WIRELESS PATIENT MONITORING SYSTEM USING THE EZ430-CHRONOS

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STATEMENT OF CANDIDATE

I, Lachlan Wild, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the Department of Electronic Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment at any academic institution.

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Date: November 7, 2016

ABSTRACT

Patient monitoring has become important in an aging society that has an increased reliance on medical care. This puts a burden on hospitals and staff that cannot be easily alleviated. In order to reduce menial tasks that need to be performed by medical staff, a wearable wireless patient monitoring device can be used. This device would track a patients vital signs and wirelessly send data to a PC, where it can be monitored by staff. Different sensors are able to achieve this goal and are outlined, with advantages and disadvantages for each. However, the foundation for the proposed wireless patient monitoring device is the eZ430-Chronos, which is detailed in this document. The main aim of the document is to research the eZ430-Chronos and test its validity as a wireless patient monitoring device, in order to better understand what areas need to be improved upon for future designs. This aim is achieved by using several experiments to test the different sensors and how they are used in the eZ430-Chronos and then analyzing the output of each. Only once the sensors have been analyzed, can a judgment be made on the effectiveness of the eZ430-Chronos for use as a wireless patient monitoring device.

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Chapter 1

Introduction

The recent surge in wearable wireless devices, such as the Fitbit or the Nike+ Fuelband SE, have shown a rising trend of people wishing to monitor their own well-being and accepting the idea of wearable wireless devices. [1] However, these devices do not have any sort of interoperability with current health care systems or expandability with upcoming sensing technologies. [2] This document focuses on a device that is able to monitor several aspects of a patients wellbeing and can then transmit the collected data to a central location within a hospital environment. This would be an invaluable tool to have within a hospital, freeing up medical professionals to attend to other tasks, but still allow them to easily monitor a patients condition.

Several different sensors could be used in order to monitor a patients vital signs, which can include thermometer, pulse oximeter, and acceleromter, all of which will be investigated in this document. Also investigated will be the ability to use a barometric pressure sensor to track a patients vertical location, or what floor they are on, within the hospital. Some data collected from these sensors are crucial to the wellbeing of a patient, whilst other are used for statistical purposes.

The basis of this research will be on the eZ430-Chronos software development tool developed by Texas Instruments (TI) and how its functions could be implemented into a modern healthcare system. The eZ430-Chronos' current software capabilities and associated sensors will be experimented on and results will be collected in order to test its validity. From this data, future work into this area will also be investigated, with possible design improvements to the eZ430-Chronos device or how such a device would be constructed using individually sourced parts, to better refine the design specifically for use within a hospital environment. Furthermore, the wireless capabilities of the device and its interfaces will be detailed to enhance an understanding of whether the device would be suitable.

1.1 Project Specifications and Timeline

1.1.1 Requirements

The main outcome of this project is to develop and test a wireless device that can monitor several aspects of a patients wellbeing. Initially, the device will monitor the patients temperature, orientation and their current vertical location within the hospital. The patients heart rate and oxygen saturation levels are also desirable pieces of information that the device could collect, but due to time restraints, these may not be implemented.

1.1.2 Approach and Timeline

There are several methods and techniques that will be used to achieve the requirements of the project. From these requirements and initial research into the design of a wireless patient monitoring device, it is clear that the following method will need to be used.

Introduction

This section of the document will introduce the overall layout as well as a brief summary of the included material. Previous knowledge and work into the area of wireless patient monitoring will also be outlined.

Literature Review

The literature review is a critical analysis of all the different documentation that is collected during the research stage of the design. This is to give a detailed understanding of current patient monitoring devices as well as sensors that can be used in their design.

Experimental Procedures

The different experiments and the methods to undergo them will be outlined in this section. Also outlined will be details on the assembly and disassembly of the device to assist with the experimental design process.

Results

The different outcomes of the experimental procedures will be shown here. This includes all tables and figures relevant to the data collected about the patient monitoring device. It will give the nature of the performance of the project as well as providing feedback on the reliability and validity of the system.

Discussion

This section of the document will discuss what is shown from the results of the experiments as well as the possible applications of the patient monitoring device. Any shortfalls in the experimentation process or any unexpected results will also be examined.

Conclusion

The final section of the main report will summarize the different parts of the document as well as reflect on the total outcome of the patient monitoring system. How the design was developed from research to working design and the significance of this will also be investigated.

Future Work

Any unfinished research on patient monitoring devices as well as any ideas and topics that could be implemented to further improve the design will be outlined here. This includes ideas into all aspects of the device such as software, hardware and compatibility.

Timeline

A timeline for the different activities that have been outlined is shown as a Gantt chart in figure 1.1

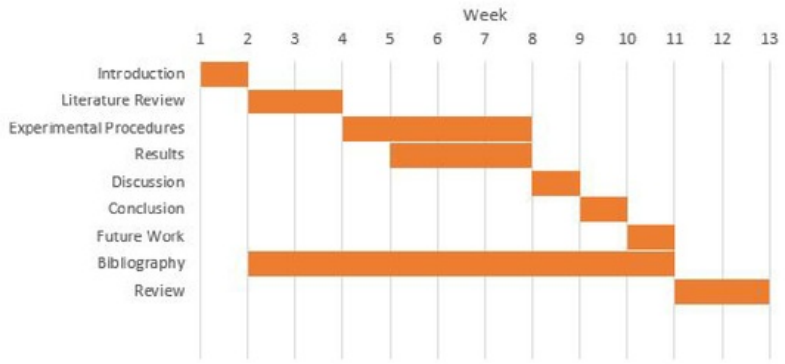

Figure 1.1: Project Timeline

Chapter 2

Background and Related Work

2.1 Current Patient Monitoring Devices

There are several different methods of wirelss patient monitoring devices that are currently available on the market, all of which have their individual advantages and disadvantages. Some devices sync with a smartphone, while other devices are connected to a PC and operate using an interface provided by the company that has designed the device.

One device that is able to sync with a smartphone is the AliveCor Heart Monitor. [3] The device is a single lead electrocardiograph (ECG) that attaches to a smartphone, and in only 30 seconds, accurately records an ECG or heart rhythm. This enables it to record and track several patient symptoms such as palpitations, effects of alcohol consumption and shortness of breath. It also allows for these recorded symptoms to be transmitted wirelessly to a medical professional without physically having to go see one in a hospital or medical facility. As of 2014, this was the only single lead ECG that is approved by the US Food and Drug Administration (FDA) for its ability to detect atrial fibrillation. [4]

Another example of a device that can transmit data wirelessly to a smartphone or tablet is called AirStrip. [5] This device uses hardware and software to connect to a hospitals medical equipment in order to monitor a patients vital signs from a remote location. Some vital signs that can be read and measured by this device include: [4]

- Temperature
- CT Scans
- Blood Pressure
- Medications
- Electronic Health Record (EHR)

All data collected by this device can be viewed and analyzed by a medical professional, who is then able to communicate with a patients care team, thus making the AirStrip device a useful tool for general care.

In order to allow for a variety of medical issues, some devices such as the Glooko, [6] offer care for specific illnesses. Glooko is a wireless glucometer that is able to sync 30 or more FDA approved wired glucometers wirelessly to smartphones. [4] This allows the now wireless device to connect blood glucose readings as well as other lifestyle data to patients for a real-time connection. Medical professionals are then able to monitor these readings on their devices, with any patients trends showing signs of risk being automatically flagged for the users convenience. A similar device, developed by Propeller Health, [7] uses a device that fits onto an inhaler and syncs wirelessly with a smartphone to record data regarding a patients asthma or chronic obstructive pulmonary disease (COPD). Once the software analyses the data, it then offers suggestions on how to possibly improve the patients control over their respiratory disease by tracking the environmental components, such as their medication usage.

Another type of device is the Withings Smart Body Analyzer. [8] This device looks and acts like a normal body weight scale, but it connects via bluetooth to a smartphone and uses an FDA approved bioelectrical impedance analysis to monitor a patients lean mass, fat mass and body mass index (BMI). [4] The device also has the ability to monitor the heart rate of a patient, by keeping a record of its history, which then allows the smartphone app to track weight loss activity and cardiovascular fitness. The smartphone app also has the ability to sync with over 100 different fitness apps, enabling data to be shared between users.

An important aspect of patient monitoring devices is the ability for them to be able to communicate with all the users that require the information. This is important when dealing with the elderly, as sometimes they are unable to deal with their own medical emergencies without assistance from professionals. The GrandCare Systems [9] device was designed in order to improve the quality of life for any residents within nursing homes, or for elderly that decide to remain at home. The user friendly software includes the ability to have medication reminders, assess a patients lifestyle, and coordinate notes relating to the patients care, that can be viewed by all the authorized people in the patients life, such as family or caregiver. The device is also able to wirelessly communicate to a range of wireless sensors, with all of the data produced from these sensors able to be viewed online using the device.

In order to eliminate the need for most bulky hospital devices, the EarlySense All-in One System [10] is able to replace them by inserting a sensor device underneath the mattress of a patient. From this position it is able to wirelessly monitor a patients respiration, movement and heart rate. The data collected from this sensor can then be monitored on computers in several locations, as well as send alerts to handheld devices if the patients condition is deteriorating. This device would be ideal for facilities that have limited access to technology and is an excellent early warning system that can eliminate unforeseen risks in patients.

Some medical processes, such as visiting the optometrist can be time consuming and expensive, especially when almost 600 million people suffer from some form of visual impairment. [4] An optometrist is also not always available to test a patients prescription and issue some for of corrective lens, which is where EyeNetra Mobile Visual Acuity Tester is extremely useful. [11] This device is a plastic eyepiece that is able to attach to a smartphone screen and using special associated software, the patient is able to generate their own prescription data. With this data it is simple for a patient to then order corrective lenses online or through a retailer. The device is also able to measure more than just a prescription, with hyperopia, myopia, astigmatism and other optical measurements being able to be detected at a claimed accuracy equivalent to a $45,000 autorefractors. [4]

A further area that has seen the introduction of a wireless monitoring device is in footwear. OpenGo [12] is a shoe insole that transmits a patients plantar pressure distribution to an associated smartphone app. This device is as thin as a normal shoe insole but can be used for research in training analysis and for rehabilitation after some form of foot injury. In order to do this, the device measures the weight bearing, temperature, balance and acceleration that a patient normally undergoes. This device can be extremely useful when monitoring patients who are prone to falling and can wirelessly determine the cause of this problem.

An important part of any form of treatment, whether it be in a hospital or a medical professionals office, is the ability to easily identify and track any form of wound. WoundRounds [13] has the ability to automatically assess a wound, as well as simplify its treatment and create a communication platform for all users to track the progress of the wound. The primary aim of this device is to identify risky bedridden patients at a stage before any pressure ulcers can develop, while also recording and monitoring the clinical state of the wound. It is possible to also track the healing of the wound through the communication platform, which may help increase the quality of care that a patient is receiving.

2.2 Accelerometers

2.2.1 Early Development

The first commercialized resistance bridge type accelerometers were developed by McCollum and Peters in 1924. [14] Their design consisted of an E-shaped frame that held 20 to 55 carbon rings situated in a tension-compression Wheatstone half-bridge thats between the center and top section of the frame and is illustrated in figure 2.1. [15]

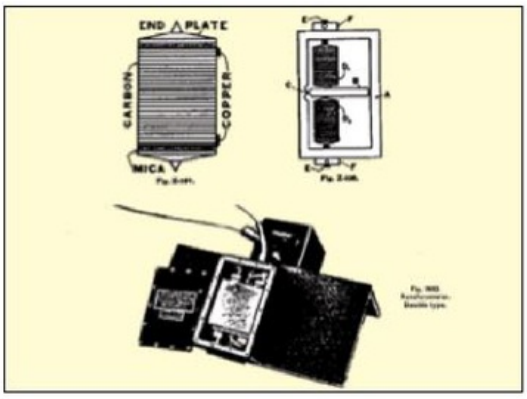

Figure 2.1: McCollum and Peters Resistance Bridge Type Accelerometer

This technology was even further advanced by 1936 where a two-axis accelerometer was advertised to have been used in a range of applications which include: [15]

- Airplane catapult
- Passenger elevators
- Aircraft shock absorbers
- Steam turbine vibration recording
- Underground pipe vibration recording
- Force of explosions vibration recording

These early designs of accelerometers have led to the creation of modern accelerometers used in applications in most areas of technology.

2.2.2 Sensors

Resistance Strain Gages

The first instance of large scale commercialized accelerometers began with the development of the bonded resistance strain gage by Arthur Ruge at the Massachusetts Institute of Technology (MIT) in 1938 after furthering the research of Edward Simmons at Caltech in 1936. [16] Only months after this development, the first strain gage accelerometer was developed, also at MIT, by J. Hans Meier which was named the "Elastic Dynamometer". [15] It contained bonded wire filaments situated on four supporting strips which supported a steel block and was able to measure 2g, 4Hz vibrations.

Wheatstone Bridge

The founder of the Wheatstone Bridge was Sir Charles Wheatstone in 1843 when he discovered a bridge circuit that was able to measure electrical resistances. [17] This bridge is now commonly used to determine unknown resistances based on known resistances as well as measuring small resistance changes. Therefore, the Wheatstone Bridge can be useful in the measurement of resistance change in a strain gage accelerometer. [18] Within a strain gage, the strain applied is proportional to the change of resistance, with the relationship between applied strain shown in equation 2.1 and the relative change of resistance described in equation 2.2. [17]

$$\epsilon = \Delta L / L_o \tag{2.1}$$

$$\frac{\Delta R}{R_o} = k \cdot \epsilon \tag{2.2}$$

In equation 2.2 the value for k depends on the chosen strain gage and is always outlined on the associated data sheet.

A simple Wheatstone Bridge, illustrated in figure 2.2 [17] contains 4 resistors in series, which form the branches of the bridge, and are typically named R_1 to R_4.

