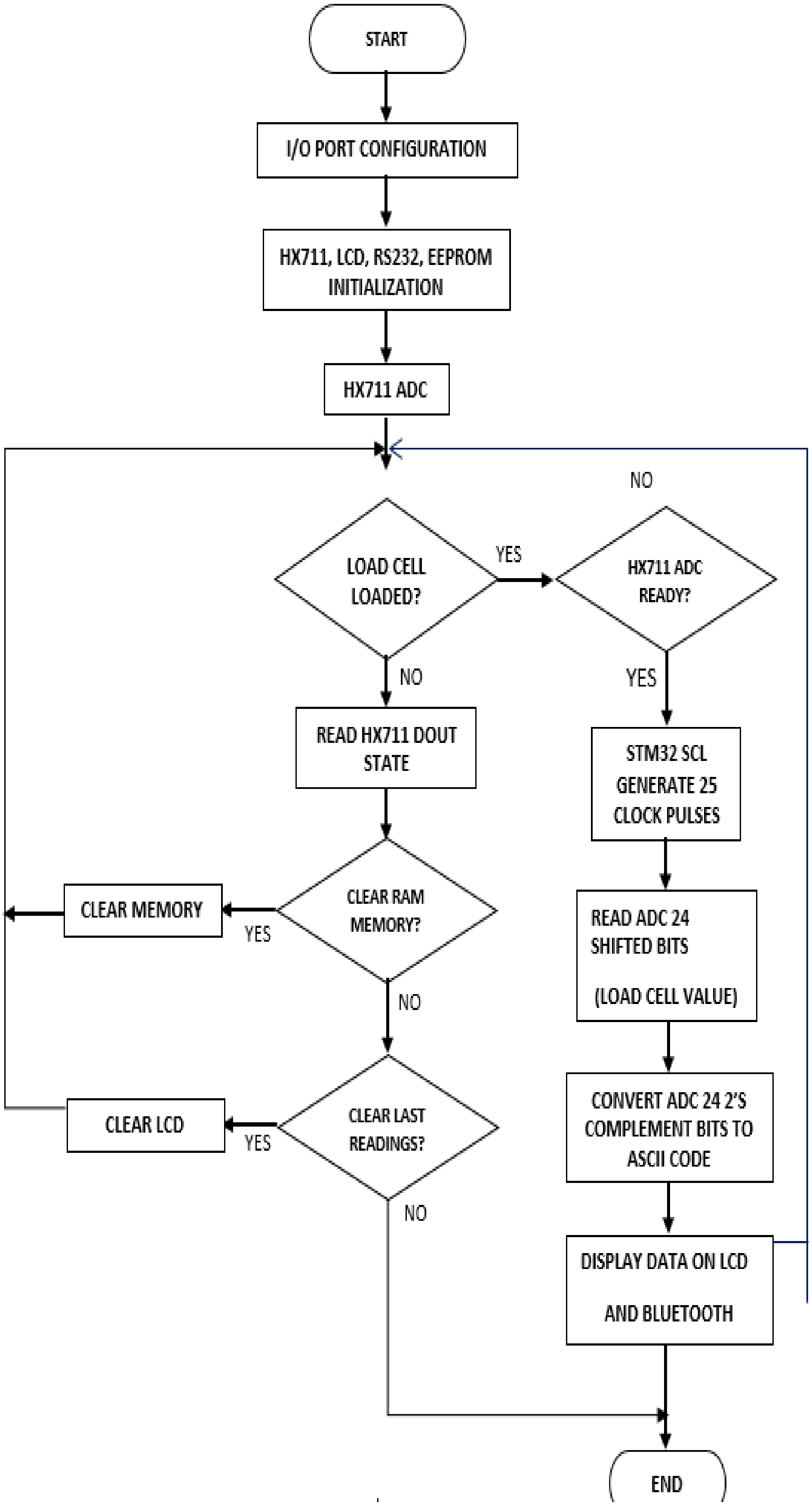


Figure 4.19 Flowchart for the proposed digital weight scale

4.6 Main Program

This program has the setup ( ), loop ( ) function, variables declaration, and library driver directives.

