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Design of Smart Wearable System for Sudden Infant Death Syndrome Monitoring

تصميم نظام ذكي قابل للإرتداء لمراقبة متلازمة موت الرُضّع المفاجئ

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science in Electronic Engineering (Computer and Network Engineering)

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الآيــة

قال تعالي :

﴿قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ

رَبِّ الْعَالَمِين﴾

صدق الله العظيم

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The completion of this thesis could not have been possible without my supervisor Dr. ***Hisham Ahmed****, with his encouragement and support. Throughout my research degree, has made me enjoy undertaking my Masters of Science (MSC) degree. I would also like to thank Eng.* ***Hashim Batran*** *and Eng.* ***Osman Abdalla*** *for their endless support throughout all of my endeavors. I would especially like to acknowledge my incredible Father and Mother who have supported me with everything I have ever done.*

ABSTRACT

Sudden Infant Death Syndrome (SIDS) is the death among infant younger than one-year-old, and the cause of deaths remain unexplained, many countries suffer from high infant mortality rate. This system is a portable device capable of continuous health monitoring for neonates. It has integrated with low-cost hardware and software to help parents and caregivers to detect a problem early. Health status is displayed on the web site so that the parent and care given can monitor and access the infant's health information anywhere at any time. This system consists of a bio-sensor (temperature and heart pulse and 6-axis motion) connected with Arduino Nano and Wi-Fi module to send data to the web site. Moreover, in emergency cases, the alarm unit is used to notify parents and caregivers. The main interest in using this device is to provide a low-cost system with 24-hour monitoring of an infant's wellness rather than illness. Since we used different sensors, using the Kalman filter can combine information from any number of redundant sensors. According to the accuracy and error rates calculated, the developed system can be less expensive and acceptable.

المستخلص

متلازمة موت الطفل المفاجئ هي وفاة الاطفال حديثي الولادة بعمر اقل من عام وتعتبر اسباب الوفاة في هذه الحالة مجهولة او غير واضحة تعاني العديد من البلدان من ارتفاع معدل وفيات الاطفال وخاصة هنا في الدول النامية وذلك لمحدودية الدخل وأثره علي الحصول على الرعاية الصحية. هذا النظام هو عبارة عن جهاز قابل للإرتداء له القدرة على المراقبة المستمرة لحالة الطفل الصحية، تم تصميم النظام بأجهزة وبرمجيات منخفضة التكلفة لمساعدة الوالدين ومقدمي الرعاية للطفل لإكتشاف المشكلة في وقت مبكر. تُعرض الحالة الصحية للطفل على موقع في الإنترنت حتى يتمكن الوالدان ومقدمي الرعاية الطبية من الوصول إليها في أي مكان وفي أي وقت عبر المتصفح. صُمم هذا النظام من مستشعرات حيوية (مستشعرات لقياس درجة الحرارة ونبض القلب و وضعية النوم) وتتصل المستشعرات بوحدة اردوينو نانو وجهاز واي- فاي لإرسال البيانات إلى موقع الإنترنت. كما توجد وحدة إنذار للتنبيه في حالة الطوارئ عن طريق الجرس و ارسال رسائل نصية. أهم ما يميز هذا الجهاز هو توفير نظام منخفض التكلفة لمراقبة الحالة الصحية للرضيع على مدار 24 ساعة. نظراً لأننا نستخدم انواع مستشعرات مختلفة فيمكننا دمج معلومات هذه المستشعرات وترشيحها للحصول على معلومات دقيقة عن الحالة الصحية. وفقاً للدقة ونسبة الخطأ المحسوبة يمكن القول أن النظام مطور بأقل تكلفة وبدقة مقبولة لتحقيق الغرض منه.

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List of Symbols

◦	Centigrade
∑	Sum of
μ	Mean of data set
σ	Standard Deviation
V	Volt
mA	Milliampere
C	Celsius
X	Value in the data set

List of Abbreviations

ABCS	Advanced Baby Care System
ADC	Analog To Digital Converter
ASSB	Accidental Suffocation and Strangulation in Bed
BPM	Beat Per Minute
CDC	Center for Disease Control
CDR	Child Death Review
DMP	Digital Motion Processor
GPIO	general input/output
HR	Heart Rate
HTTP	Hypertext Transfer Protocol
HTML	Hypertext Markup Language
I2C	Inter-Integrated Circuit
IBI	Inter Beat Interval
ICWC	International Conference on Wearable Computing
IMU	Inertial Measurement Unit
IoT	Internet of Things
LED	Light Emitting Diode
LDR	Light Dependent Resistor
NTC	Negative Temperature Coefficient
SCL	Serial Clock Line
SDA	Serial Data Line
SIDS	Sudden Infant Death Syndrome
SSH	Secure Shield
SUID	Sudden Unexpected Infant Death

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 Preface

Recently years, wide range of wearable devices, sensors and data capture technology for processing and decision support [1]; have been developed for clinical research and health monitoring. Various kinds of wearable sensors have emerged for different purposes with the development of sensing technologies.