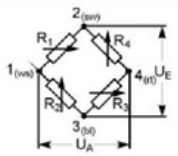

Figure 2.2: Typical Wheatstone Bridge Configuration

The nodes between each resistor are similarly named, with nodes 2 and 3 being connected to the voltage source or the known voltage area (U_E). The voltage output (U_A) is then defined between nodes 1 and 4 and depends on the ratio of the resistors $R1 : R2$ and $R4 : R3$. This ratio can be illustrated by using the known voltage and the output voltage which is shown in equation 2.3: [17]

$$\frac{U_A}{U_E} = \frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} = \frac{R_1 \cdot R_3 - R_2 \cdot R_4}{(R_1 + R_2)(R_3 + R_4)} \tag{2.3}$$

From this equation it is clear that if $\frac{U_A}{U_E} = 0$, then $R_1 = R_2 = R_3 = R_4$ or $R_1 : R_2 = R_4 : R_3$. Most strain gage accelerometers include some form of balancing elements in order to reach an output ratio of 0, which indicates the initial state. This allows for the strain gage accelerometer to be properly calibrated by the user.

2.3 Temperature Measurement

2.3.1 Introduction

The human bodies temperature is necessary to measure as it can detect symptoms of medical stress, which can lead to conditions such as strokes, heart attacks and shock. Temperature can be measured from within the body but can also be measured on the surface of the skin of a patient. The temperature of the skins surface varies in different regions of the body, as well as with the environmental temperature of the patient. In a comfortable environmental temperature, the skin temperature is usually from 33.5°C to 36.9°C, with the main regions of the body affected by significant environmental change being the extremities such as the arms and legs. [19]

Areas of the body are traditionally measured by contact thermometers in the oral, rectal or auxiliary sites, however they do not produce the most accurate measurement of the internal body temperature of a patient. The hypothalamus is located at the base of the brain and is the way that the core temperature of the human body is measured. The goal of this system is to keep the body's internal temperature between 36°C and 38°C [20] and would be the best area for measurement. However, this area of the brain is not accessible without surgery and thus not an efficient way to constantly monitor a patients temperature.

2.3.2 Sensors

Several sensors are used as convenient ways to measure the human body's temperature and several different designs have been used throughout history. These sensors have been used in many different regions of the body in order to achieve an accurate measurement, with most being quite efficient in their readings.

Liquid-in-Glass Thermometers

Liquid-in-glass thermometers are an older style of oral temperature measurement which consists of a liquid contained within a glass envelope. The envelope has a bulb which is to be placed in the area that requires the temperature to be measured, which is followed by a narrow and graduated capillary, forming the thermometers stem as illustrated in figure 2.3. [21]

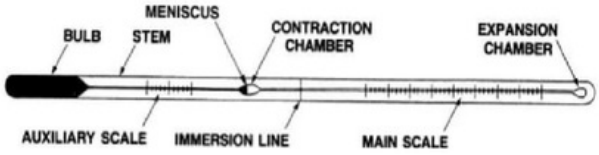

Figure 2.3: Liquid in Glass Thermometer

The liquid within the bulb and capillary has a higher thermal expansion than the glass and as the temperature increases, the liquid expands, which forces it to rise from the bulb into the capillary. The level of liquid can then be measured, which reflects a temperature reading if properly calibrated. [21] Most versions of these types of thermometers use mercury, as it is a liquid within the temperature range of -38.0°C to 356.7°C and has a linear thermal expansion rate, allowing for accurate calibration. [22]

Thermocouple

Thermocouples consist of a pair of dissimilar wires that are joined at a point known as a measuring junction. This point ensures that there is no electrical difference between the two wires in order to establish a starting point where a thermoelectric voltage can be developed and measured. The reference junction is located at the other end of the wires, where they are no longer joined and are connected to signal conditioning circuitry traces. The thermocouple effect is continuously distributed along the entire length of the thermocouple conductor and is powered by temperature difference between the measurement junction and the reference junction which gives a voltage output. [23] This thermocouple design is illustrated in figure 2.4: [24]

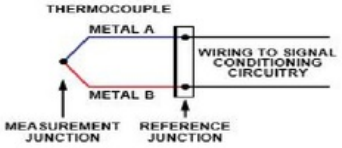

Figure 2.4: Thermocouple Design

Thermocouples are manufactured in different types which vary due to their temperature rise, also known as the Seebeck Coefficient after the founder of thermocouple design. The different thermocouple types are detailed in table 2.1. [24]

Thermocouple Type	Seebeck Coefficient
E	61
J	52
K	41
N	27
R	9
S	6
T	41

Table 2.1: Thermocouple Types vs. Temperature Rise at 25°C

Thermistors

A thermistor is semi conductive resistor made from metal oxides and then pressed at high temperatures into the desired shape before being coated with epoxy or glass. This device then has an electrical resistance that varies with the temperature of the resistor and would be mounted on the surface of the skin on the human body. There are two different types of thermistors:

1. Negative Temperature Coefficient (NTC) Thermistor: a thermistor whose resistance decreases with an increase in temperature
2. Positive Temperature Coefficient (PTC) Thermistor: a thermistor whose resistance increases with an increase in temperature

NTC thermistors are more commonly used than PTC thermistors however both have advantages for temperature measurement. Thermistors have extremely high sensitivity and also a relatively high resistance when compared to a Resistance Temperature Detector (RTD), yielding a faster response time using a smaller connection. Figure 2.5 [25] shows a comparison example of a 2252 Ω thermistor with a sensitivity of -100 Ω/°C, which is significantly better than a 100 Ω platinum RTD whose sensitivity is only 0.4 Ω/°C. [25]

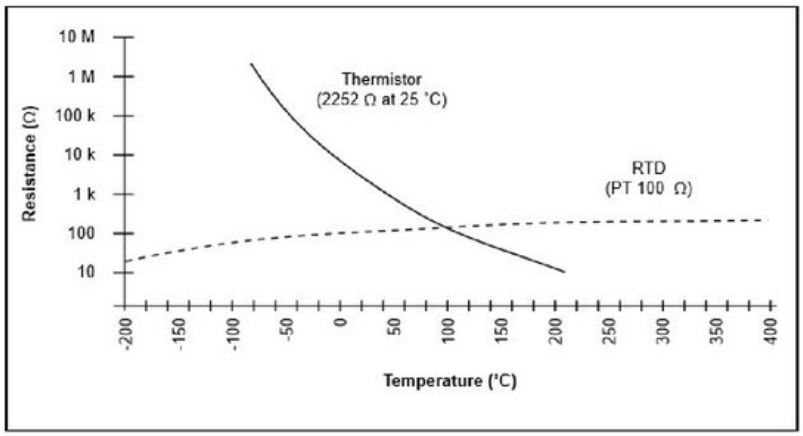

Figure 2.5: Liquid in Glass Thermometer

However, from this figure the main disadvantage of thermistors becomes clear, which is their highly non linear output, accompanied by a limited operating range. Typically a thermistors upper limit is 300°C, which is low in an overall standard but falls within measurement range for the body temperature. The above curve is approximated by the Steinhart-Hart equation [26] with relatively high accuracy:

$$T = \frac{1}{a_0 + a_1 ln(R_T) + a_2 [ln(R_T)]^3} \tag{2.4}$$

$$\begin{aligned} &where: \\ T &= Temperature\ (^\circ K) \\ R_T &= Resistance\ (\Omega) \\ a_0, a_1, a_2 &= Constants\ derived\ in\ calibration\ procedure \end{aligned}$$

The temperature in this equation is given in Kelvin however, this can be converted to Celcius using the following equation [25]:

$$T(^\circ C) = T(^\circ K) - 273.15 \tag{2.5}$$

Once complete, the resistance is converted theoretically into a readable metric temperature value.

2.4 Pulse Sensors

The main idea behind pulse sensors is to measure the arterial pulse waveform that is produced as the heart circulates blood around the cardiovascular system. This measurement is taken either using arterial wall deflection or the force at the surface of the skin, normally above a substantial vessel. [27] These sensors are not calibrated to the pressure of each individuals blood vessel, but instead is able to respond to any proportional changes in the pressure. There are several different types of sensors designs available, but the two main ones are volume and pressure.

2.4.1 Volume Sensor

A volume sensor uses arterial wall deflection, which relies on a non-deflecting frame reference such as the tissue adjacent to the measured blood vessel as outlined in figure 2.6. [28] This is contrasted to skin deflections which are measured directly above the blood vessel by comparing a general reference to a change in arterial pressure. From this, several different methods of transduction may be used such as capacitive, resistive or optical. The main disadvantage of volume sensing is that it only responds directly to volume distention and indirectly to the arterial pressure. This leads to complex waveforms on the vascular wall that are difficult to analyze and correct experimentally. [28]

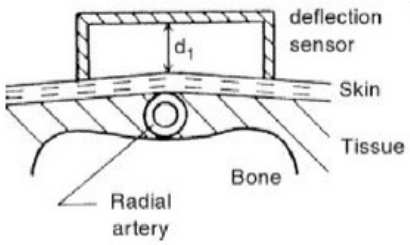

Figure 2.6: Volume Sensor

Capacitive Transduction

The capacitive transduction technique involves the measurand interacting with the pulse sensing device, in order to change the capacitance in the capacitor. In order for this effect to happen, the distance between two electrodes of the capacitor must be changed. If this is not possible, then the dielectric constant of the chosen insulator material should be changed in order to achieve the same effect. [29]

Resistive Transduction

One resistive technique involves the use of piezoresistance to convert a measurand into a change in resistance, however most other resistance transduction techniques are similar in their design. They use a measurand that interacts with some form of film, which in turn changes the electrical property of the sensor. [29]

Optical Transduction

Optical transduction techniques are able to measure and quantify an optical spectrum, as well as any change in the mechanical measurand, by using some form of radiation such as ultraviolet (UV) or infrared (IR). This is done by using the radiation to probe the material to be sensed via some form of structure which creates an output signal that must be quantified using a detector. The detector compares the amplitude and phase of original source beam to the returning beam which is allows for the quantification of the optical spectrum. [29]

2.4.2 Pressure Sensor

A pressure pulse sensor measures stress that is transmitted through the skin directly above the artery due to a change in pressure that is seen during each heart beat. This process is illustrated in figure 2.7. [27] The main difference between pressure sensors and volume sensors is that pressure sensors require zero surface deflections so that the contact forces at the skins surface are in proportion to the pressure within the artery.

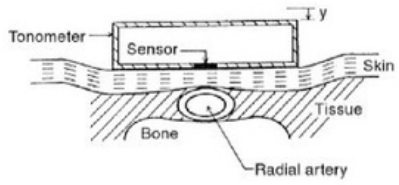

Figure 2.7: Pressure Sensor

2.4.3 Sensor Differences

The main differences between the volume and pressure sensors are the pulse waveforms that are recorded using both techniques. The pressure sensor pulse method was discovered to be the superior pulse measuring method as the waveform was more accurate since it did not have the effects of vascular nonlinear viscoelastivity. The pressure sensor also has a higher stiffness relative to the radial artery, which creates a better approximation of the heart rate. In order for the most accurate reading, the sensor must remain stationary as any changes in the position of the sensor or if any acceleration is undergone, the reading will change in magnitude and frequency.

2.5 Oxygen Saturation Sensors

An oxygen saturation sensor, or oximeter, is able to measure the oxygen saturation of the hemoglobin (SaO_2) contained in the blood of an artery. It is common for oxygen saturation and pulse to be measured using the same device known as a pulse oximeter. Modern medical care now regards the measurement of oxygen saturation to be one of the key vital signs that must be measured in a patient and it is important to understand what is considered to be a correct way of measuring it to ensure that no false readings are taken from a patient. [30] The two main functions of a pulse oximeter are to distinguish oxyhemoglobin (O_2Hb) from deoxyhemoglobin (HHb) and how to calculate SpO_2 from the blood contained within the artery. [31]

In order to differentiate O_2Hb from HHb, it first must be known that they both absorb red and near-IR as these are the only two wavelengths that are able to penetrate into human tissue, whereas all other colors are absorbed. [32] However, O_2Hb absorbs more near-IR light and less red light than HHb, which is consistent with expected hypotheses, as higher O_2Hb levels means that the blood has higher concentrations of oxygen, explaining why well oxygenated blood appears bright red when visually examined.

Therefore, pulse oximeters need to emit two different wavelengths of light, red light at 660nm and near-IR at 940nm, via a light-emitting diode (LED) that transmits through the finger to be received by a photodiode in order to determine the relative amount of light being absorbed by the finger. [31] This data is then used to determine the proportion of O_2Hb to HHb, which in turn shows the amount of hemoglobin that is bound to oxygen molecules in the blood.

The second consideration when determining oxygen saturation is to calculate SpO_2 levels within the blood. This is due to the fluctuating amount of red and near-IR light absorption during the cardiac cycle, which occurs when the volume of blood within an artery increases during systole and decreases during diastole.

The LED and photodiode combination operates as previously described, but light that passes through the finger that is not absorbed by the arterial tissue, creates a stable signal that outputs both a pulsatile AC and a non-pulsatile DC component as illustrated in figure 2.8. [31]

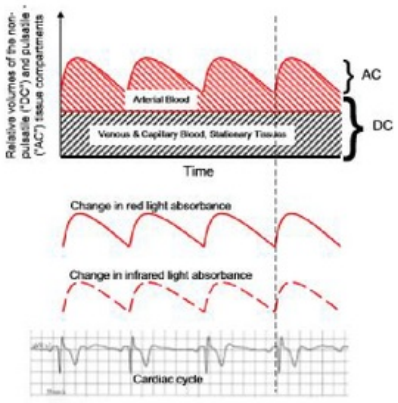

Figure 2.8: Oxygen Saturation Cardiac Cycle Waveform

From these diagrams it is clear that the DC component is a stable waveform as opposed to the AC, thus making it easier for the sensor to differentiate between an artery and a capillary or vein. The amplitudes of the different levels of red light and near-IR absorption are then used to calculate the modulation ratio (R) which is described by equation 2.6.

$$R = \frac{(A_{red,AC}/A_{red,DC})}{(A_{IR,AC}/A_{IR,DC})} \tag{2.6}$$

From this ratio it is clear that when oxygen saturation is low, the absorption of red light is greater than that of near-IR $(A_{red,AC} > A_{IR,AC})$, resulting in a higher modulation ratio, which means that there is an increase in HHb in the patients blood. [33] The converse is also true, which is that when oxygen saturation is high, nea-IR absorption is greater than red light absorption $(A_{IR,AC} > A_{red,AC})$, resulting in a lower modulation ratio. This ratio between red light and near-IR is illustrated in figure 2.9. [31]

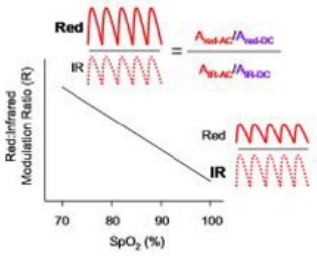

Figure 2.9: Oxygen Saturation Light Absorption Ratio

A MCU within an oxygen saturation sensor uses the modulation ratio over a series of pulses to determine the SpO_2 levels after calibration. Figure 2.9 only shows readings with a minimum of 70% SpO_2, as below this should not be considered reliable due to the calibration techniques used. [34] Readings higher than 90% SpO_2 is considered to be within the normal range and any readings below this range should be considered abnormal and medical assistance should be supplied to the patient.