4.6.1 Initialization

This part of software performs initialization for IO ports, HX711, LCD and Bluetooth module when the system get power supply and activation. The IO port initialization mean setup which pin will be output and which pin will be input. And by using (HX711 scale ( )) function define the interface pins between STM32 MCU and HX711 and the pins should be SSP hardware module. RS232 serial TTL port initialization is being through (Serial. begin(9600)) function by set the RS232 baud rate communication to 9600bps. Then LCD initialization and here the (lcd.begin (20, 4)) function will initialize the interface to the LCD , and specifies the dimensions (width and height) of the display.

The HX711 initialization is done through the (HX711::begin(byte dout, byte pd_sck, byte gain)) function and define the DOUT , PD_SCK pins as input/output and set the gain level. And the (tare(byte times = 10)) subroutine is initialize the weight scale to zero weight by read the offset value of scale with no load and subtracted this value. And set the calibration factor for the system.

4.6.2 HX711 ADC Read

It’s the management subroutine for HX711, the functions included in this subroutine are defined in HX711 header file and those functions support ADC status, read the out raw data, convert the raw data to ASCII code, read offset value of scale, put ADC in power mode and power up.

4.6.3 LCD Display Subroutine

This subroutine of main software is an LCD control subroutine. Upon the initialization of the LCD there are functions to move the cursor on screen, clear screen, displays title, displays the ADC values in decimal format.

4.6.4 Bluetooth and RS232 Subroutine

This subroutine of main software is Bluetooth serial data control subroutine after the initialization of RS232 port and protocol baud rate. This subroutine functions send the weighted values to the Bluetooth radio module and the UART module in two units kilograms and pounds.

4.6.5 Uploading the Compilation File to STM32 MCU

The main program has been written by used open-source Arduino Software (IDE). After compilation step and checked errors, the generated binary file has been saved and then uploaded from computer to the ROM of STM32 MCU by used RS232 to USB adapter module. This program makes the STM32 MCU ready to work and implement the functions and algorithms. Figure 4.21 shows the uploading of binary file to STM32 MCU.

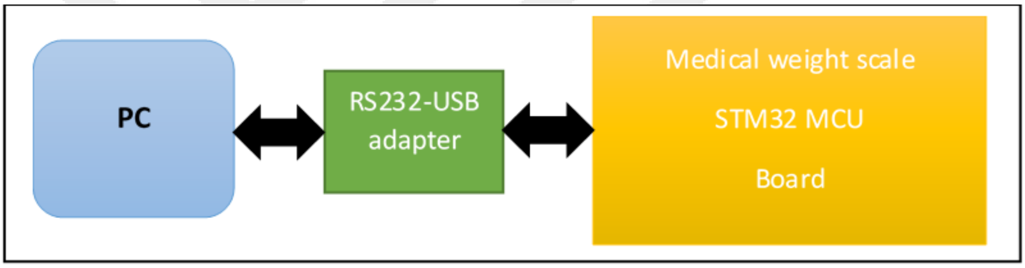


Figure 4.20 STM32 MCU binary file uploading

4.7 Testing the System

4.7.1 Testing the Load Cell

The experiment test for load cell Wheatstone bridge has been done by using digital multimeter (DMM) with resistance test mode which has been done by putting the DMM probes on the bridge output terminals S+, S- and powering off the bridge. The DMM has been used to measure the load cell bridge at zero balance (no load) and then change the load size. The test result of each single gauge's strain shows that the the resistance between the white and red wires is 1kΩ and the resistance between white and blue is 0.99kΩ while the resistance between blue and red wires is 1.99kΩ. The Wheatstone bridge output resultant resistance between S+ and S- is 1.99kΩ with zero balance (no load) and 2.009kΩ with load.

When powering the load cell bridge with 5V dc between E+ and E- the bridge output voltage is 0.3mV at zero balance (no load) and the bridge output voltage is 0.9mV at 13.4kg load as shown in figure 4.22 below.

Figure 4.21 Load cell bridge output voltage test

4.7.2 On-Chip Power Supply Test

The power supply voltage test has been carried by using fluke DMM with DC voltage test mode and by applying the voltmeter probe (red) on the VCC of the STM32 MCU pin and the common probe (black) on the ground of the STM32 MCU pin.By repeating the above test for HX711 ADC chip, LCD module and Bluetooth module. The voltage test showed that STM32 and Bluetooth are operating at 3.3v and HX711ADC and LCD are operating at 5v.