Health monitoring is an essential application of wearable sensor systems, especially for infants. Since these tiny, vulnerable infants can hardly articulate pain and comfortableness in Neonatal Intensive Care Units (NICU) or at home, continuous monitoring of their vital signs and physiological parameters is crucial for clinicians and parents to know their exact health conditions. Preterm infants or critically ill infants admitted into the NICU need sustained monitoring in case of various dangerous situations, which may include apnea, hypoglycemia, sepsis or sepsis-like infection, seizure, arterial hypotonia, bradycardia, hypoxia, hypothermia, acidosis [2], and even problems of Sudden Infant Death Syndrome (SIDS).

The traditional method for monitoring infant health is usually carried out under clinicians and parent direct supervision. This method requires dedicated human resources, and sometimes it is difficult for clinicians and parents to identify the infant's potential physiological condition.

1.2 Sudden Infant Death Syndrome (SIDS)

Also known as Cot Death and Crib Death is defined as an infant's death younger than one-year-old. Deaths' cause remains unexplained even after an autopsy, examination, and investigation of the death scene, and clinical history is classified as SIDS [3, 4]. One possible way to discover the cause of sudden death is by continuous monitoring of newborn children's vital signs.

1.3 Data fusion

Data fusion is a formal framework used to express the convergence of data from different sources. It is defined as the means and tools for the alliance of data originating from various sources [5]. Multi-sensor data fusion is a technology that enables combining information from different sensors into a unified result data fusion is a useful tool in many fields such as robotics, decision making, image processing, sensor networks, tracking system, etc. The main concept of data fusion is so popular that it may be used in all areas of our lives, in many different ways, and thus with different terminologies.

1.4 Problem Statement

Many countries still suffer from high infant mortality rates, particularly those in the African region. Inequalities in infant mortality among high and low-income countries remain large. In 2015, the under-five mortality rate in low-income countries was 76 deaths per 1,000 live births, about 11 times the average rate in high-income countries (7 deaths per 1,000 live births)[6]. An unknown phenomenon causes death among infants from birth up to the first year of age during their sleeping. We seek low-cost continuous monitoring of the infant's vital parameters 24 hours and notice any change in the baby's physical parameters.

- The proposed system consists of different sensors, so we need to combine information from various sensors to obtain a more precise evaluation.

1.5 Proposed Solutions

A system for continuous infant health monitoring will be developed to measure the vital parameters using wearable sensors and notify if the potential life-threatening events may accrue, and recognize any disease's development with a low cost.

Since the sensors used to measure the physical parameters are different, so the data fusion occurs to fuse the reading and give an accurate measure. It is a technology used to combine information from various sensors into a unified result; data fusion has been implemented through the Kalman filter.

1.6 Research Aims and Objectives

The objectives of this research are:

- To design a low-cost monitoring system.
- To increase the safety of infants by provides infant 24 hours centered care.

1.7 Methodology

The design consists of two parts hardware and software. The hardware design from the sensors (heart rate, temperate, and accelerometer) connected to Arduin nano and sent the sensors data to the web site through WI-FI module. In abnormal cases, the buzzer and SMS will set to notify the parent and caregiver. Before the infant monitoring device's actual design, the design's electronic circuit simulation is implemented using Proteus virtual system modeling and software implementation.

The software design consists of programming using Arduino IDE to write the algorithm of collecting sensor data and manipulate them. Since the different sensors are used, the sensor data fusion needs to be implemented using the Kalman filter code. The code is uploading in Arduino nano, and the data sensors send to the web site. The thing-Speak web site received data sensor, analyze and store in the database to make it easy for parent and caregiver to monitor the status of the baby in real-time or even for a time before.

1.8 Thesis Outline

In this research, the infant health monitoring system is explained and design. This dissertation will be divided into five chapters. Each chapter has a various issue related to the research, chapter two provides the background required to understand the kalman filter and the proposed study and some examples of others related research, while chapter three introduce the proposed methodology that used for design, and chapter four provides the result obtained from the application and the hardware and analyzes and compared with the calculated ones. Finally, in chapter five, the conclusion and recommendations for future studies are summarized.

CHAPTER TWO

BACKGROUND AND RELATED WORK

CHAPTER TWO

BACKGROUND AND RELATED WORK

This section provides the existing system, and a previous study of related works.

2.1 Background

The purpose of this project is to recommend a solving method by monitoring the biofeedback that tried to avoid sudden infant death. This system used real-time data collection from sensors to sense and detects the health of a baby. When abnormal data is detected, the system will warn the corresponding people responsible for the baby.

2.1.1 Wearable Technology

The Definition of Wearable Device is the system where a computing device accept and deal with the input to provide a meaningful output to obtain a certain function, it lay under the personal area of a user, controlled by the user, and has operational as well as interaction constancy, i.e., it work all time and always accessible.[7]

The era of cyber technology contribute in the development of wearable sensor technology, and system, and the growth micro- and nanotechnology system, led to emerge various kinds of wearable sensors which have different purposes and jobs.