2.6 Barometric Pressure Sensors

The term barometric pressure alludes to the air pressure that exists at a point within the atmosphere and is often referenced against the value that occurs at sea level, although this value may change due to overall weather conditions changing over time, which can result in a pressure fluctuation of approximately $\pm$in-Hg. Despite this, the standard barometric pressure at sea level is regarded as 29.9in-Hg which relates to an altitude of 0m. [35] Any increase or decrease in altitude corresponds exponentially to the barometric pressure and must be properly calibrated to a known altitude and pressure in order to get accurate readings at all other points. Table 2.2 shows several standard pressure values and their related altitudes.

Altitude (ft.)	Barometric Pressure(in-Hg)
0	29.92
500	29.38
1000	28.85
6000	23.97
10000	20.57
15000	16.86

Table 2.2: Barometric Pressure and Altitude Standards

2.6.1 Early Sensors

Early air pressure sensors were able to collect this data using a mercury filled tube containing a vacuum of air which was sitting in a reservoir of mercury, illustrated in figure 2.10, [36] that was calibrated by hand to the altitude and temperature of the sensor.

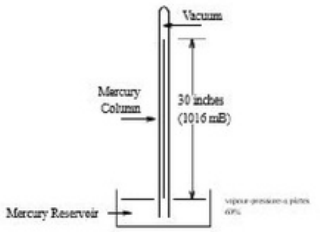

Figure 2.10: Mercury Barometric Pressure Sensor

The mercury reservoir contains a balance between the mercury columns downward pressure (P_m) and the surrounding air pressure (P_A), outlined in equation 2.7. [36]

$$P_m = \frac{f_m}{a_m} = P_A \tag{2.7}$$
$$where:$$
$$f_m = force\ exerted\ by\ the\ column$$
$$a_m = cross-sectional\ area\ of\ the\ column$$

From this equation, the air pressure can be obtained using only the column height and column density, along with the effects due to gravity. This can be achieved by equating the column force (f_m) to the mass of the mercury column (m_m) and acceleration due to gravity (g); and the mass of the mercury column to the density of mercury (d_m), the cross-sectional area of column and the height of the column (h_m). This creates a simplified formula as shown in equation 2.8.

$$\begin{aligned} P_A &= \frac{d_m a_m h_m g}{a_m} \\ &= d_m h_m g \end{aligned} \tag{2.8}$$

2.6.2 Electronic Barometric Sensors

Current barometric sensors use transducers to take the sensor response and transform it into an electrical quantity, in the form of an analogue signal or digital signal, ensuring that the data lies within the correct protocols. Most electronic barometers use digital read outs due to their increased accuracy, which relies on the calibration of the barometer as well as the effectiveness of the barometer to compensate for changes in temperature. [37] In order for the barometer to correct for these inaccuracies, most barometers comprise of the actual barometer sensor as well as a temperature sensor, both connected to an MCU which corrects any irregularities.

There are known faults and errors that are associated with electronic barometers, [37] with one being calibration drift. This is one of the key errors within the sensor and occurs more often when the barometer is new. In order to prevent this and maintain an acceptable performance in the barometer, the calibration must be checked at set intervals for early detection of faulty sensors. Temperature is also a factor that can cause errors within a barometer, as electric barometers are designed to be kept at the same temperature with which they were calibrated. Long term effects of temperature change in the barometers environment could possibly lead to shifts in calibration, whilst short term pressure measurement effects could include hysteresis errors. Further faults can occur as a result of electrical interference from sources such as magnetic fields, radars and computers which can create noise and decrease the devices precision. Finally, the nature of the operation of the barometer can also cause errors especially if there are differences in the way that the barometer was being operated during calibration and how it normally operates.

2.7 eZ430-Chronos

2.7.1 Overview

The experiments conducted will be based upon the eZ430-Chronos software development tool developed by TI, which is a wearable wireless development system based on the CC430F6137 Microcontroller (MCU). [38] It has many uses which include being a reference program for watch systems as well as a wireless sensor node for remote data collection and can be disassembled and reprogrammed with custom applications through the provided eZ430-RF JTAG USB programming/debugging interface. The wireless aspects of the system work through a wireless MSP430F5509 + CC1101 USB RF access point transceiver when using the chosen white PCB model of the wrist module which is illustrated in figure 2.11. [38]

Figure 2.11: eZ430-Chronos White PCB Model

The CC430F6137 MCU used in the eZ430-Chronos is part of the TI CC430 family which are ultra low powered MCU system-on-chip's (SoC) with an integrated RF transceiver core. The relevant diagrams and information for this component are seen in appendix H.

2.7.2 Sensors

The eZ430-Chronos includes four sensors within the wrist module, two standalone sensors and two built in to the CC430F6137 MCU. The two standalone sensors are the Bosch Sensortec 3-Axis Accelerometer (BMA250) and Pressure Sensor (BMP085) [39], while the built in sensors are a temperature and battery/voltage sensor.

The BMA250 is a digital, triaxial $\pm 2g$ to $\pm 16g$ acceleration sensor with intelligent on-chip motion-triggered interrupt controller. [40] It is contained in a 12 pin LGA package with an SPI I^2C digital interface and has an operating voltage range between 1.2V and 3.6V. It allows for simple measurements of tilt, motion and shock vibration acceleration on three perpendicular axes and uses an evaluation circuit to convert the output of the micro-electromechanical system (MEMS) according to the differential capacitance principle. [40] The specifications of the BMA250 are outlined in appendix B.

Also within the eZ430-Chronos wrist module is the BMP085 Pressure Sensor. It is a digital, high precision pressure sensor with ultra-low power and low voltage that interfaces with I^2C for simple integration with the eZ430-Chronos' CC430F6137 MCU. [41] The BMP085 has an operating voltage range between 1.62V and 3.6V which allows for a pressure range of between 300hPa and 1100hPa. In order to achieve this, it uses a piezo-resistive technology that allows for linear, high accuracy of pressure measurements and long term stability. [41] Further specifications of the BMP085 are outlined in appendix C.

2.7.3 USB Access Point

The USB access point included with the eZ430-Chronos wireless device is the CC1101 Low-Power Sub-1GHz RF Transceiver. [42] This transceiver is designed for applications that use low-power and is intended for use in the industrial, scientific and medical industry. The circuit is pre-programmed to work at short range frequency bands of:

- 315MHz
- 433MHz
- 868MHz
- 915MHz

Integrated into the RF transceiver is a baseband modem that is highly configurable and is able to configure a data rate of up to 600kbps. The CC1101 operates using an SPI control interface which is typically integrated into a circuit with a MCU and additional passive components.

2.7.4 Wireless Range

An important aspect of any radio transmission is the range at which it can travel. The eZ430-Chronos used in this design has a 433MHz RF transceiver that undergoes a transmission of signal energy that is limited by several factors that include the data rate, antenna size and output power. This transmission of energy is described by the Friis-equation of the theory of path loss and propagation, outlined in equation 2.9. [43]

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^n}, \quad at\ n = 2 \tag{2.9}$$

$$\begin{aligned}
&where: \\
&P_R = Power\ available\ from\ receiving\ antenna \\
&P_T = Power\ supplied\ to\ the\ transmitting\ antenna \\
&G_R = Gain\ in\ receiving\ antenna \\
&G_T = Gain\ in\ transmitting\ antenna \\
&\lambda = wavelength \\
&d = distance
\end{aligned}$$

There are several other factors that are important in the wireless range of radio transmissions, however this equation is effective in calculating the range of the eZ430-Chronos wireless RF transmission in an open area.

2.7.5 Associated Software

There are several different software tools that are used for different areas of the eZ430-Chronos design and its features, which are based on TI's SimpliciTI protocol stack. Some functions however, use the BlueRobin ultralow-power protocol stack and either this or SimpliciTI will be selected automatically depending on the feature being used.

Control Center

The eZ430-Chronos Control Center software provides features that are able to effectively demonstrate the wireless capabilities of the device, which are: [38]

- 3D acceleration graph of real time accelerometer data
- Wireless PowerPoint remote control
- Synchronization control for the time, date, altimeter and thermometer
- Heart rate, distance and speed simulator
- Wireless firmware updater

These features are located on the different tabs of the user interface, shown in figure 2.12. [38]

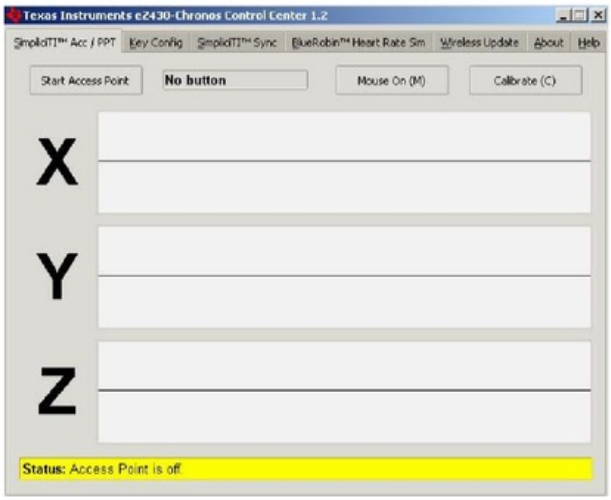

Figure 2.12: eZ430-Chronos Control Center Interface

The tabs, as well as a brief description of each, is outlined in table 2.3.

Tabs	Description
SimpliciTI Acc	Transmits near real time graphical and numerical acceleration data from the eZ430-Chronos to the PC
SimpliciTI PPT	Allows the eZ430-Chronos to be used as a simple PC remote control, with the default setting being PowerPoint control
Key Config	Allows the user to map PC key bindings to the eZ430-Chronos for different functions in the SimpliciTI PPT mode
SimpliciTI Sync	Allows the time, date, temperature and altitude readings to be calibrated for the eZ430-Chronos
BlueRobin Heart Rate Sim	Simulates the heart rate of a patient, as well as simulate the speed and distance that a patient could be traveling
Wireless Update	Allows for a wireless firmware update of the eZ430-Chronos without disassembly

Table 2.3: Control Center Tabs

eZ430-Chronos Datalogger

This piece of software can turn the eZ430-Chronos into a data logger that can be defined in intervals between 1-255 seconds and can log anywhere from several hours to days of data. The data can then be transferred from the eZ430-Chronos to a PC, in comma-separated values (CSV) format, where it can be analyzed by an authorized staff member.

This mode contains fewer features than the default eZ430-Chronos software, as memory for extra features is freed up in order to increase the storage capacity. Some of the available features in Data Logger mode are: [38]

- Altitude
- Heart Rate
- Data Logger Information

To enable the Data Logger Mode on the eZ430-Chronos wrist module, the # button needs to be pushed until the word dLog appears on the bottom line of the LCD screen. This mode is then enabled or disabled by simply pushing the DOWN button of the wrist module.

Similar to the Control Center outlined in section 2.7.5, the features of the data logger software are located within different tabs of the user interface, as outline in figure 2.13. [38]

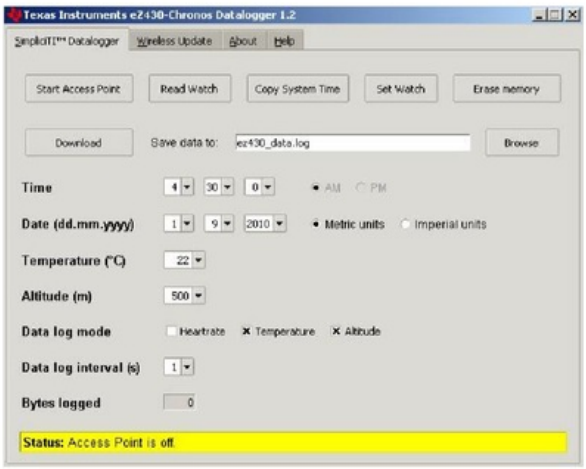

Figure 2.13: eZ430-Chronos Data Logger Interface

The tabs for the data logger software, as well as a brief description of each, is outlined in table 2.4.

Tabs	Description
SimpliciTI Datalogger	This mode allows for the calibration of the wrist module data, as well as the ability to view logged data
Wireless Update	This tab allows for a wireless firmware update of the eZ430-Chronos without disassembly

Table 2.4: Data Logger Interface Tabs

eZ430-Chronos Integrated Development Environments (IDE)

In order to download any code to the CC430F6137 MCU inside the eZ430-Chronos, the Code Composer Studio (CCS) or IAR Embedded Workbench Kickstart IDE's will need to be used. For the design of the patient monitoring device, TI's CCS IDE was used.