CHAPTER 5

TEST RESULTS AND DISCUSSION

5.1 The load cell resistance test

By using Fluke DMM with resistance test mode on the input and output the resistance measured of input and output of each single load cell is 1kΩ and 0.98kΩ respectively. As outlined by load cell datasheet from the manufacturer, these resistances are 1k ±50Ω and 1k ±50Ω respectively. And the measured resistance between blue and red wires is 2kΩ at zero balance according manufacture datasheet. The measured resistance for bridge output between S+ and S- terminals is 1.99KΩ at zero balance. These measurements have been done with bridge powering off.

5.2 Bridge Output and Input Voltage

The bridge power measurement result that is the bridge output voltage is 0.3mV at zero balance (no load) on the platter of scale and 0.9mV at 14.3kg platter loading. The test results show that the excitation dc voltage (E+ and E-) are in-between 5V this mean the system is stable without any ripple signal.

5.3 Bridge Offset Voltage

The bridge offset measured voltage is 0.3mV when no load on weight scale platter (zero balance) and the excitation voltage is 5V dc.

5.4 Calibration

The calibration operation of weighing scale is very important to overcome the error that would be produced at the output of the scale due to offset voltage of the Wheatstone bridge no load case and temperature drift offset which deviates the output of the bridge from zero value in the case of zero load or balance condition. In this research the calibration has been done by used STM32 MCU software procedure only (because of using on-chip PGA ADC there not have hardware calibration). In software calibration, the correction factors have been stored within nonvolatile memory

EEPROM in the computer or in data acquisition system and have used to compute the correct digital value depending on the readings from the ADC. However, the ADCs are factory calibrated prior to shipped, but operating temperature and time can change the settings. The ADCs will need to recalibrate often after one year according to manufacture calibrate certificate, Calibration methods vary, but all generally need a stable reference source with known weight loads. After calibration the offset value of scale is zero with zero load and ADC gain is 128 with full excitation voltage 5V. The output weight scale value after calibration is zero kg, zero pound with no load.

5.5 Number of Main ICs

The number of on-chip ICs used in weight is related to the application and the option offers. The developed digital medical weight scale uses an STM32 microcontroller based on-chip PGA ADC. The Wheatstone bridge uses the on-chip regulator power supply to provide excitation voltage and the system has built in RAM and ROM memory inside the STM32 MCU not need external RAM, ROM and EEPROM like using microprocessor unit. And regarding analog part the using of on-chip PGA INA is reduce the noise level and gain error with board size.

5.6 Results and Discussion

The medical weight scale can work as standalone with internal LCD screen to display the person's weight in two standard units as kilogram and pound with assistance of android operating system. The output of the scale can be sent remotely to smart phones by Bluetooth wireless communication link.

The first step in operating the system is testing the basic connections of the HX711 to power supply, the load cell, Bluetooth, LCD screen and the microcontroller.

The next step is testing the HX711 24-bit ADC result data line state so the HX711 serial communications protocol results in the data line (DT pin on the HX711 breakout board), which is normally in the "high" state, being pulled low by the HX711. This provides a simple test if the HX711 is connected and responding correctly (this is also the signal from the HX711 that data is ready for retrieval). The bool is_ready ( ) routine check if HX711 is ready or not.

When the output data isn't ready for return, the DOUT (digital output pin) is high. Then the PD_SCK pin will need to be low. As the DOUT comes to low, it means that the data is available for retrieval.

The get units ( ) routine returns the average of 10 times readings from the ADC minus tare weight then divided it by the scale factor after calibration.

Zero balance is the difference from the load cell (the signal between the A- and A+ pins of the HX711 breakout board) when no load is applied. This is typically stated in terms of percentage of full scale. Therefore, zero balance is the "offset" that needs to be applied when measuring and calibrating weights and represents inherent differences between the strain gauges (and strain gauge connections) that form the load cell. Full scale is simply the output from the HX711 when the load cell is full loaded.

In order to produce data for the zero-balance load cell test, the load cell was simply connected to the HX711 without applied load and data from the HX711 collected at 30 second intervals via the RS232 connection to PC. Each data point at each successive 30 second interval was in turn the average of 20 readings taken as quickly as possible with the HX711. The results are 227193 as raw data from HX711 ADC after converting the serial 24 bit to human readable format with no load (zero balance) and the differential input signal of load cell (the signal between the A- and A+ pins of the HX711 breakout board) is 0.4 mv mill volt at this reading.