A wearable sensor system may consist of a wide variety of components: sensors, wearable materials, smart textiles, actuators, power supplies, wireless communication modules and links, control and processing units, an interface for the user, software, and advanced algorithms for data extraction and decision-making. Wearable sensor systems for health measuring and monitoring used to achieve specific functions under strict medical criteria and significant hardware resource limitations. A wearable monitoring system should provide the specific requirements determine by the scientist and/or doctor, the weight and the size of the system have to be small, and it should not effect on the user’s activity and movement, especially in the case of infants. In addition, the system should remind safety so, not allowed any types of health hazards [8].

Wearable sensor systems have to achieve different things like: it must be reliable, comfortable and also user-friendly, be easy to wear and easy-to-remove non-washable parts. And also provide appropriate feedback that is easy to interpretable for both parents and hospital staff on whether the system’s components are functioning correctly. It should satisfy all requirements and more. [9]

Nowadays, probably the most benefit use of wearable technologies has been carried out in the medical sector, the most important characteristic of wearable technologies in the health sector is providing a continuous monitoring and measuring of an infant’s health status and gathering information about the infant in real-time.

2.1.2 Sudden Unexpected Infant Death (SUID) Cases in Child Death Review CDR

According to death certificate data occurred among Washington residents is 2,044 infant deaths between 2011 and 2015. In this period of time there were 256 infant deaths due to SIDS, 23 deaths due to unknown cause, and 55 deaths due to ASSB, for a total of 334 infant deaths in the SUID category. 123 (37 percent) of these deaths were reviewed by CDR teams, while 211 of the deaths were not reviewed by CDR teams. [10, 11]

In 2016, there were about 1,500 deaths due to SIDS, 1,200 deaths due to unknown causes, and about 900 deaths due to accidental suffocation and strangulation in bed. The report shows the breakdown of sudden unexpected infant deaths by cause in 2016. 42% of cases were categorized as sudden infant death syndrome, followed by unknown cause (34%), and accidental suffocation and strangulation in bed (24%). [12]

An American Academy of Pediatrics provide many recommendations for safe infant sleep include the following: [13]

• Back to sleep for every sleep
• Room-sharing without bed-sharing
• Keeping soft objects and loose bedding out of the crib
• Avoiding smoke exposure during pregnancy and after birth
• Avoid alcohol and illicit drug use during pregnancy and after birth
• Breastfeeding is recommended
• Avoid overheat

A continuous monitoring of newborn vital signs is providing a nonstop feedback to the parents in order to prevent some of the risk factors of SIDS.

2.1.3 Vital Signs

Vital signs are defined as the initial measurements to the body's physical parameter the basic functions of them and how it works. They are many basic signs which are very important for the doctor, medical professionals and health care to be monitoring to supply by a health status of the body, The four main vital signs measurements in most medical settings include body temperature, heart rate, respiration rate, and blood pressure are play an significant role in knowing a human health information. Doctors use various kinds of medical apparatus like thermometer for checking fever or body temperature, BP monitor for blood pressure measurement and heart rate monitor for heart rate measurement to represent the general health condition of an individual. This wearable system project aims to provide parents with reliable, convenient, real time updated vital signs of their babies.

2.1.3.1 Body Temperature

Temperature is the most vital sign have to be known in order to ensure the safety and health of the baby. Sudden onset of fever in the newborns, caused by different factors such as system infection and physical surroundings, has caused many parents sleepless nights. The immune system in the infants is not fully developed. In addition, hyperthermia and hypothermia can be factors leading to SIDS.

The temperature gets a different reading depends upon the human age and the place in the body where the temperature has been measured, human activity and the day light or dark time also wellness or illness. Nevertheless, commonly mentioned typical value of the temperature of a baby is between 36 degree Celsius and 38 degree Celsius.

There are many methods to measure and monitor the temperature of a body, by using usual method, through thermometer, which is very inconvenient and cannot achieve a long-term temperature measuring which need for infant health monitoring continuously. Constant monitoring of temperature can be achieved by using various kinds of electrical devices.

2.1.3.2 Pulse Rate

The heart is the strongest muscle that is responsible for pumping blood and delivering oxygen all around the body. Regardless it's just the size of a person's fist, the heart rate measurement is essential for providing infant's cardiovascular fitness.

Heart rate, heartbeat or heart pulse, define as the speed of the heartbeat and it indicates the number of times the heartbeats counts, it measured by the number of beat of the heart per unit of time typically beats per minute (bpm). It's very important physical parameter because it controls whole body. It may take or measured from many spots on the body, at which an artery is close to the surface and a pulse can be felt. The most common places to measure heart rate is at the wrist (radial artery) and the neck (carotid artery) using the palpation method.

The heart rate can vary according to the age, illness or the body's physical needs including the need to absorb oxygen and excrete carbon dioxide. The normal resting infant heart rate ranges 80 - 160 beats per minute [14].

Bradycardia is a slow heart rate, defined as below 80 bpm. Tachycardia is a fast heart rate, defined as above 160 bpm at rest.

They are different way used in measuring heart rate like an Electrocardiography, But the Heartbeat Sensor is easiest way to monitor the heart rate here the SEN-11574 Pulse Sensor choose to measure a heart pluses in this project.

2.1.3.3 Body position

Although body position itself is not considered a vital sign, it plays an important role for a person’s wellbeing. Babies spend majority of their time in the crib and their sleep time is much longer than adults. The babies do not have full control of their bodies. They may be harmed if their sleep position ‘ tragic event such as SIDS could happen. Having the right body position, it can have direct impact on other vital signs such as respiration.