The eZ430-Chronos software structure follows the menu items that are available on the wrist module. Therefore, each menu item is stored as a separate source file that contains the menu and functions for that item. This structure is shown in figure 2.14. [38]

Figure 2.14: eZ430-Chronos Software Structure

From this structure it is clear that the following steps are followed in the operation of the eZ430-Chronos device: [38]

- Power-up reset initializes the hardware
- Display memory clears and radio is on standby
- Main loop needs a wake-up event to be initiated. Wake up events include a scheduled event or button event
- Button events within this structure lead to mx_functions or sx_functions
- If the LCD receives updated data, one of or both of the LCD Lines will be updated with specific display functions

Chapter 3

Experimental Procedures

3.1 Introduction

The proposed design for this device uses the eZ430-Chronos and its associated software to create an initial working prototype for a wireless patient monitoring device. The device needs to be tested to ensure its validity as a way to monitor patients wirelessly in a hospital and collect statistical data for analysis by medical staff. For these experiments to be achieved, a method for experimenting on separate aspects of the device needs to be considered and are outlined in this section. The accelerometer, temperature sensor, altimeter, and wireless range of the device are the main tests with correct operation of the software also being experimented on to ensure that data can be sent and collected correctly from the eZ430-Chronos to a PC.

3.2 eZ430-Chronos Tests

3.2.1 Disassembly, Debugging and Reassembly

In order to program and debug the CC430F6137 MCU, it needs to be connected to the PC using the associated JTAG interface. However, the module can only be connected to the interface after being removed from the housing and this can be achieved by using the following method from TI. [38]

1. Remove screws on the rear of the wrist module using Phillips screwdriver
2. Remove the metal plate from the wrist module, ensuring not to damage any of the exposed gaskets
3. Lift out the Chonos module using the screwdriver
4. Remove the battery by placing the screwdriver tip under the small metal tab between the battery and battery holder, and lifting

5. Connect the Chronos module to the JTAG emulator interface. Ensure that the Chronos module and the USB connector are on the same side as the PCB as shown in figure 3.1. [38]

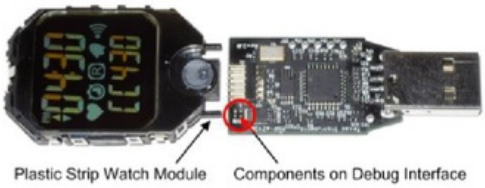

Figure 3.1: eZ430-Chronos Module to Interface Connection

Once connected and plugged into a PC, the MCU can be reprogrammed using the software protocols outlined in section 2.7.5 before reassembly. The process for reassembly is outlined in the following continuation of the previous method.

6. Reinsert the battery with the, "+" side facing up, into the module and close the battery clip
7. Insert the eZ430-Chronos module parallel to the housing and ensure that the small metal button strips slide over the buttons in the housing
8. Place the metal plate onto the rear of the housing and replace screws, ensuring they are properly tightened

If all of the steps are followed, successful debugging of the eZ430 Chronos wrist module will occur.

3.3 eZ430-Chronos Sensor Tests

The eZ430-Chronos inbuilt and additional sensors will be experimented on using the Control Center PC software to assess its ability in patient monitoring. Not all the required sensors for patient monitoring are included in the device and will not be tested in this document. However, to implement further sensors, default operating data and information collected in this section will be required.

3.3.1 Accelerometer Tests

Initial accelerometer tests were conducted using the inbuilt accelerometer and orientating the eZ430-Chronos in all possible directions in order to give a significant reading on one axis and a reading of zero on the other two. This was achieved using two metal beams and a level to ensure that the accelerometer was aligned on perfect angles at all times to get accurate readings. For the purpose of this experiment, the default orientation of the eZ430-Chronos has its face orientated perpendicular to the ground.

3.3.2 Temperature Tests

Temperature can be calibrated to read 36°C after being left on wrist for a suitable amount of time. In order to test the integrated thermometer from the eZ430-Chronos' CC430F6137 MCU, the experimental environment must be kept at a constant temperature. The ambient response time of the thermometer will be tested by wearing the device and allowing the thermometer to reach skin temperature then removing it, allowing the thermometer to naturally cool down. This will be done over the period of 1°C, noting down the time in seconds between each 0.1°C.

3.3.3 Altimeter Tests

The inbuilt barometric pressure sensor/altimeter within the eZ430-Chronos device is a useful too that can be used to monitor a patients vertical location within an environment. For this experiment the altimeter will be used to determine the floor of the Macquarie University Hospital that a patient will be located on. This is achieved by calibrating the altimeter to read zero when wearing the device at a neutral level, approximately 1m above ground floor level. Readings will then be taken from the eZ430-Chronos wrist module at a neutral 1m above the floor on each level of the building, to find a correlation between altitude and floor height.

3.3.4 Wireless Range Tests

In order test the range of the eZ430-Chronos device, a PC with the CC1101 USB RF access point will be set up in an open, unobstructed area, with no large radio towers nearby, to test the maximum ideal range. It is also important that all devices with wireless capabilities within the test zone are to be turned off to ensure that no other small radio traffic will interfere with the readings. The measured range then needs to be compared to a calculated range based on equations used in section 2.7.4.

3.3.5 Heart Rate, Speed, Calories and Distance Sensor Testing

The eZ430-Chronos allows for the measurement of heart rate, speed, calorie loss and distance traveled by a patient. However, this requires a separate chest belt device that is unobtainable, as the Australian version of the eZ430-Chronos operates at a 433MHz frequency which is no longer sold. This means the associated accessories are also no longer available.

The operation of this device would have greatly increased the functionality of the eZ430-Chronos, with more data being able to be transmitted to the Control Center, in turn increasing the amount of data that hospital staff would be able to monitor. When the heart rate monitor is active, it allows for a near real time output of a patients heart rate as well as being able to determine the calories burned by a patient. The calorie data output is dependent on an initial setup of the device that includes a patients weight and gender. There is also an included speed mode which can show the running or movement speed of the patient while they are up and moving around, which is controlled by a built-in accelerometer on the chest belt. The chest belt data cannot be accurately collected without the actual device, but it can be simulated using the TI Control Center's BlueRobin Heart Rate Sim as outlined in table 2.3 of section 2.7.5

3.4 Data Output Tests

The eZ430-Chronos has the ability to log temperature and altitude data at certain intervals and transmit the data back to the RF transceiver. From there, the data can be saved onto a PC for further analysis. This function will tested by setting both the temperature and data to values of 20°C and 20m respectively and wearing the wrist module for a period of one hour whilst undertaking various tasks. Once the hour is complete, logging of the data should be stopped and connected to the PC to receive a result. This should, theoretically, output data into a csv format which can then be graphed and viewed by a user.

Chapter 4

Results

4.1 Introduction

The results of the tests that are outlined in chapter 3 are shown in this section, with possible improvements for further testing also detailed. The results outlined are intended to prove that the eZ430-Chronos is a valid device for wirelessly monitoring patients within a hospital.

4.2 ez430-Chronos Sensor Test Results

4.2.1 Accelerometer Test Results

The readings taken from the SimpliciTI Acc mode of the Control Center software as outlined in section 3.3.1 are detailed in table 4.1

The data outlined in the table is able to show, in near real time, the orientation of a patient within the hospital. Therefore, it will be clear whether a patient is up moving around or lying down in their bed. This can be important for medical staff to show how much exercise or movement a patient is undergoing on a daily basis. The data will be collected and compiled at the end of each day to show daily statistics of each patient for medical staff.

	x	y	z
Up	0	0	1200
Down	0	0	-1200
Right/Up	1200	0	0
Right/Down	-1200	0	0
Right/Right	0	-1200	0
Right/Left	0	1200	0
Left/Up	1200	0	0
Left/Down	-1200	0	0
Left/Right	0	-1200	0
Left/Left	0	1200	0
In/Up	1200	0	0
In/Down	-1200	0	0
In/Right	0	1200	0
In/Left	0	-1200	0
Out/Up	1200	0	0
Out/Down	-1200	0	0
Out/Right	0	-1200	0
Out/Left	0	1200	0

Table 4.1: Accelerometer Test Results

4.2.2 Temperature Test Results

The readins taken from the eZ430-Chronos wrist module as outlined in section 3.3.2 are detailed in table 4.2.

Temperature Change (°C)	Time (s)
34 → 33.9	10.2
33.9 → 33.8	9.3
33.8 → 33.7	9.7
33.7 → 33.6	9.7
33.6 → 33.5	9.5
33.5 → 33.4	10.0
33.4 → 33.3	10.1
33.3 → 33.2	9.9
33.2 → 33.1	10.0
33.1 → 33	9.8

Table 4.2: Temperature Test Results

From these results it is clear that the temperature sensor within the eZ430-Chronos has a slow response time which might not relay information over the wireless signal fast enough for the system to pick up an irregular temperature. This will increase the response of medical staff and could potentially be harmful to a patient.

4.2.3 Altimeter Test Results

The readings taken from the eZ430-Chronos wrist module as outlined in section 3.3.3 are detailed in table 4.3.

Hospital Level	Altimeter Reading (m)
Level 1	2
Level 2	3
Level 3	5
Level 4	7
Level 5	8

Table 4.3: Altimeter Test Results

The altimeter data produced by the eZ430-Chronos pressure sensor algorithm that is used relies on air pressure and ambient temperature in order to calculate the altitude. Therefore in order to achieve precise measurements from the device, the altimeter must be calibrated regularly to account for differences in weather and room temperature. The device also should not be worn on the patients wrist when determining the altitude as the module works more effectively in ambient temperature. [38] This is reflected in the above results which only show readings of between 1 and 2 meters difference between the floors of the hospital.

4.2.4 Wireless Range Test Results

The wireless range of the eZ430-Chronos have been calculated and measured as outlined in section 3.3.4 The calculated results are detailed in equation 4.1.

$$
\begin{aligned}
P_R &= P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^n}, \quad at\ n = 2 \\
&= 0.001 \cdot \frac{1 \cdot 1 \cdot (\frac{3 \cdot 10^8}{433 \cdot 10^9})^2}{(4\pi)^2 \cdot 100^2} \\
&= 3.04 \cdot 10^{-16} \\
&= -125.17(dBm)
\end{aligned}
\tag{4.1}
$$

Therefore, the path loss in free space over a 100m distance is 125.17 dBm over a 100m distance. This shows, theoretically, that the wireless range of the eZ430-Chronos is limited and would require improvements in order to function effectively for the proposed design. The measured results for the wireless range of the eZ430-Chronos are illustrated in figure 4.1.

Figure 4.1: Wireless Range Test Results

Figure 4.1 clearly illustrates the poor range of the eZ430-Chronos wireless device. The wireless range is therefore an area of the design that needs to be significantly improved for a working wireless patient monitoring device to be constructed. The range cannot be improved for this device as the frequency is restricted to 433MHz and the size of the antenna cannot be altered.

4.3 Data Output Test Results

The eZ430-Chronos was used as a data logger over the period of one hour, logging every 10 seconds. The logger is able to collect data on the altitude of the eZ430-Chronos as well as the temperature and, if the separate accessory is connected, the patients heart rate. The results of a test of the data logging function of the device is illustrated in figure 4.2.

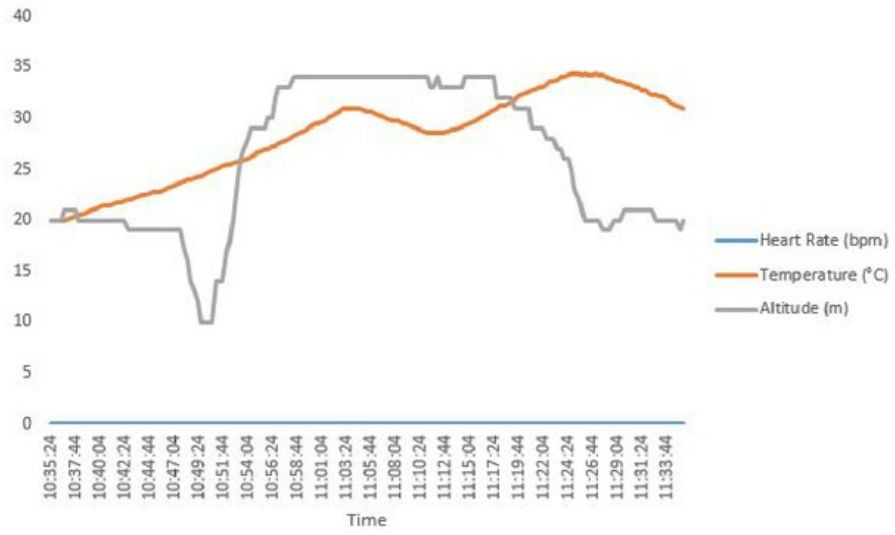

Figure 4.2: Data Output Test Results

In order to improve on this method, the logging interval should be increased to a period of 10 minutes. This would allow the data to be logged for longer periods of time, thus allowing for a more efficient usage of the device. This is significant as the memory of the eZ430-Chronos is limited to 8KB of data, which will stop recording data after extended periods of time. Furthermore, the current design requires the user to manually connect the eZ430-Chronos with a PC to upload the logged data, which is not an ideal situation for use in a hospital. The patient cannot be expected to upload their own data when often they may be physically unable to. Therefore, an improvement on this design would be to configure the device to automatically switch on and off its wireless capabilities to upload the data to the hospital server. Finally, the uploaded data only outputs as a csv file, which is acceptable for numerical information, but needs to be manually graphed. A final improvement would be a modification to the associated Control Center software, to allow for the data to be outputted numerically and also have it automatically graph the results.

Chapter 5

Discussion

A way for hospitals, and their medical staff, to wirelessly monitor a patients wellbeing would be extremely useful with the current aging population, in order to better handle the increasing trend in people needing medical care. There are several designs already in the market such as, AliveCor, AirStrip or GrandCare Systems [3] [5] [9] that function similar to the proposed design, but none achieve the result that is required. An important factor in being able to monitor a patient effectively, is choosing a sensor that can handle the specific requirements of vital signs that need measuring. A quality accelerometer, to measure a patients orientation; a sensitive thermometer, to measure a patients temperature; a pulse oximeter to measure a patients heart rate and oxygen saturation levels; and finally, a barometric pressure sensor to be able to track what floors of the hospital that the patient is visiting.