Figure 8a and figure 8b show the testing of the prototype digital medical weight scale with modern load cell sensors. The weight scale can measure up to 200KG weight. It can store up to 10 weight values in the STM32 MCU EEPROM through the SET/MEM pushbuttons with an accuracy of 0.1KG. So, the system can support the weight of children and adults. The weight data can be monitored and controlled remotely through smartphone applications.

Figure 5.1 The testing prototype digital medical weight scale with no load or zero balance.

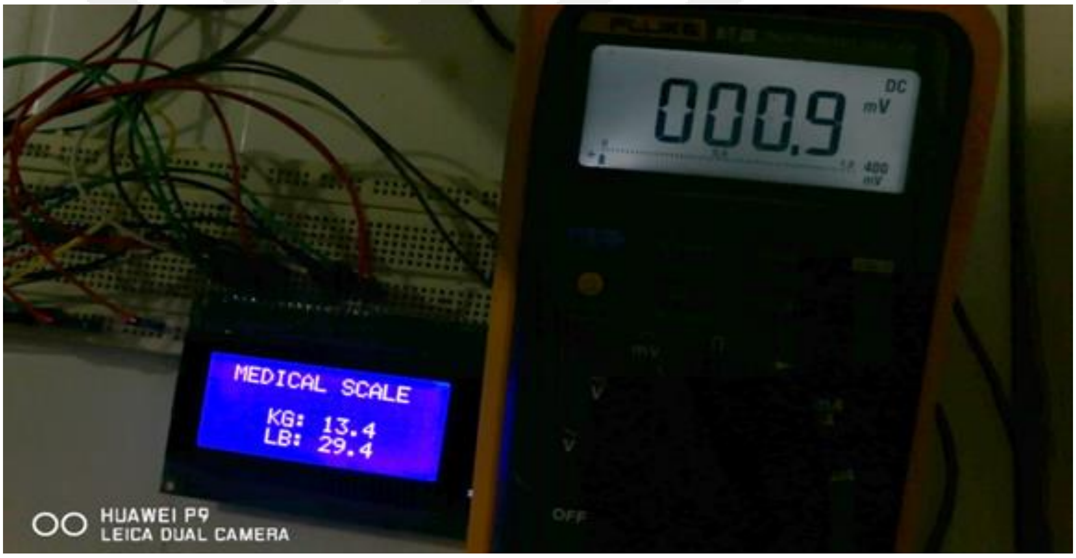


Figure 5.2 The testing prototype digital medical weight scale with load scale at 13.4 kg load.

After completing the testing and calibrating of the scale different loads with known weight values are applied to the scale and output of the scale is measured. Table 1 shows the results of the measurement: it is clear from the results the accuracy of the scale is in ±grams. This accuracy is regarded very high and supports other applications which require very high accuracy in addition to medical applications.

Table 5.1 The output results of the electronic scale

The real weight value in KG	The output of the scale in KG
1	1.1
	0.9
1.5	1.6
	1.4
2	2.1
	1.9
2.5	2.6
	2.4
7	6.9
	7.1
20	20.1
	19.9

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

In this thesis, the digital weight scale is implemented using the ARM32 CPU and high precision 24-bit analog to digital converter technology with a high sensitivity strain gauge sensor bridge. In an easy to use, low cost digital weight scale with a high resolution of 0.1KG has been produced. The system has the future of displaying the weight data and also has the ability to send this data remotely through Bluetooth radio module to smartphones for continuous data monitoring. The weight scale system has been designed and implemented using advanced digital electronic technology with Arduino software. It can be used in most environments, including home, hospital fitness centers or pharmacies. The system offers a modern, easy means of monitoring fitness and health data. The system has been tested in a real-world situation and has been found to fulfill all the requirements of a medical scale.

6.2 Future Work

The following future works are suggestion to develop the present system.

1. Increasing the accuracy and resolution of the system for small weights.
2. Increase the efficacy of system by using FPGA technique.
3. Increase range of the weight data transmission by using WIFI instead of Bluetooth technique.

REFERENCES

[1] Microchip Co. (2016), Connected Weight Scale Reference design, USA.