Position of the baby was at the top of a list of 10 steps to help prevent SIDS from a current WebMD article sponsored by Johnson’s baby.[15] The CDC (Center for disease control) states that, SIDS related deaths have decreased by over 50% since the steps to prevent SIDS have been instituted [16].

Since the main goal of this project is to help and aid in the prevention of SIDS, being able to know the baby’s position is vital to success. Position of the baby can be monitored through different methods.

Although the various sensors (such as pressure sensor array) are used to detect the sleeping position the accelerometers are also used quite often in recent times

2.2 Multi-Sensors Data Fusion

Data fusion is the process of combining information from different sources to provide a representational data format. The source of information may come from different sensors, which mean that a process of combining information from multiple sources to produce the most accurate and complete unified data about an entity, activity, or event [17]; or may provide information about the same aspect of the system and its environment, but with different signal quality or frequency.

Data fusion is based on the probabilistic methods. The probabilistic methods that derive based on Bayer's rule for combining prior and observation information, data fusion is a useful tool in many fields such as robotics, decision maker, image processing, sensor networks tracking system and etc. The main concept of data fusion is so popular that it may be used in all areas of our lives, by many different ways, and thus with different terminologies.

In Khaleghi et al in (2013), authors provide a more comprehensive definition. They say that "Information fusion is the study of efficient methods for automatically or semi-automatically transforming information from different sources and different points in time into a representation that provides effective support for human or automated decision making".

In general, each individual sensor may provide imprecise and inconsistent measurement. One of the advantages of a data fusion method could be reducing such uncertainty.

Since this project consists of 3 different sensors so, we implement a kalman filter for sensor data fusion to combine information from different sensors to obtain a more precise evaluation. kalman filter is one of the most significant techniques used since past decade. It has a widespread use because of the solutions are a testament to their accuracy and effectiveness.

2.2.1 Kalman Filter

Kalman Filter is Mathematical tools that can be used for stochastic estimation from noisy sensor measurements, it the most well-known and often-used tools. The Kalman filter is more over 50 years old but is still remind as one of the most important and common data fusion algorithms is used today. Kalman filter is Named after Rudolf E. Kalman who in 1960 published his famous paper describing a recursive solution to the discrete-data linear filtering problem, the great success of the Kalman filter is due to its small computational requirement, elegant recursive properties, and its status as the optimal estimator for one-dimensional linear systems with Gaussian error statistics[18].

From a theoretical standpoint, the Kalman filter is an algorithm permitting exact inference in a linear dynamical system, which is a Bayesian model similar to a hidden Markov model. It implements a predictor-corrector type estimator that is optimal in the sense that it minimizes the estimated error covariance when some presumed conditions are met. [19]

2.2.2 Kalman Filter Works

Kalman filter consist of two types of equations or steps as shown in the figure below. The first is the prediction equations also known as Prediction step, the filter produces estimates of the current state, along with their error probabilities. At the start initial conditions are used. Once the next raw sensor reading is entered to the filter. The second set of equations known as the update equations or Estimation step, in it the estimates are updated using a weighted average of the raw readings, with more weight being given to estimates with higher certainty. [19]

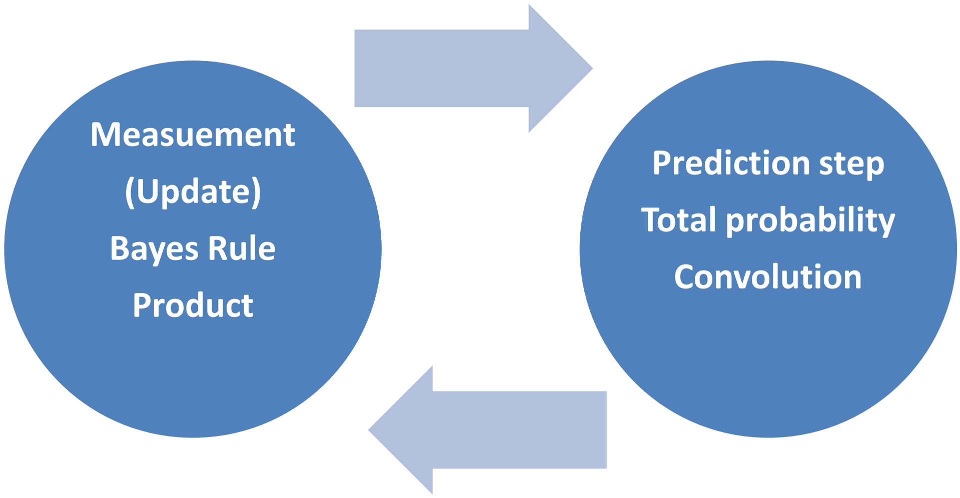

Figure 2-1: Kalman filter steps

2.3 Hardware Design

Hardware of this project can be considered as integration of three units: the data acquisition, the MCU and alarm unit.

2.3.1 Data Acquisition Unit:

This unit is mainly responsible for obtaining infant's vital parameters utilizing sensors.