The eZ430-Chronos contains most of the sensors required for a successful patient monitoring device, which are its built in temperature sensor and its additional accelerometer and pressure sensor from Bosch Sensortec. [40] [41] These sensors are able to connect to the associated RF transceiver to wirelessly transmit sensor data to the PC. On the PC, the associated software is able to show, in near real time, output from the sensors. However, in its current design, the wireless range of the device is limited and would need to be increased in a future design. Another main drawback of the eZ430-Chronos' design are its computer interfaces. The Control Center interface outputs near real time accelerometer data, but does not log the data for later analysis. Conversely, to use the device with its data logging design, the eZ430-Chronos' firmware needs to be altered, and the associated Datalogger PC interface needs to be used. Unfortunately, the Datalogger interface only outputs altitude, heart rate and temperature data from the device and not any data relating to the accelerometer. For an effective wireless patient monitoring device, all of the sensors should output data to a single interface in order to streamline the users experience with the software.

The sensors within the eZ430-Chonos all operate as expected, but with some areas requiring improvement in future designs. The accelerometer behaves exactly as intended, showing the orientation of a patient, whether they are upright moving around or lying down in bed. The temperature sensor gives an accurate reading of the temperature, but due to the nature of the integrated sensor design, there is a significant delay in temperature changes. This could have negative consequences when relying on this data as it is an important tool for monitoring the patient. The altimeter works to some extent, however when dealing with such small changes in altitude, the specific sensor within the eZ430-Chronos is not accurate enough to achieve quality readings in order to create an altitude range that applies for each of the different floors of the hospital. The wireless range of the device is definitely an area that needs improvement, however the eZ430 is restricted to 433MHz in Australia and cannot be altered.

While the eZ430-Chronos device is able to operate as a wireless patient monitoring device, there are some areas that need improvement. The range of the device is a significant factor which will be solved possibly by using a different signal transmission protocol. The use of WiFi, Bluetooth or ZigBee may better handle the range and data transfer rates that are required for the design. What may also be used are multiple transceiver to bounce the signal from the device to the interface or different frequencies that may allow for a greater range given the small size of the antenna that would be required. More sensors will also need to be added, such as a pulse sensor or oxygen saturation sensor to improve the range of vital signs that the device will be able to monitor. In order to solve many of these hardware problems, it may be viable to create a design from scratch using individually sourced sensors that are compatible with one another. One final improvement that could be made is a completely redesigned PC interface that is able to log data from all of the sensors, store it and output it both numerically and graphically. Other than these improvements the eZ430-Chronos was able to perform as an effective wireless patient monitoring device.

Chapter 6

Conclusion

In conclusion, it is clear that the eZ430-Chronos is able to perform as an effective wireless patient monitoring device. The device is an excellent example of a wireless wearable system that can use its accelerometer, thermometer and pressure sensor to monitor vital signs in a patient. It also seamlessly interfaces with the associated RF access point transceiver, which can then display relevant data on the eZ430-Chronos' PC interface. The device can successfully take an accelerometer and temperature data reading and output it to the user in a clear format. The altimeter also performs satisfactorily and data can be easily outputted to a csv file. The wireless range of the device is lower than expected and will need to be improved upon for the final design of the device, but overall achieves the desired result.

Future iterations of the design have some areas of improvement. Such areas include the quality and precision of some sensors as well as a redesigned interface. Different types of sensors, and how they compare with one another, have been outlined in this document and if the design was made from scratch, sensors could be easily picked based on this information. A redesigned interface would be a challenging task, but would improve the overall design by streamlining the experience and clearly displaying, on the PC, the necessary information relevant to a patients wellbeing. Despite these improvements, the eZ430-Chronos is an excellent foundation for the design of an extremely successful wireless patient monitoring device.

Chapter 7

Future Work

7.1 Privacy Leakage in Wireless Systems

A main concern in the wireless wearable devices industry is the privacy of the data being collected by these devices with a violation of privacy being described as an intentional or unintentional disclosure of personal data. [2] Different wearable devices often use different traffic patterns and any information that is sent via those patterns periodically, can possibly be vulnerable to leakage to other users using the same patterns.

For example, Fitbit was discovered to have several areas of poor security that makes a users personal data vulnerable. [44] The Fitbit device focuses on recording the fitness sensor data of its user such as calories burned, steps climbed and distance traveled, which is then automatically uploaded to the online network where it displays and shares the retrieved data. [45] The vulnerabilities appear in its communication protocol, which relies on a Personal Area Network (PAN) protocol named ANT which uploads the data. This protocol allows external attacks that intercept data, upload false data and launch denial of service (DDoS) attacks by simply reverse engineering the service logs that the Fitbit produces. [44]

The Fitbit is just one example of how private data collected on a wireless device can easily be made vulnerable by a competent attacker. This therefore extends over to the proposed design of the patient monitoring device in this document. The data being collected by the system when in a hospital would be expected to be kept private and therefore requires that the device transmissions are secured.

7.2 Wireless Range

The wireless range that was measured from the eZ430-Chronos device as outlined in section 4.2.4 does not have a significantly large range and will vary between floors in the hospital, as well as being interfered by the radio traffic that that will be present within other medical devices in the hospital. This means that the following items will need to be addressed in future work to improve the wireless connection of the system:

- Range
- Multiple transceivers
- Different frequencies

With the limited wireless range of the eZ430-Chronos device it is possible that multiple transceivers may be used in order to extend the range. The multiple transceivers will act as nodes that will allow the wireless signal to be bounced between them until it reaches the final terminal that contains the interface. A greater range will increase the usability of the device as it will work in all areas of the hospital, including outdoors and in recreation facilities that are incorporated as part of the hospital.

Many of the medical devices that are within a hospital need to operate at certain frequencies in order to communicate information to hospital staff. For the eZ430-Chronos to work effectively, it needs to operate at a frequency that is empty and does not interfere with any other devices. The current device operates at a frequency of 433MHz which is an international frequency, but may not be allowed within a hospital.

7.3 Additional Sensor Integration

The eZ430-Chronos only contains the four sensors outlined in section 2.7.2, however more sensors, not experimented on in this document, will be required in an improved design in order to allow for better monitoring of a patients vital signs. Currently, the device only allows for the patients body temperature, body orientation and vertical location within the hospital to be measured. This allows for some degree of patient monitoring, but not enough for a fully operational device to be used within a hospital which requires more information. Further sensors that will need to be used are:

- Pulse Sensor
- Oxygen Saturation Sensor

With these sensors implemented in the final design, an accurate measurement of a patients vitals will be able to be measured by the staff within a hospital.

7.4 Alternate Wireless Signal Transmission Protocols

The wireless transmission protocol that is used in the eZ430-Chronos is a 433MHz RF radio operating frequency, with a 868MHz and 915MHz also available in other countries worldwide. This type of transmission is inversely proportional to the range of the device, with lower frequencies such as 433MHz, traveling greater distances, with greater penetration than higher frequencies. However, frequencies with a greater wavelength will require a larger antenna which needs to be taken into account when designing a wireless device.

Other wireless transmission protocols could possibly be used for the design of a wireless patient monitoring device, with one such possible protocol being ZigBee. ZigBee is a low-cost and low-power, open standard protocol based on the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard [46] that uses a short range radio transmission that is primarily designed for RF applications. These applications generally require long battery lives and low data rates as well as a secure networking protocol, which is ideal for usage as a wireless patient monitoring device. [47] The ZigBee protocol may be a more advantageous protocol than the current eZ430-Chronos protocol, as it provides a higher reliability as well as a greater range due to its mesh networking. The disadvantages of ZigBee are based around its current protocol standards which, at this stage, do not consider how reliable messages are that are sent over its network or how slowly, averaging at only 250Kbps. [48] This can be deadly if the information being sent involves delicate patient information or emergency messages that contain information regarding deteriorating vital signs of a patient.

The use of WiFi as the protocol of a wireless patient monitoring device some advantages over ZigBee, such as allowing for a more reliable and secure connection and faster connectivity with its IEEE 802.11N protocol standards. [48] WiFi is mainly used in applications that require devices to be connected with one another as well as the internet and some wired networks. Therefore, WiFi operates in the radio band range of between 2.4GHz and 5GHz, which is able to deliver significant data speeds of up to 600Mbps.

Another protocol that may be used for wireless patient monitoring is Bluetooth, which operates using the IEEE 802.15.1 standard. [48] Bluetooth has possibly the highest security of the previously detailed transmission protocols, using a spread spectrum with a full duplex signal that operates at a nominal frequency hopping of 1600 hops/s, which allows for the transmissions to be protected against any users trying to eavesdrop on the signal. There are several advantages with using Bluetooth, which include a high bandwidth with low latency and that it is a low cost product, supported by many mobile platforms allowing for easy integration with any designed interface system. Despite these advantages, Bluetooth also has a relatively short range of only 10m, a high power consumption due to its inefficient idling and long start up times. [49]

The newest version of Bluetooth, version 4.0, is known as Bluetooth Low Energy (BLE) and it has similar design properties to older versions of Bluetooth but has a 10% lower power consumption, with a three millisecond faster start up time and a data transfer rate of approximately 1Mbps. [50]

In order to create an ideal patient monitoring device it is important to consider the option that will allow for a small size, so it is not inconvenient to the user, and low power consumption in order to last for long periods of time without having to interact with the device in some form. The correct wireless protocol is important when it comes to deciding these factors as it can be the the aspect of the device that can create the largest problem in one of these areas. Therefore from this information, ZigBee would be the most ideal transmission protocol for a wireless patient monitoring device. It is able to communicate easily with most devices due to its open standard configuration as well as having a low power consumption and low cost. However, when using ZigBee in this scenario it is important that it will be properly programmed to ensure the most secure and reliable connection possible.

7.5 Computer Interface

The Control Center interface that is associated with the eZ430-Chronos shows valuable information related to the device. However, for the proposed design different information needs to be seen on the interface than the current Control Center interface is able to show. Therefore, a new interface needs to be designed that can show the relevant information that needs to be included. Incorporating the additional sensors that would be included, the interface needs to show the following information:

Sensor	Information Required
Patients Name	In order to identify the patient
Illness/Injury	Detailing the reason the patient is in hospital
Temperature	A reading of the patients body temperature
Altitude	A diagram illustrating the floor that the patient is on
Accelerometer/Distance	Shows the distance the patient has traveled
Pulse/Oxygen Saturation	Tracks the heart rate/oxygen saturation of the patients blood

Table 7.1: Proposed Computer Interface Requirements

The interface is also required to be user friendly in order to allow for all levels of user technology experience to be valid for the devices use. It also needs to be able to send out alerts when there is an abnormal reading from one of the sensors on the device. This includes spikes in temperature, weak/no pulse or low oxygen saturation. All other included sensors merely collect statistical data relevant to individual patient.

The information that is shown on the interface screen will change depending on the location within the hospital that the user is located. The patients will be shown on the interface based on what floor or section of the hospital they are located. Whether the patient is in intensive care or rehabilitation, the users in those sections will only be able to access information specific to patients in that area.

7.6 From Scratch Design

The device proposed in this document uses the pre-designed eZ430-Chronos developed by TI. In order to improve the design of this project, individual components need to be sourced and programmed to achieve the desired result without using any other companies designs. The sensors that will need to be sourced are chosen from the different sensor types outlined in chapter 2

7.6.1 Temperature Sensor

For a simple measurement of temperature in a patient, an analogue thermistor is the best design available. It allows for an easy conversion of a change in temperature of the resistor, into a simple voltage drop which can be measured and recorded through a MCU and then displayed using a designed interface. An appropriate thermistor choice is the Microchip MCP9701-E/TO 3-pin temperature sensor. [51] This is an analogue sensor that has an accuracy of $\pm 2^{\circ}C$ and operates on a standard voltage of between 3.1V and 5.5V. Further specifications of this component are outlined in appendix D.

7.6.2 Accelerometer

Similar to the temperature sensor, an analogue accelerometer will also be used to allow for a basic patient monitoring device system. The Analog Devices ADXL335 triple axis MEMS accelerometer breakout board [52] is an analogue sensor that has a sensitivity range of $\pm 3g$. It also has low power consumption and emits little to no noise which is ideal for the proposed system. A breakout board system is used to ensure simplicity and easy integration with all other components and has a low profile design to reduce the size of the overall device. There are further specifications regarding this sensor in appendix E.

7.6.3 Pulse Sensor

A further analogue sensor that will be used to improve the design of the wireless patient monitoring device is the SparkFun SEN-11574 Pulse Sensor. [53] This device allows for live heart rate data to be easily incorporated into the proposed design with the circuit comprising of a simple optical heart rate sensor and noise cancellation and amplification components. The allows for a fast a reliable pulse reading which only draws a maximum of 5V, fitting into the design criteria. The sensor is also small in dimensions, only measuring 0.625" in diameter and 0.125" thickness, for a small profile to help with the small overall size requirement of the patient monitoring device.

7.6.4 Oxygen Saturation Sensor

As outlined in section 2.5, most oxygen saturation sensor are equipped with the ability to monitor a patients pulse. This can lead to a more efficient design in terms of space, which is why the MAX30100 pulse oximeter and heart rate sensor IC from Maxim Integrated [54] will be used in the design of a wireless patient monitoring device. The MAX30100 is an analogue sensor that combines technology for sensing pulse and oxygen saturation, such as LED's and photodetectors, with a 1.8V to 3.3V operating range allowing for seamless integration into the proposed design. Further information regarding the MAX30100 can be found in appendix F.

7.6.5 Barometric Pressure Sensor

Despite the somewhat low accuracy of the eZ430-Chronos' BMP085 pressure sensor at precision heights, the sensor was effective in giving a simple altitude output. Therefore, the newer BMP280 barometric pressure sensor by Bosch Sensortec [55] will be used for this design. This device improves on the BMP085 by increasing performance by using digital interfaces, while decreasing the size and lowering power consumption. The design is based on piezoresistive pressure sensing technology, known for its high accuracy and linear outputs, as well as being able to quickly and easily output altitude data. Detailed in appendix G are the specifications regarding this sensors design.