[2] A. S. Prabuwono, H. Akbar, and W. Usino, "PC Based Weight Scale System with Load Cell for Product Inspection," in Computer Engineering and Technology, 2009. *ICCET '09. International Conference on*, 2009, pp. 343-346.

[3] J. Higino and C. Couto, "Digital filtering in smart load cells," in Industrial Electronics, Control, and Instrumentation, 1995., Proceedings of the 1995 IEEE *IECON 21st International Conference on*, 1995, pp. 990-994 vol.**2**.

[4] Ramsay, D.C. (2000), Engineering Instrumentation and Control, Stanley Thorner (Publishers) Ltd. 2nd Edition, pp 29-123.

[5] Geoffrey Brown (2012), "Discovering the STM32 Microcontroller" , June 5, 2016.

[6] A.L. Window , "Strain Gauge Technology " , 2nd Edition , Nov 30, 1992.

[7] Bentley, J. P., Measurement Systems, Addison Wesley Longman Ltd., UK, 2000.

[8] Colm Slattery and Mariah Nie, "A Reference Design for High-Performance, Low-Cost Weigh Scales", DEC. 2005.

[9] D Sargent (2012), "Weighing-scale design: Measure signals accurately", March 1, 2012

[10] Karl Hoffmann , "An Introduction to Stress Analysis and Transducer Design using Strain Gauges".

[11] M. Thoren, ''Delta Sigma ADC Bridge Measurement Techniques, ''Linear Technology Corporation, 2005.

[12] SparkFun Electronics, ‘‘Getting Started with Load Cells, ’’ 2003. [Online]. Available: https://learn.sparkfun.com/tutorials/getting-started-with-load-cells. [Accessed 15 August 2017].

[13] MICROCHIP, “PIC14000,” 1996. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/40122b.pdf. [Accessed 10 August 2017].

[14] SparkFun Electronics, ‘‘SparkFun Product Page Gets a Redesign.’’ 2003. [online]. Available: https://www.sparkfun.com/. [Accessed 16 August 2017].

[15] M. Thoren, ‘‘Delta Sigma ADC Bridge Measurement Techniques, ’’Linear Technology Corporation, 2005.

[16] K. D. Gaikwad, and P. B. Dahkar, ‘‘Development of Digital Weighing Scale for Finding Adulteration & Cost Standardization,’’ *International Journal of Scientific & Engineering Research*, vol. **5**, pp. 22-30, 2014.

[17] K. D. Gaikwad, and P.B. Dahikar, “Design and Development of Novel Weighing Scale System”, *IJERT*, vol. **2** pp. 1668-1671, 2013.

[18] P. B. Dahikar, and K. S. Patle, ‘‘Design of an Embedded Platform for Digital Weighing System to Enhance Measuring Capabilities’’, International Journal of Innovative Research in Computer and Communication Engineering, vol. **1**, pp. 1881-1887, 2013.

[19] E. Koruk, ‘‘Design and Implementation of microcontroller based electronic weighing and bagging machine,’’ Ms.C. dissertation, Dep. Elect. and Electro. Eng., METU, Ankara, 1994.

[20] Life augmented, ‘‘STM32F103C8,’’ 2017. [online]. Available: http://www.st.com/en/microcontrollers/stm32f103c8.html. [Accessed 17 August 2017].

[21] Arduino for STM32, ‘‘Board Index.’’ 2017. [online]. Available: http://www.stm32duino.com/. [Accessed 20 August 2017].

[22] AVIASEMECONDECTOR (XIMEN) CO., LTD, ‘‘Products,’’ 2012. [online]. Available: http://www.aviaic.com/ENProducts.aspx?sort_id=43&FID=1&FID2=43. [Accessed 22 August 2017].

[23] I Tead Studio, ‘‘HC-05 -Bluetooth to Serial Port Module, ’’ 2010. [online].. Available: http://www.electronicaestudio.com/docs/istd016A.pdf. [Accessed 24 August 2017].