Sensor is a device which gives an output by detecting the changes in quantities or events. Generally, sensors produce an electrical signal or optical output signal corresponding to the changes in the inputs. All types of sensors can be basically classified into analog sensors and digital sensors. These sensors are interfaced to the embedded system providing real time sensor values. Sensors have been widely use due to the development of microcontrollers and wide spread. The sensors are used in many applications like: robotics, monitoring airplanes and aerospace, cars and health monitoring applications.

2.3.1.1 Temperature Sensor

The temperature sensor is a sensor which is designed specifically to measure the hotness or coldness of an object, the temperature sensor used here is LM35. This temperature sensor generates an analog output voltage that is proportional to the temperature. The precision integrated-circuit temperature sensor output a voltage linearly proportional to the centigrade temperature. With LM35, temperature is measured more accurately than using a thermistor. For accurate readings, the sensor’s package required to be in contact directly with the patient. It has many features; some of them are [20]:

1. Guarantee accuracy at +25 C.
2. Wide range (-55 to +150 C).
3. Suitable for use for remote applications.
4. Operation voltage from 4 to 30 volts.
5. Low self-heating and output’s impedance.

LM35 has three pins except that the left pin is for the input voltage, while the middle one output the signal. Therefore, the pin on the right is the GND.

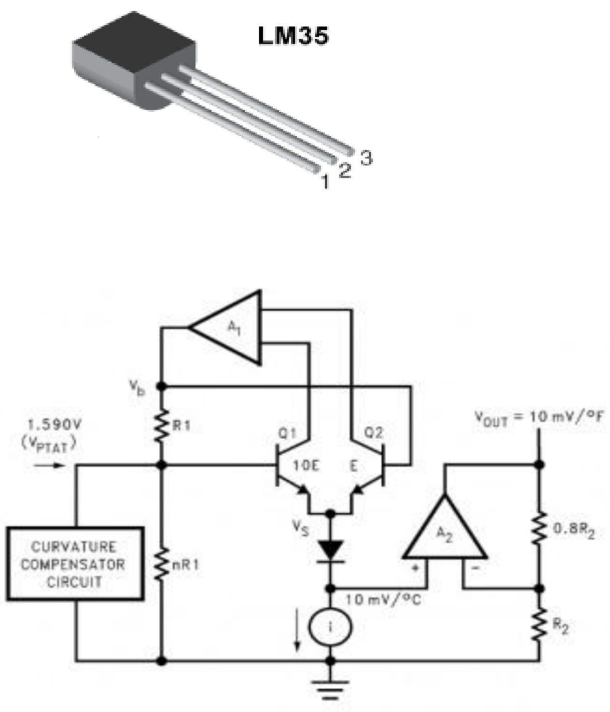

Figure 2-2: Temperature sensor [21]

Working principle

There are two transistors in the center of the drawing. One has ten times the emitter area of the other. This means it has one tenth of the current density, since the same current is going through both transistors. This causes a voltage across the resistor R1 that is proportional to the absolute temperature, and is almost linear across the range. The "almost" part is taken care of by a special circuit that straightens out the slightly curved graph of voltage versus temperature.

The amplifier at the top ensures that the voltage at the base of the left transistor (Q1) is proportional to absolute temperature (PTAT) by comparing the output of the two transistors.

The amplifier at the right converts absolute temperature (measured in Kelvin) into either Fahrenheit or Celsius, depending on the part (LM34 or LM35).

The integrated circuit has many transistors in it two in the middle, some in each amplifier, some in the constant current source, and some in the curvature compensation circuit. All of that is fit into the tiny package with three leads. [21]

2.3.1.2 Heart Beat Sensor

The Heartbeat or pulse sensor is an IR sensor having a photocell which is used to emit and detect the infrared light. It is essentially a photoplethysmograph (PPG), which is a well-known medical device used for non-invasive heart rate monitoring [22]. The SEN-11574 is used.

Figure 2-3: the SEN-11574 Pulse Sensor [22]

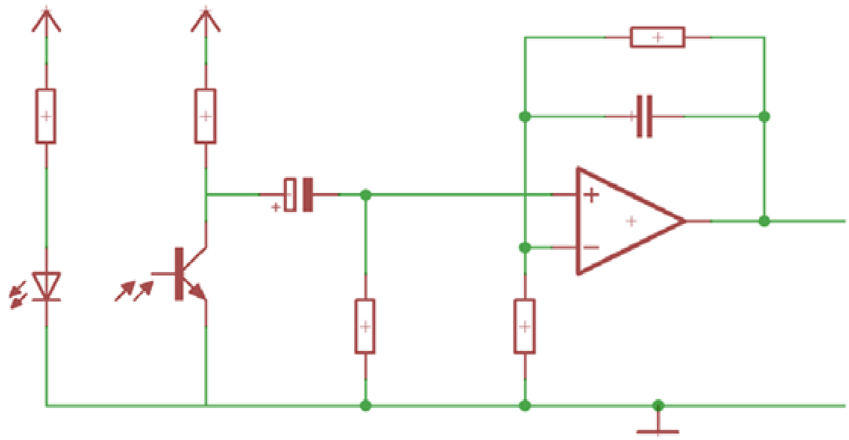

Figure 2-4: pulse sensor circuit [22]

Working of a Heartbeat Sensor

The basic heartbeat sensor consists of a light emitting diode and a detector like a light detecting resistor or a photodiode. The heart beat pulses causes a variation in the flow of blood to different regions of the body. When a tissue is illuminated with the light source, it either reflects (a finger tissue) or transmits the light (earlobe). Some of the light is absorbed by the blood and the transmitted or the reflected light is received by the light detector. The amount of light absorbed depends on the blood volume in that tissue. The detector output is in form of electrical signal and is proportional to the heart beat rate.