7.6.6 MCU

In order for all the different components to communicate with one another, a suitable MCU must be chosen that will be compatible with each sensor. The PIC16F1615 by Microchip [56] has eight 10-bit analogue-to-digital converter (ADC) which is more than enough to support all the analogue sensors that are required for the wireless patient monitoring device design. It also supports an operating range of 1.8V to 5.5V and has three digital communication peripherals to support any digital sensors that may be added in future designs. Additional PIC16F1615 information is shown in appendix H.

Chapter 8

Abbreviations

ADC	Analogue-to-Digital Converter
BLE	Bluetooth Low Energy
BMI	Body Mass Index
CCS	Code Composer Studio
COPD	Chronic Obstructive Pulmonary Disease
CSV	Comma-Separated Values
DDoS	Denial of Service
ECG	Electrocardiograph
EHR	Electronic Health Record
FDA	Food and Drug Administration
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IR	Infrared
LED	Light-Emitting Diode
MCU	Microcontroller
MEMS	Micro-electromechanical system
MIT	Massachusetts Institute of Technology
NTC	Negative Temperature Coefficient
PAN	Personal Area Network
PTC	Positive Temperature Coefficient
RTD	Resistance Temperature Detector
SoC	System-on-Chip
TI	Texas Instruments
UV	Ultraviolet

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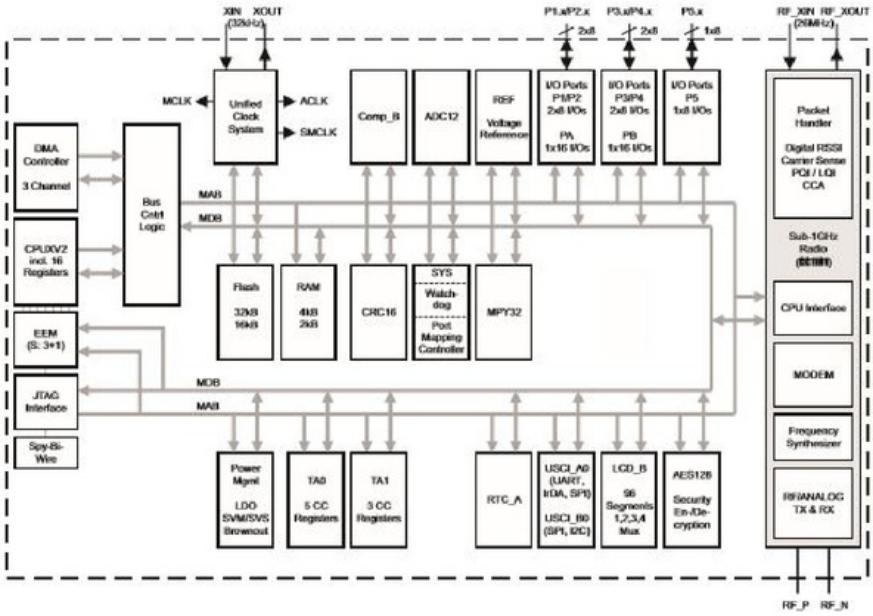
Appendix A

CC430F6137 MCU

A.1 Overview

This appendix contains elements from the data sheet of the CC430F6137 MCU from Texas Instruments. [57]

A.2 Functional Block Diagram



A.3 MCU Features

- True System-on-Chip (SoC) for Low-Power Wireless Communication Applications
- Wide Supply Voltage Range: 3.6 V Down to 1.8 V
- Ultralow-Power Consumption:
  - CPU Active Mode (AM): 160 µA/MHz
  - Standby Mode (LPM3 RTC Mode): 2.0 µA
  - Off Mode (LPM4 RAM Retention): 1.0 µA
  - Radio in RX: 15 mA, 250 kbps, 915 MHz
- MSP430 System and Peripherals
  - 16-Bit RISC Architecture, Extended Memory, up to 20-MHz System Clock
  - Wake Up From Standby Mode in Less Than 6 µs
  - Flexible Power-Management System With SVS and Brownout
  - Unified Clock System With FLL
  - 16-Bit Timer TA0, Timer_A With Five Capture/Compare Registers
  - 16-Bit Timer TA1, Timer_A With Three Capture/Compare Registers
  - Hardware Real-Time Clock (RTC)
  - Two Universal Serial Communication Interfaces
    - USCI_A0 Supports UART, IrDA, SPI
    - USCI_B0 Supports I^2C, SPI
  - 12-Bit Analog-to-Digital Converter (ADC) With Internal Reference, Sample-and-Hold, and Autoscan Features (CC430F613x and CC430F513x Only)
  - Comparator
  - Integrated LCD Driver With Contrast Control for up to 96 Segments (CC430F61xx Only)
  - 128-Bit AES Security Encryption and Decryption Coprocessor
  - 32-Bit Hardware Multiplier
  - Three-Channel Internal DMA
  - Serial Onboard Programming, No External Programming Voltage Needed
  - Embedded Emulation Module (EEM)
- High-Performance Sub-1-GHz RF Transceiver Core
  - Same as in CC1101
  - Wide Supply Voltage Range: 2.0 V to 3.6 V
  - Frequency Bands: 300 MHz to 348 MHz, 389 MHz to 464 MHz, and 779 MHz to 928 MHz
  - Programmable Data Rate From 0.6 kBaud to 500 kBaud
  - High Sensitivity (–117 dBm at 0.6 kBaud, –111 dBm at 1.2 kBaud, 315 MHz, 1% Packet Error Rate)
  - Excellent Receiver Selectivity and Blocking Performance
  - Programmable Output Power Up to +12 dBm for All Supported Frequencies
  - 2-FSK, 2-GFSK, and MSK Supported as Well as OOK and Flexible ASK Shaping
  - Flexible Support for Packet-Oriented Systems: On-Chip Support for Sync Word Detection, Address Check, Flexible Packet Length, and Automatic CRC Handling
  - Support for Automatic Clear Channel Assessment (CCA) Before Transmitting (for Listen-Before-Talk Systems)
  - Digital RSSI Output
  - Suited for Systems Targeting Compliance With EN 300 220 (Europe) and FCC CFR Part 15 (US)
  - Suited for Systems Targeting Compliance With Wireless M-Bus Standard EN 13757-4:2005
  - Support for Asynchronous and Synchronous Serial Receive or Transmit Mode for Backward Compatibility With Existing Radio Communication Protocols

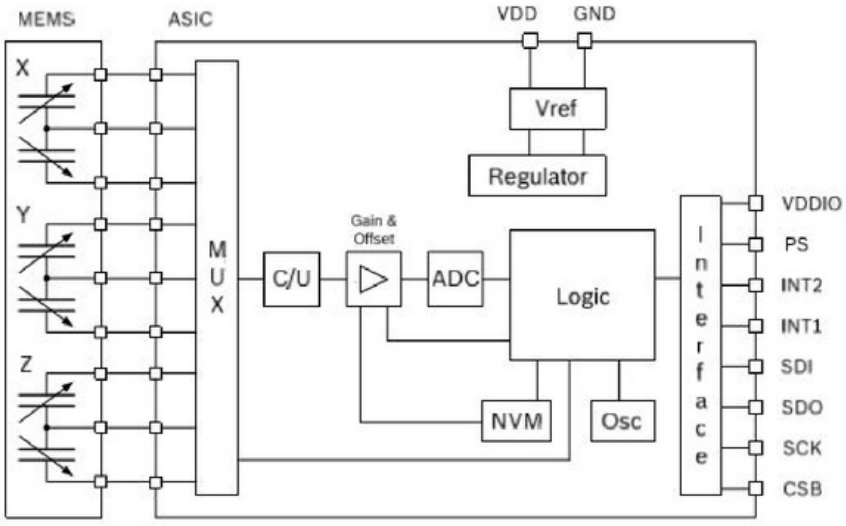
Appendix B

Bosch Sensortec BMA250 Accelerometer

B.1 Overview

This appendix contains elements from the data sheet of the BMA250 Accelerometer from Bosch Sensortec. [40]

B.2 Block Diagram



B.3 Parameter Specifications

OPERATING CONDITIONS						
Parameter	**Symbol**	**Condition**	**Min**	**Typ**	**Max**	**Units**
Acceleration Range	g_{FS2g}	Selectable via serial digital interface		±2		g
	g_{FS4g}			±4		g
	g_{FS8g}			±8		g
	g_{FS16g}			±16		g
Supply Voltage Internal Domains	V_{DD}		1.62	2.4	3.6	V
Supply Voltage I/O Domain	V_{DDIO}		1.2	2.4	3.6	V
Voltage Input Low Level	V_{IL}	SPI & I²C			$0.3V_{DDIO}$	-
Voltage Input High Level	V_{IH}	SPI & I²C	$0.7V_{DDIO}$			-
Voltage Output Low Level	V_{OL}	V_{DDIO} = 1.62V I_{OL} = 3mA, SPI & I²C			$0.2V_{DDIO}$	-
		V_{DDIO} = 1.2V I_{OL} = 3mA, SPI & I²C			0.23 V_{DDIO}	-
Voltage Output High Level	V_{OH}	V_{DDIO} = 1.62V I_{OL} = 2mA, SPI & I²C	$0.8V_{DDIO}$			-
		V_{DDIO} = 1.2V I_{OL} = 2mA, SPI & I²C	0.62 V_{DDIO}			-
Supply Current in Normal Mode	I_{DD}	Nominal V_{DD} supplies T_A=25°C, bw = 1kHz		139		µA
Supply Current in Low-Power Mode	I_{DDlp}	Nominal V_{DD} supplies T_A=25°C, bw = 1kHz sleep duration ≥ 25ms		7		µA
Supply Current in Suspend Mode	I_{DDsm}	Nominal V_{DD} supplies T_A=25°C		0.5		µA
Wake-Up Time	t_{w_up}	from Low-Power Mode or Suspend Mode, bw = 1kHz		0.8		ms
Start-Up Time	t_{s_up}	POR, bw = 1kHz		2		ms
Operating Temperature	T_A		-40		+85	°C

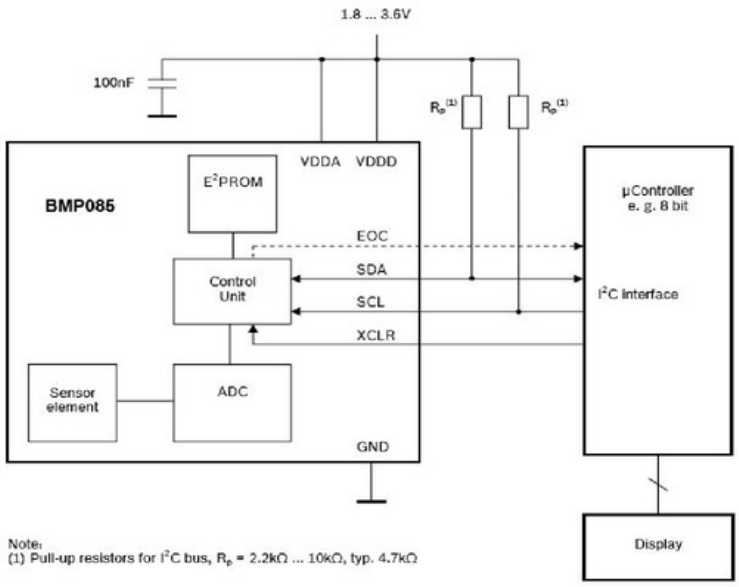
Appendix C

Bosch Sensortec BMP085 Pressure Sensor

C.1 Overview

This appendix contains elements from the data sheet of the BMP085 Pressure Sensor from Bosch Sensortec. [41]

C.2 Typical Circuit



C.3 Electrical Characteristics

Parameter	Symbol	Condition	Min	Typ	Max	Units
Operating temperature	T_A	operational	-40		+85	°C
		full accuracy	0		+65	
Supply voltage	V_{DD}	ripple max. 50mVpp	1.8	2.5	3.6	V
	V_{DDIO}		1.62	2.5	3.6	V
Supply current @ 1 sample / sec. 25°C	I_{DDLOW}	ultra low power mode		3		µA
	I_{DDSTD}	standard mode		5		µA
	I_{DDHR}	high resolution mode		7		µA
	I_{DDUHR}	ultra high res. mode		12		µA
Peak current	I_{peak}	during conversion		650	1000	µA
Standby current	I_{DDSBM}	at 25°C		0.1		µA
Serial data clock	f_{SCL}				3.4	MHz
Conversion time temperature	t_{C_temp}	standard mode		3	4.5	ms
Conversion time pressure	$t_{c\_p\_low}$	ultra low power mode		3	4.5	ms
	$t_{c\_p\_std}$	standard mode		5	7.5	ms
	$t_{c\_p\_hr}$	high resolution mode		9	13.5	ms
	$t_{c\_p\_luhr}$	ultra high res. mode		17	25.5	ms
Absolute accuracy pressure V_{DD} = 3.3V		700 . . . 1100 hPa 0 . . . +65 °C	-2.5	±1.0	+2.5	hPa
		300 . . . 700 hPa 0 . . . +65 °C	-3.0	±1.0	+3.0	hPa
		300 . . . 1100 hPa -20 . . . 0 °C	-4.0	±1.5	+4.0	hPa
Resolution of output data		pressure		0.01		hPa
		temperature		0.1		°C
Relative accuracy pressure		700 . . . 1100 hPa @ 25 °C		±0.2		hPa
V_{DD} = 3.3V		0 . . . 65 °C @ p const.		±0.5		hPa
Noise in pressure		see table on page 10				
Absolute accuracy temperature V_{DD} = 3.3V		@ 25 °C	-1.5	±0.5	+1.5	°C
		0 . . . +65 °C	-2.0	±1.0	+2.0	°C

Appendix D

MCP9701-E/TO 3-Pin Temperature Sensor

D.1 Overview

This appendix contains elements from the data sheet of the MCP9701-E/TO 3-Pin Temperature Sensor. [51]