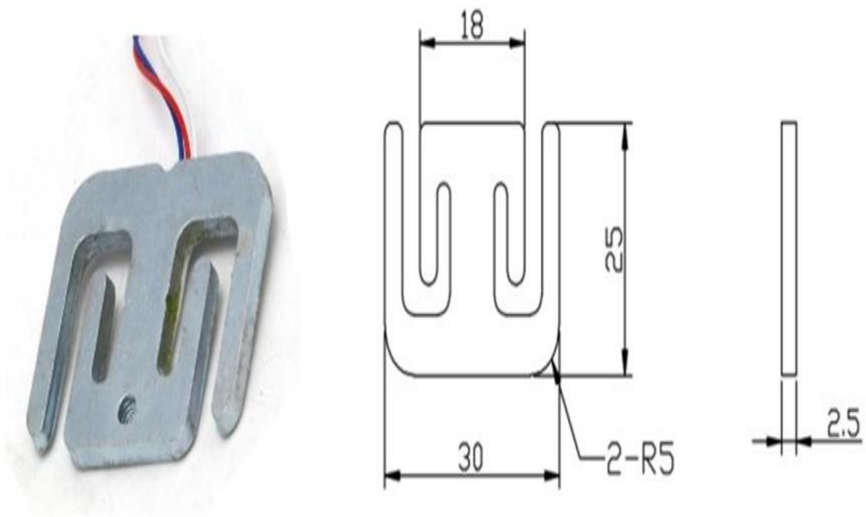
[24] ARDUINO, ‘‘Access the Online IDE,’’ 2017. [online]. Available: https://www.arduino.cc/en/Main/Software. [Accessed 25 August 2017].

[25] Life augmented, ‘‘STM32 forum,’’ 2016. [online]. Available: https://community.st.com/community/stm32-community/stm32-forum/content. [Accessed 27 August 2017].