This signal is actually a DC signal relating to the tissues and the blood volume and the AC component synchronous with the heart beat and caused by pulsatile changes in arterial blood volume is superimposed on the DC signal. Thus the major requirement is to isolate that AC component as it is of prime importance. [22]

To achieve the task of getting the AC signal, the output from the detector is first filtered using a 2 stage HP-LP circuit and is then converted to digital pulses using a comparator circuit or using simple ADC. The digital pulses are given to a microcontroller for calculating the heat beat rate, given by the formula:

$$\text{BPM(beats per minute)} = 60 * \text{f} \qquad (2\text{-}1)$$

Where f is the pulse frequency.

Specifications of heart rate sensor are:

- Operating voltage is +5V DC regulated.
- Operating current is 100 mA.
- Output data levels are 5V TTL level.
- LED is use to Heart beat detection and Output High Pulse.
- Light source are 660nm Super Red LED

2.3.1.3 Three Axis Accelerometer and Gyroscopes

The position detecting system based on an IMU-system, containing accelerometer, gyroscopes and magnetometers.

The MPU-6050 sensor which contains a MEMS accelerometer and a MEMS gyro in one chip is used, The three axis accelerometer are basically used to identify the movements across the three axis i.e. x-axis, [23] /5which is small low profile package, can measure minimum full scale range of +/- 3g in this way movement of an infant is monitored by placing accelerometer properly. It is positioned in the socks of an infant so accurate motion will be detected.

It is accurate, as it contains 16-bits analog to digital conversion hardware for each channel, there for it captures the x, y, and z channel at the same time, outputs x, y, and z channels, a 3-axis MEMS accelerometer with 13-bit resolution and measurement at up to +/-16 g. Digital output data is formatted as 16-bit twos complement and is accessible through either a SPI (3- or 4-wire) or I2C digital interface.

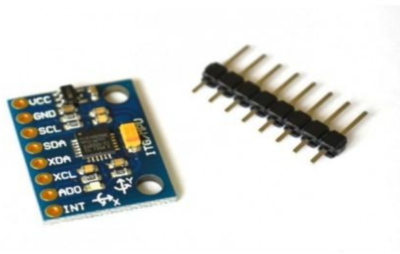

Figure 2-5: MPU-6050 [23]

2.3.2.1 Microcontroller (MCU)

The measured signals will apply calculation on MCU, and prepare the MCU for transmission to the next unit.

Arduino Nano fits perfectly for this project as it’s easy to use as well as it provides mobility feature due to its suitable size for a wearable device.

Arduino Nano is a surface mount breadboard embedded version with integrated USB. It is a smallest and complete breadboard. It has everything that Diecimila/Duemilanove has (electrically) with more analog input pins and onboard +5V AREF jumper.

The Arduino Nano can be powered via the Mini-B USB connection, 6-20V unregulated external power supply, or 5V regulated external power supply. The power source is automatically selected to the highest voltage source.

The ATmega328 has 32 KB, (also with 2 KB used for the boot loader. The ATmega328 has 2 KB of SRAM and 1 KB of EEPROM.

Each of the 14 digital pins on the Nano can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms.

A Software Serial library allows for serial communication on any of the Nano's digital pins. The ATmega328 support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus.

The Arduino Nano can be programmed with the Arduino software. [24]

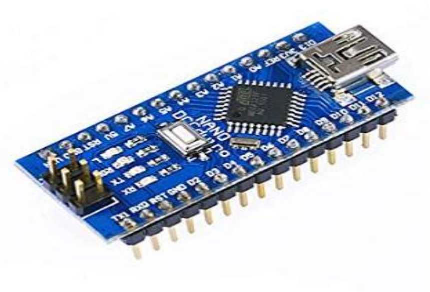

Figure 2-6: Arduino Nano [24]

2.3.2.2 Node MCU module

The ESP-01 micro-controller is a small breakout board based on the ESP8266 [25].

Internally, the ESP chips sport a 32-bit RISC CPU that normally operates at80MHz or 160MHz and has 64 kB of RAM for instructions and 96 kB for data.

It has general-purpose IO (GPIO) pins that can be configured as input or output pin as well as a single analog input with a 10-bit ADC. The controller supports I2C, SPI communication as well as RS-232. On the ESP-01 there are only 8 pins pin’s exposed and accessible. Additionally, it has built-in support for WIFI according to IEEE 802.11 b/g/n including authentication with WPA or WEP. Finally, ESP8266 can be programmed very conveniently through the Arduino development system [26], after installing a support package.