D.2 Temperature Characteristics

Electrical Specifications: Unless otherwise indicated:
MCP9700/9700A: V_{DD} = 2.3V to 5.5V, GND = Ground, T_A = -40°C to +125°C and No load
MCP9701/9701A: V_{DD} = 3.1V to 5.5V, GND = Ground, T_A = -10°C to +125°C and No load

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Specified Temperature Range (Note 1)	T_A	-40	—	+125	°C	**MCP9700/9700A**
	T_A	-10	—	+125	°C	**MCP9701/9701A**
	T_A	-40	—	+150	°C	High Temperature **(MCP9700,** SOT23-3 and SC70-5 only)
Operating Temperature Range	T_A	-40	—	+125	°C	Extended Temperature
	T_A	-40	—	+150	°C	High Temperature
Storage Temperature Range	T_A	-65	—	+150	°C	
Thermal Package Resistances						
Thermal Resistance, 5LD SC70	θ_{JA}	—	331	—	°C/W	
Thermal Resistance, 3LD SOT-23	θ_{JA}	—	308	—	°C/W	
Thermal Resistance, 3LD TO-92	θ_{JA}	—	146	—	°C/W	

D.3 Electrical Characteristics

Electrical Specifications: Unless otherwise indicated:
MCP9700/9700A: V_{DD} = 2.3V to 5.5V, GND = Ground, T_A = -40°C to +125°C and No load
MCP9701/9701A: V_{DD} = 3.1V to 5.5V, GND = Ground, T_A = -10°C to +125°C and No load

Parameter	Sym.	Min.	Typ.	Max.	Unit	Conditions
Power Supply						
Operating Voltage Range	V_{DD} V_{DD}	2.3 3.1	— —	5.5 5.5	V V	**MCP9700/9700A** **MCP9701/9701A**
Operating Current	I_{DD}	—	6	12	µA	
	I_{DD}	—	—	15	µA	T_A = 150°C (**Note 1**)
Line Regulation	$\Delta°C/\Delta V_{DD}$	—	0.1	—	°C/V	
Sensor Accuracy (Notes 2, 3)						
T_A = +25°C	T_{ACY}	—	±1	—	°C	
T_A = 0°C to +70°C	T_{ACY}	-2.0	±1	+2.0	°C	**MCP9700A/9701A**
T_A = -40°C to +125°C	T_{ACY}	-2.0	±1	+4.0	°C	**MCP9700A**
T_A = -10°C to +125°C	T_{ACY}	-2.0	±1	+4.0	°C	**MCP9701A**
T_A = 0°C to +70°C	T_{ACY}	-4.0	±2	+4.0	°C	**MCP9700/9701**
T_A = -40°C to +125°C	T_{ACY}	-4.0	±2	+6.0	°C	**MCP9700**
T_A = -10°C to +125°C	T_{ACY}	-4.0	±2	+6.0	°C	**MCP9701**
T_A = -40°C to +150°C	T_{ACY}	-4.0	±2	+6.0	°C	**High Temperature (Note 1)**
Sensor Output						
Output Voltage, T_A = 0°C	$V_{0°C}$	—	500	—	mV	**MCP9700/9700A**
Output Voltage, T_A = 0°C	$V_{0°C}$	—	400	—	mV	**MCP9701/9701A**
Temperature Coefficient	T_C	—	10.0	—	mV/°C	**MCP9700/9700A**
	T_C	—	19.5	—	mV/°C	**MCP9701/9701A**
Output Nonlinearity	V_{ONL}	—	±0.5	—	°C	T_A = 0°C to +70°C (**Note 3**)

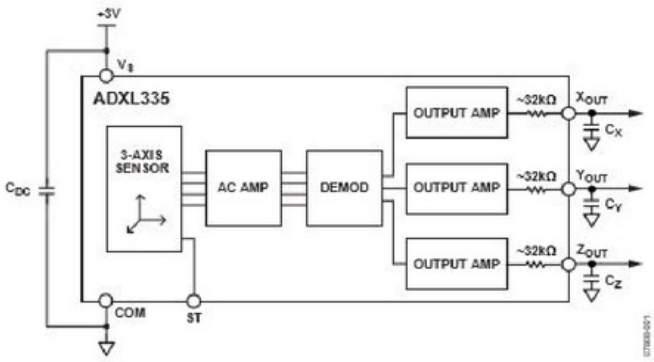
Appendix E

ADXL335 Small, Low Power, 3-Axis $\pm 3g$ Accelerometer

E.1 Overview

This appendix contains elements from the data sheet of the ADXL335 Small, Low Power, 3-Axis $\pm 3g$ Accelerometer. [52]

E.2 Functional Block Diagram



E.3 Specifications

T_A = 25°C, V_S = 3 V, C_X = C_Y = C_Z = 0.1 µF, acceleration = 0 g, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

Table 1.

Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range		±3	±3.6		g
Nonlinearity	% of full scale		±0.3		%
Package Alignment Error			±1		Degrees
Interaxis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity[1]			±1		%
SENSITIVITY (RATIOMETRIC)[2]	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 3 V	270	300	330	mV/g
Sensitivity Change Due to Temperature[3]	V_S = 3 V		±0.01		%/°C
ZERO g BIAS LEVEL (RATIOMETRIC)					
0 g Voltage at X_{OUT}, Y_{OUT}	V_S = 3 V	1.35	1.5	1.65	V
0 g Voltage at Z_{OUT}	V_S = 3 V	1.2	1.5	1.8	V
0 g Offset vs. Temperature			±1		mg/°C
NOISE PERFORMANCE					
Noise Density X_{OUT}, Y_{OUT}			150		µg/√Hz rms
Noise Density Z_{OUT}			300		µg/√Hz rms
FREQUENCY RESPONSE[4]					
Bandwidth X_{OUT}, Y_{OUT}[5]	No external filter		1600		Hz
Bandwidth Z_{OUT}[5]	No external filter		550		Hz
R_{FILT} Tolerance			32 ± 15%		kΩ
Sensor Resonant Frequency			5.5		kHz
SELF-TEST[6]					
Logic Input Low			+0.6		V
Logic Input High			+2.4		V
ST Actuation Current			+60		µA
Output Change at X_{OUT}	Self-Test 0 to Self-Test 1	−150	−325	−600	mV
Output Change at Y_{OUT}	Self-Test 0 to Self-Test 1	+150	+325	+600	mV
Output Change at Z_{OUT}	Self-Test 0 to Self-Test 1	+150	+550	+1000	mV
OUTPUT AMPLIFIER					
Output Swing Low	No load		0.1		V
Output Swing High	No load		2.8		V
POWER SUPPLY					
Operating Voltage Range		1.8		3.6	V
Supply Current	V_S = 3 V		350		µA
Turn-On Time[7]	No external filter		1		ms
TEMPERATURE					
Operating Temperature Range		−40		+85	°C

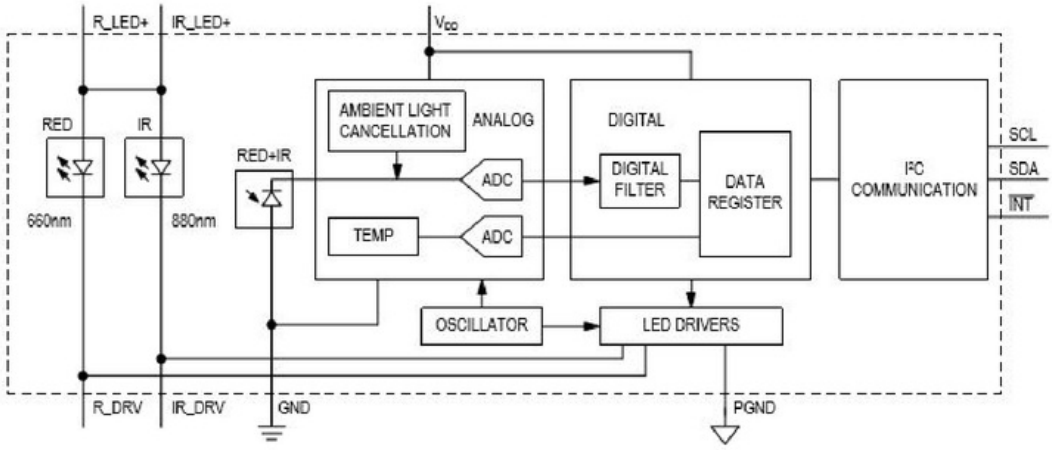
Appendix F

MAX30100 Pulse Oximeter and Heart-Rate Sensor IC

F.1 Overview

This appendix contains elements from the data sheet of the MAX30100 Pulse Oximeter and Heart-Rate Sensor IC. [54]

F.2 Functional Block Diagram



F.3 Electrical Characteristics

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
POWER SUPPLY							
Power-Supply Voltage	V_{DD}	Guaranteed by RED and IR count tolerance		1.7	1.8	2.0	V
LED Supply Voltage (R_LED+ or IR_LED+ to PGND)	V_{LED+}	Guaranteed by PSRR of LED Driver		3.1	3.3	5.0	V
Supply Current	I_{DD}	SpO_2 and heart rate modes, PW = 200µs, 50sps			600	1200	µA
		Heart rate only mode, PW = 200µs, 50sps			600	1200	
Supply Current in Shutdown	I_{SHDN}	T_A = +25°C, MODE = 0x80			0.7	10	µA
SENSOR CHARACTERISTICS							
ADC Resolution					14		bits
Red ADC Count (Note 3)	RED_C	Propriety ATE setup RED_PA = 0x05, LED_PW = 0x00, SPO2_SR = 0x07, T_A = +25°C		23,000	26,000	29,000	Counts
IR ADC Count (Note 3)	IR_C	Propriety ATE setup IR_PA = 0x09, LED_PW = 0x00, SPO2_SR = 0x07, T_A = +25°C		23,000	26,000	29,000	Counts
Dark Current Count	DC_C	RED_PA = IR_PA = 0x00, LED_PW = 0x03, SPO2_SR = 0x01			0	3	Counts
DC Ambient Light Rejection (Note 4)	ALR	Number of ADC counts with finger on sensor under direct sunlight (100K lux) LED_PW = 0x03, SPO2_SR = 0x01	RED LED		0		Counts
			IR LED		0		

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
IR ADC Count—PSRR (V_{DD})	$PSRR_{VDD}$	Propriety ATE setup 1.7V < V_{DD} < 2.0V, LED_PW = 0x03, SPO2_SR = 0x01, IR_PA = 0x09, IR_PA = 0x05, T_A = +25°C		0.25	2	%
		Frequency = DC to 100kHz, 100mV_{P-P}		10		LSB
RED/IR ADC Count—PSRR (X_LED+)	$PSRR_{LED}$	Propriety ATE setup 3.1V < X_LED+ < 5V, LED_PW = 0x03, SPO2_SR = 0x01, IR_PA = 0x09, IR_PA = 0x05, T_A = +25°C		0.05	2	%
		Frequency = DC to 100kHz, 100mV_{P-P}		10		LSB
ADC Integration Time	INT	LED_PW = 0x00		200		µs
		LED_PW = 0x03		1600		µs
IR LED CHARACTERISTICS (Note 4)						
LED Peak Wavelength	λ_P	I_{LED} = 20mA, T_A = +25°C	870	880	900	nm
Full Width at Half Max	$\Delta\lambda$	I_{LED} = 20mA, T_A = +25°C		30		nm
Forward Voltage	V_F	I_{LED} = 20mA, T_A = +25°C		1.4		V
Radiant Power	P_O	I_{LED} = 20mA, T_A = +25°C		6.5		mW
RED LED CHARACTERISTICS (Note 4)						
LED Peak Wavelength	λ_P	I_{LED} = 20mA, T_A = +25°C	650	660	670	nm
Full Width at Half Max	$\Delta\lambda$	I_{LED} = 20mA, T_A = +25°C		20		nm
Forward Voltage	V_F	I_{LED} = 20mA, T_A = +25°C		2.1		V
Radiant Power	P_O	I_{LED} = 20mA, T_A = +25°C		9.8		mW
TEMPERATURE SENSOR						
Temperature ADC Acquisition Time	T_T	T_A = +25°C		29		ms
Temperature Sensor Accuracy	T_A	T_A = +25°C		±1		°C
Temperature Sensor Minimum Range	T_{MIN}			-40		°C
Temperature Sensor Maximum Range	T_{MAX}			85		°C

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DIGITAL CHARACTERISTICS (SDA, SDA, $\overline{INT}$)						
Output Low Voltage SDA, $\overline{INT}$	V_{OL}	I_{SINK} = 6mA			0.4	V
I²C Input Voltage Low	V_{IL_I2C}	SDA, SCL			0.4	V
I²C Input Voltage High	V_{IH_I2C}	SDA, SCL	1.4			V
Input Hysteresis	V_{HYS}	SDA, SCL		200		mV
Input Capacitance	C_{IN}	SDA, SCL		10		pF
Input Leakage Current	I_{IN}	V_{IN} = 0V, T_A = +25°C (SDA, SCL, INT)		0.01	1	µA
		V_{IN} = 5.5V, T_A = +25°C (SDA, SCL, INT)		0.01	1	µA
I²C TIMING CHARACTERISTICS (SDA, SDA, $\overline{INT}$)						
I²C Write Address				AE		Hex
I²C Read Address				AF		Hex
Serial Clock Frequency	f_{SCL}		0		400	kHz
Bus Free Time Between STOP and START Conditions	t_{BUF}		1.3			µs
Hold Time (Repeated) START Condition	$t_{HD,START}$		0.6			µs
SCL Pulse-Width Low	t_{LOW}		1.3			µs
SCL Pulse-Width High	t_{HIGH}		0.6			µs
Setup Time for a Repeated START Condition	$t_{SU,START}$		0.6			µs
Data Hold Time	$t_{HD,DAT}$		0		900	ns
Data Setup Time	$t_{SU,DAT}$		100			ns
Setup Time for STOP Condition	$t_{SU,STOP}$		0.6			µs
Pulse Width of Suppressed Spike	t_{SP}		0		50	ns
Bus Capacitance	C_B				400	pF
SDA and SCL Receiving Rise Time	t_R		$20 + 0.1C_B$		300	ns
SDA and SCL Receiving Fall Time	t_{RF}		$20 + 0.1C_B$		300	ns
SDA Transmitting Fall Time	t_{TF}		$20 + 0.1C_B$		300	ns