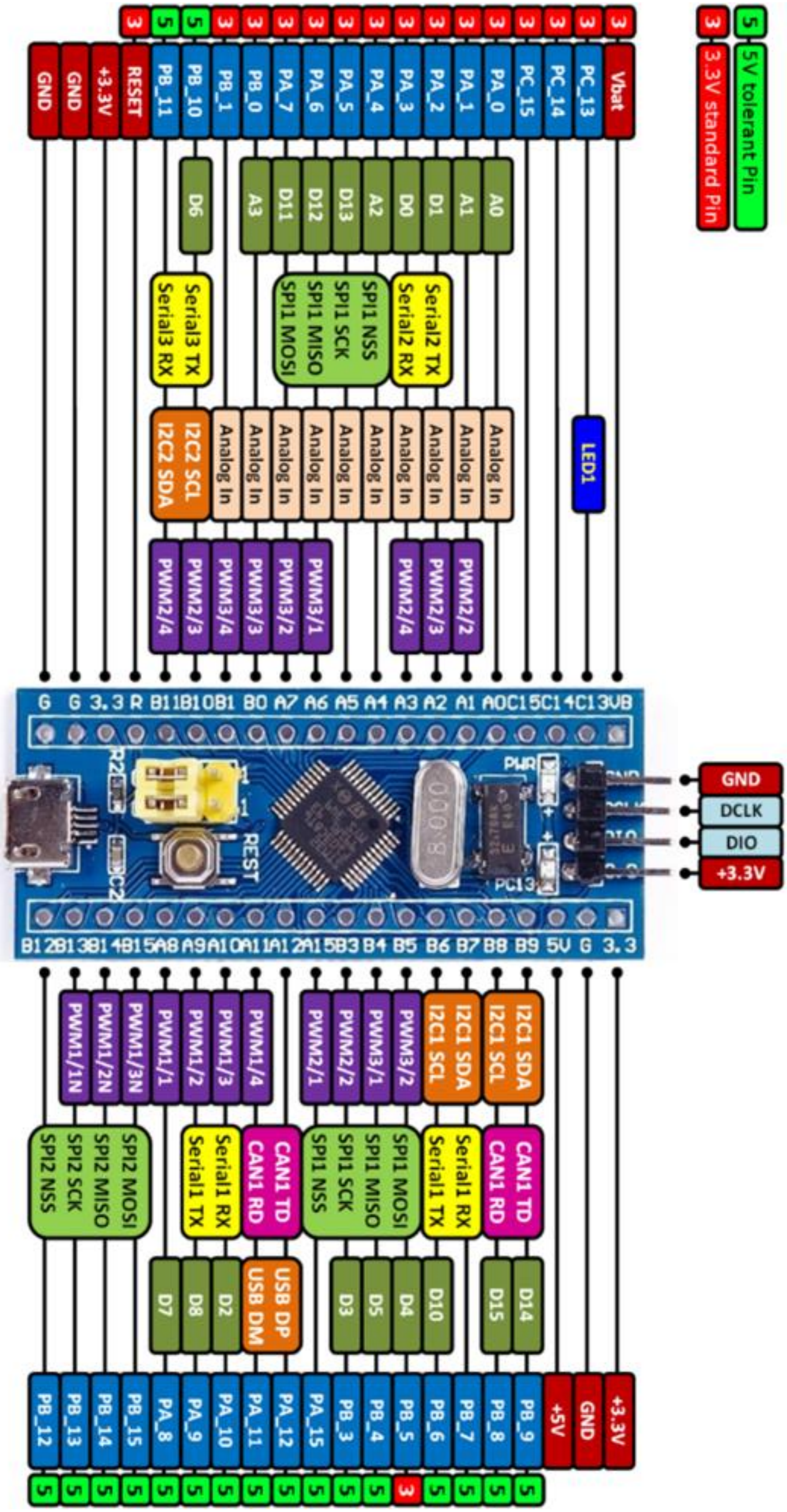
APPENDIX

APPENDIX A Load Cell Calibration Certificate

Application	Medical scale, bathroom scale , body scale
Model	SC932, SC928, SC928H
Capacity	50kg
Comprehensive Error	0.2
Output sensitivity	1.0±0.1mV/V
Nonlinearity	0.2% F.S.
Repeatability	0.1% F.S.
Hyteresis	0.2% F.S.
Creep	0.1 (3min) % F.S.
Zero balance	0.1 (1min) % F.S.
Temp.effect on zero	0.2% F.S./10℃
Temp. effect on span	≤0.15 F.S./10℃
Zero output	±0.3MV/V
Input resistance	1000±50 ohm
Output resistance	1000±50 ohm
insulation resistance	≥2000 MΩ
Recommended excitation voltage	5-10V
Ultimate overload	150%F.S.
loadcell material	Aluminum alloy



Load Cell Figure



STM32F103C8 BREAKOUT BOARD PIN CONFIGURATION

APPENDIX B Steps involved in the PCB Fabrication

1. Design of the board layout

The PCB track layout was drawn usin ExpressPCB software. The image was reversed, using the „flip horizontal‟ function, before printing. The image was printed on normal A4 paper to make sure that it was correct in size. It was checked carefully.

2. Printing the negative plastic film

When the layout was done, the board layers were printed onto glossy photo papers with a laser printer, top layer on one and bottom layer on the other.

3. Exposing/developing the board

The copper clad board was cleaned with steel wool. Very fine wet sandpaper could also do. It was dried thoroughly. The board had to be clean and free from fingerprints. The glossy photo papers were placed face down on the copper clad board top and bottom surfaces.The board "image" was transferred to the bare copper board in a UV box. Areas of the PCB exposed to UV light (through the film) turned into a protective plastic film. 3-5 minutes exposure time produced good results. After laminating, and allowing cooling, the board with the paper stuck to it was soaked in water solution of NaOH to remove the paper, leaving only the toner behind. The developing phase took about 1-2 minutes. The board was then showered with fresh water to remove NaOH remains.

4. The Etching process

The board was etched in a Ferric Chloride etching solution (etchant). Ammonium Persulfate could also serve the purpose. The etchant reacts with exposed copper and removes it from the PC board leaving the copper covered with resist (toner, rubon patterns, tape, permanent marker). This process took about10-30 minutes. After etching, the board was rinsed under a cold tap. The toner (etch resist) or protective plastic film was then removed with Acetone (solvent). Steel wool could also do. The board was dried.

5. Tinning

The PC board was tinned using a soldering iron and a small piece of tinned solderwick. Tinning isn‟t absolutely necessary but it improves the appearance of the board, and prevents the copper from oxidizing before it‟s time to solder the parts to the board.

6. Drilling

A 0.8 mm PCB drill bit was used for drilling out all of the leaded component holes. Some 1.0 mm holes were drilled out for connectors. 3.0 mm holes for corner fixings (mounting holes) were drilled.

7. Soldering

Finally, the copper was cleaned using a PCB rubber ready for soldering.

The components were then mounted and soldered in.