The raw chips are very small, the boards have normal 0.1" spacing for external pins that are connected to the power lines and to the communication bus, here I2C. Thus only four external lines are needed for interfacing: GND, VCC, and the I2C clock SCL, and data line SDA.

The ESP-01 has eight pins exposed, of which four can be used for general applications. Two pins RX and TX are typically used for serial communication, and two others, GPIO0 and GPIO2, are available. The latter we use for the I2C communication as SCL and SDA lines, respectively.

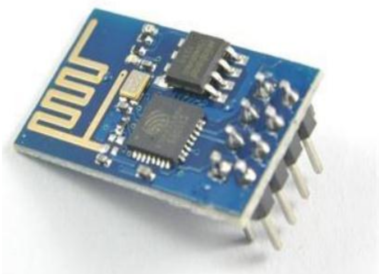

Figure 2-7: ESP-01[25]

2.3.2.3 Direct Current to Direct Current Converter

Dc to dc converter is the step down voltage (while stepping down current) from its input (supply) to its output (load).

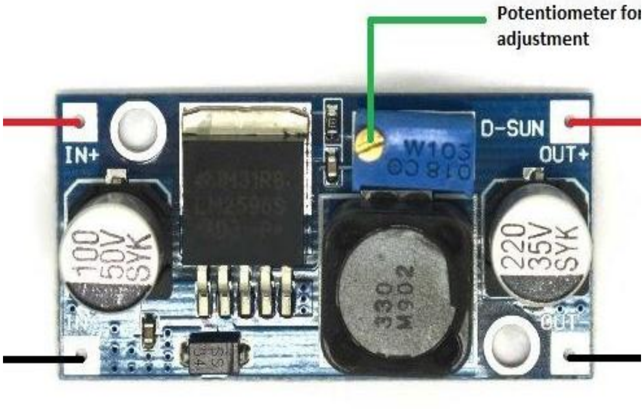

Figure 2-8: the DC TO DC Converter [27]

2.3.3 Alarm Unit

This unit is composed of a GSM Module and a 5v DC buzzer.

Global System for Mobile Communications GSM Module

The GSM Module is an open, digital cellular technology used for transmitting mobile voice and data services responsible for the communication part of the circuit. It takes information from the Arduino on where to send information and what information needs to be sent. It uses a GSM SIM card for communication purposes. It is basically just a modem which uses serial communication to interface with and needs Hayes compatible AT commands for communicating with the Arduino.

The alert message and the phone number of the recipient are given on the project codes. As soon as fire is detected abnormal condition an SMS will be sent to the recipient’s phone number from the SIM card inserted into the module.

For GSM module, GSM SIM900A type is selected to carry the task in communication part. It can operate on Dual-Band 900-1800 MHz and designed solely for outside Europe and USA usage. [28]. since it consumes small of power in its operation, thus it is said able to communicate with any low power consumption microcontroller. It can be interfaced by using many interfaces which some are I2C, SPI interface, PWM, antenna pad, two serial interface and so forth. Figure 2 shows the GSM SIM900A device before connecting to the Arduino board.

Figure 2-9: The GSM SIM900A module [28]

Buzzer

Buzzer 5v DC is an audio signaling device that has many applications includes timers and alarm devices. Many types of buzzers are available mainly they are electromechanical, mechanical and electrical buzzers**.**

The DC buzzer will peep if any vital sign increased or went below the specified threshold, issued a voice (alarm) as a warning to the patient and people around him that this patient needs help. [29]

Buzzer important features are:

1. Operation power (3-6 DC)
2. No electrical noise
3. Low consumption of current

Figure 2.10: Piezo buzzer sensor [29]

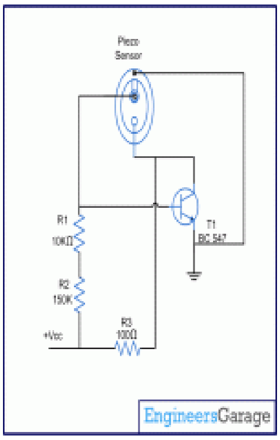

Figure 2-11: Piezo buzzer circuits [29]

Working principle

The voltage drop across resistors R1 (10k) and R2 (150k) is provided to the piezoelectric diaphragm. Due to the applied potential, the diaphragm starts vibrating. These vibrations are fed to the base of a transistor T1 (BC547). T1 acts as an amplifier to amplify these vibrations and the output appears across the collector resistor R3 (100). [29]

2.4 Review of Related Work

Recently the needs of measuring infant vital signs and physical parameters have an important role in science and technology.