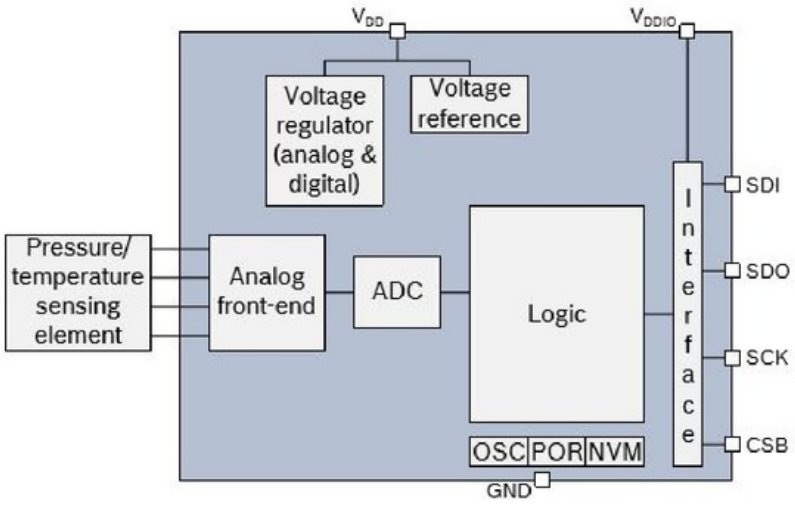
Appendix G

BMP280 Barometric Pressure Sensor

G.1 Overview

This appendix contains elements from the data sheet of the BMP280 Barometric Pressure Sensor. [55]

G.2 Functional Block Diagram



G.3 Specifications

Parameter	Symbol	Condition	Min	Typ	Max	Units
Operating temperature range	T_A	operational	-40	25	+85	°C
		full accuracy	0		+65	
Operating pressure range	P	full accuracy	300		1100	hPa
Sensor supply voltage	V_{DD}	ripple max. 50mVpp	1.71	1.8	3.6	V
Interface supply voltage	V_{DDIO}		1.2	1.8	3.6	V
Supply current	$I_{DD,LP}$	1 Hz forced mode, pressure and temperature, lowest power		2.8	4.2	µA
Peak current	I_{peak}	during pressure measurement		720	1120	µA
Current at temperature measurement	I_{DDT}			325		µA
Sleep current[1]	I_{DDSL}	25 °C		0.1	0.3	µA
Standby current (inactive period of normal mode) [2]	I_{DDSB}	25 °C		0.2	0.5	µA
Relative accuracy pressure	A_{rel}	700 ... 900hPa		±0.12		hPa
V_{DD} = 3.3V		25 . . . 40 °C		±1.0		m

Offset temperature coefficient	TCO	900hPa 25 . . . 40 °C		±1.5		Pa/K
				12.6		cm/K
Absolute accuracy pressure	A^P_{ext}	300 . . . 1100 hPa -20 . . . 0 °C		±1.7		hPa
	A^P_{full}	300 . . . 1100 hPa 0 . . . 65 °C		±1.0		hPa
Resolution of output data in ultra high resolution mode	R^P	Pressure		0.0016		hPa
	R^T	Temperature		0.01		°C
Noise in pressure	$V_{p,full}$	Full bandwidth, ultra high resolution See chapter 3.5		1.3		Pa
				11		cm
	$V_{p,filtered}$	Lowest bandwidth, ultra high resolution See chapter 3.5		0.2		Pa
				1.7		cm
Absolute accuracy temperature[3]	A^T	@ 25 °C		±0.5		°C
		0 . . . +65 °C		±1.0		°C
PSRR (DC)	PSRR	full V_{DD} range			±0.005	Pa/mV
Long term stability[4]	ΔP_{stab}	12 months		±1.0		hPa
Solder drifts		Minimum solder height 50 µm	-0.5		+2	hPa
Start-up time	$t_{startup}$	Time to first communication after both V_{DD} > 1.58V and V_{DDIO} > 0.65V			2	ms
Possible sampling rate	f_{sample}	*osrs_t* = *osrs_p* = 1; See chapter 3.8	157	182	tbd[5]	Hz
Standby time accuracy	$\Delta t_{standby}$			±5	±25	%

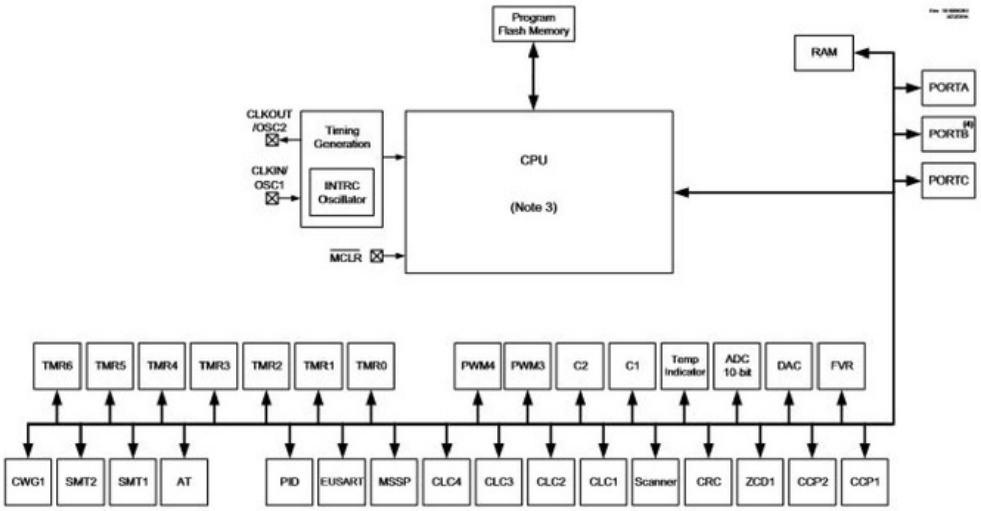
Appendix H

Microchip PIC16F1615 MCU

H.1 Overview

This appendix contains elements from the data sheet of the PIC16F1615 MCU from Microchip. [56]

H.2 Functional Block Diagram



H.3 Features

Core Features

- C Compiler Optimized RISC Architecture
- Only 49 Instructions
- Operating Speed:
  - DC – 32 MHz clock input
  - 125 ns minimum instruction cycle
- Interrupt Capability
- 16-Level Deep Hardware Stack
- One 8-Bit Timer
- Four 16-bit Timers
- Low Current Power-on Reset (POR)
- Configurable Power-up Timer (PWRT)
- Brown-out Reset (BOR) with Selectable Trip Point
- Windowed Watchdog Timer (WWDT):
  - Variable prescaler selection
  - Variable window size selection
  - All sources configurable in hardware or software

Memory

- 8 KW Flash Program Memory
- 1024 Bytes Data SRAM
- Direct, Indirect and Relative Addressing modes
- High-Endurance Flash Data Memory (HEF):
  - 128 B of nonvolatile data storage
  - 100K erase/write cycles

Operating Characteristics

- Operating Voltage Range:
  - 1.8V to 3.6V (PIC16LF1615/9)
  - 2.3V to 5.5V (PIC16F1615/9)
- Temperature Range:
  - Industrial: -40°C to 85°C
  - Extended: -40°C to 125°C

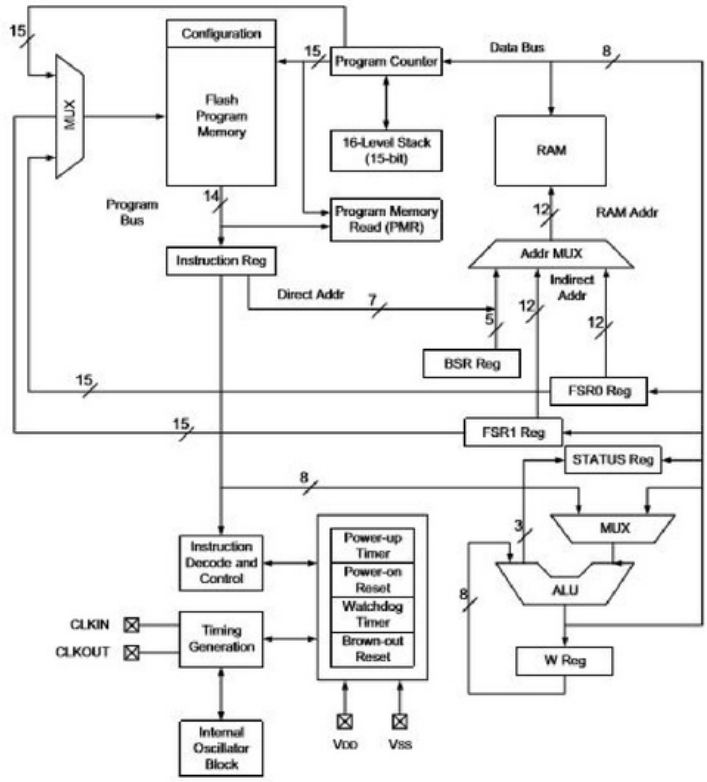
eXtreme Low-Power (XLP) Features

- Sleep mode: 50 nA @ 1.8V, typical
- Watchdog Timer: 500 nA @ 1.8V, typical
- Secondary Oscillator: 500 nA @ 32 kHz
- Operating Current:
  - 8 uA @ 32 kHz, 1.8V, typical
  - 32 uA/MHz @ 1.8V, typical

Digital Peripherals

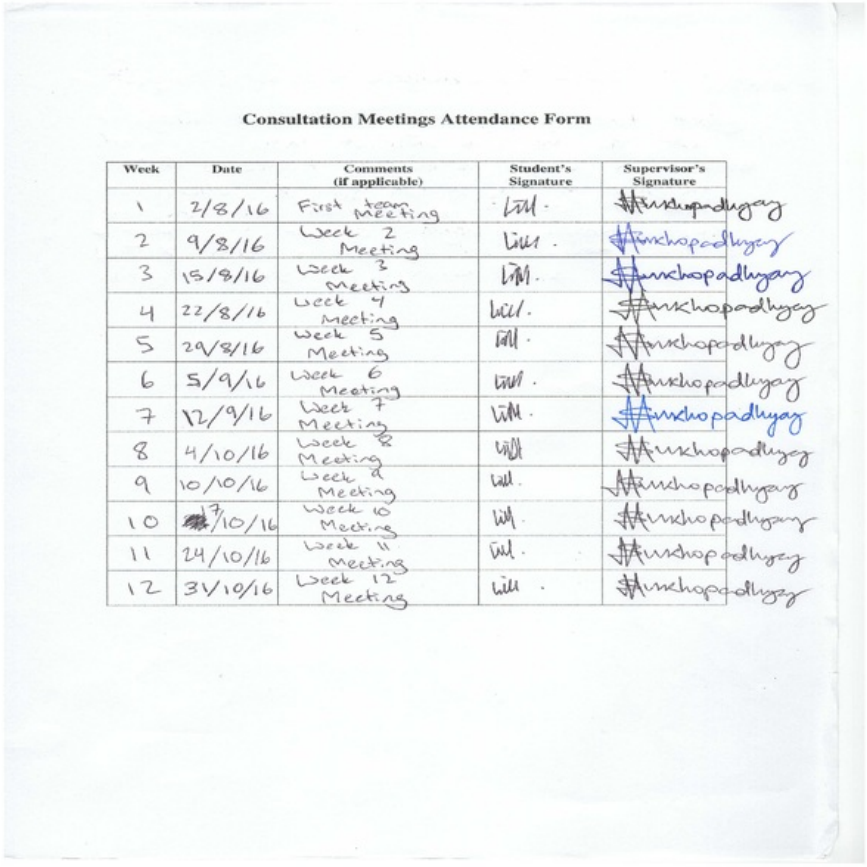
- Configurable Logic Cell (CLC):
  - Four CLCs
  - Integrated combinational and sequential logic
- Complementary Waveform Generator (CWG):
  - Rising and falling edge dead-band control
  - Full-bridge, half-bridge, 1-channel drive
  - Multiple signal sources
- Two Capture/Compare/PWM (CCP) modules
- PWM: Two 10-bit Pulse-Width Modulators
- Two Signal Measurement Timers (SMT):
  - 24-bit timer/counter with prescaler
  - Multiple gate and clock inputs
- Angular Timer:
  - Single pulse
  - Multiple pulses with missing pulse recovery
- 8-Bit Timers (TMR2+HLT/4/6):
  - Up to 3 Timer2/4/6 with Hardware Limit Timer (HLT)
  - Monitors Fault Conditions: Stall, Stop, etc.
  - Multiple modes
  - 8-bit timer/counter with prescaler
  - 8-bit period register and postscaler
  - Asynchronous H/W Reset sources
- Math Accelerator with Proportional-Integral-Derivative (PID):
  - Four operation modes
  - Add and multiply
  - Simple multiplier
  - Multiply and Accumulate
  - Programmable PID controller
- Cyclic Redundancy Check with Memory Scan (CRC/SCAN):
  - Software configurable
- Serial Communications:
  - Enhanced USART (EUSART)
  - SPI, I^2C, RS-232, RS-485, LIN compatible
  - Auto-Baud Detect, Auto-Wake-up on start

H.4 Core Block Diagram



Appendix I

Consultation Meetings Attendance Form



Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
1	2/8/16	First team Meeting		
2	9/8/16	Week 2 Meeting		
3	15/8/16	Week 3 Meeting		
4	22/8/16	Week 4 Meeting		
5	29/8/16	Week 5 Meeting		
6	5/9/16	Week 6 Meeting		
7	12/9/16	Week 7 Meeting		
8	4/10/16	Week 8 Meeting		
9	10/10/16	Week 9 Meeting		
10	17/10/16	Week 10 Meeting		
11	24/10/16	Week 11 Meeting		
12	31/10/16	Week 12 Meeting		