Andre G. Ferreira et al, introduced The wearable IoT device which is a wireless sensor node integrated into a chest belt, and it monitors physical parameters such as body temperature, breathing rates heart and body position. When a critical event occurs, the device will trigger a visible and audible alarm, in the proximity and sends a distress message to a mobile application. [30]

Mairo Leier et al. proposed a monitoring system that can detects the most necessary vital signals of neonate and transmits results by a wireless link to the control device that may be any Smartphone. By measuring the raw signals, it is possible to use this system in different, possible life threatening situations during long-term monitoring. [31]

Angelo M. Fonseca et al. proposed a mobile solution based on biofeedback monitoring that tries to prevent the sudden death of infants. When an issue is detected by this system, it sends a warning to parents. Mobile devices are used to process the sensed data and monitoring baby and performing alerts/ warnings when an abnormal situation is detected. [32]

Savita P. Patil et al, their system is about monitor's vital parameters such as body temperature, pulse rate, moisture condition and movement of an infant. By using GSM network, this information is transferred to their parents. Measurements of these vital parameters can be done and under risk situations, this information is conveyed to the parents with alarm triggering system to initiate the proper control actions. [33]

G. Rajesh et al. proposed a system provides solutions by making a smart crib using WSN i.e. Wireless Sensor Networks and Smart phones. The service of visual monitoring is also being provided through live video. The alert services can be provided by making use of fencing of the crib. Also, monitoring services can be delivered by temperature reading, vaccine reminder and weight monitoring etc. [34]

Suresh B et al. In this, a mobile robotic device has been designed and developed which can help a parent to track their baby and its surroundings without having to check on the baby every now and then. Advanced Baby Care System (ABCS) has a Master Controller (Arduino Mega 2560), which integrates all the different modules of the robot by receiving the necessary signals from the sensor modules and sending signals to the trigger alarm and the DC motors. It is a microcontroller board based on the ATmega328. This board can be easily interfaced with the CMUCam5 module, used for tracking, as well as other sensors which are being used in the project. ABCS is an intelligent, baby friendly system, which integrates many functions into a single device, automatically alerting the parent when it is necessary and allowing them to carry on with their activities uninterrupted. [35]

CHAPTER THREE

DESIGN AND IMPLEMENTATION

CHAPTER THREE

DESIGN AND IMPLEMENTATION

3.1 Overview

The project design is considered the most important stage in each project's development process; hence, this step takes considerable time in the overall project life cycle.

The system is a combination of hardware and software components. The hardware part consists of an embedded system, and the software is the Arduino Integrated Development Environment and thing-speak.

3.2 System Block Diagram

The following block diagram illustrates the designed system.

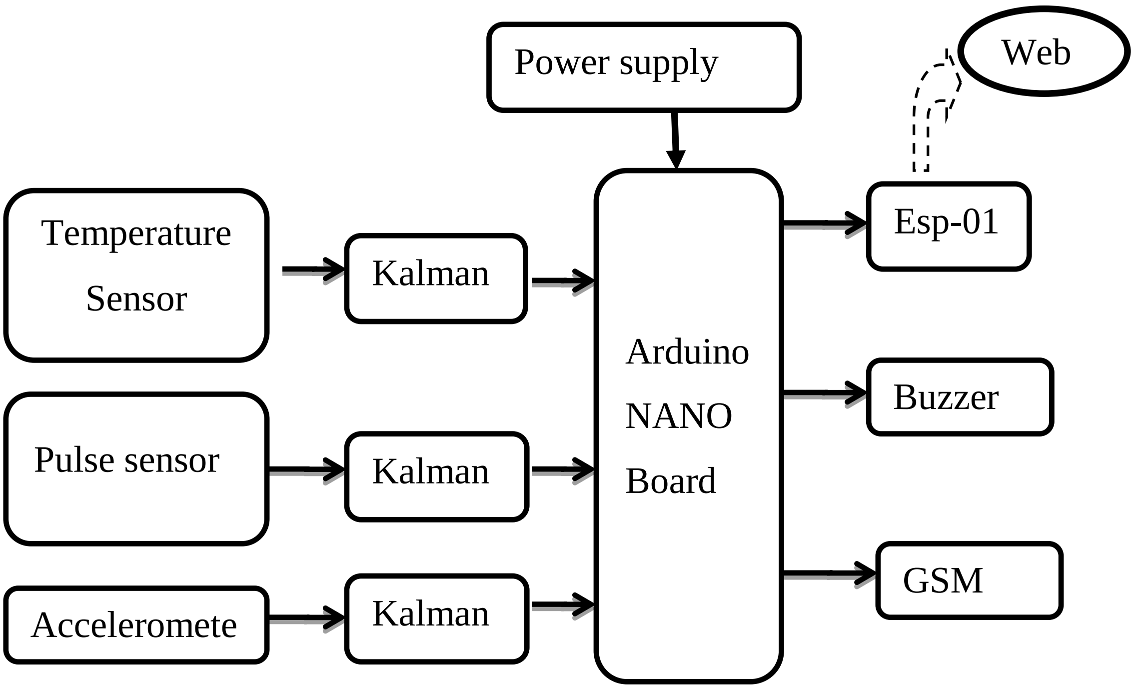

Figure 3-1: system block diagram

Block diagram consists of all sensors (temperature sensor, pulse sensor, acceleration sensor), and alarm system.

The sensing signals will pass to Arduino nano. In the transmitting part, the information is sent to the web site via an esp-01. If the values exceed a critical range, then the alarm system (SMS and buzzer) will set.

3.3.1 The System Flow Chart

A visual representation of the sequence of steps and decisions needed to perform monitoring of infant vital signs. The figure below shows the flow chart of the infant monitoring system process.

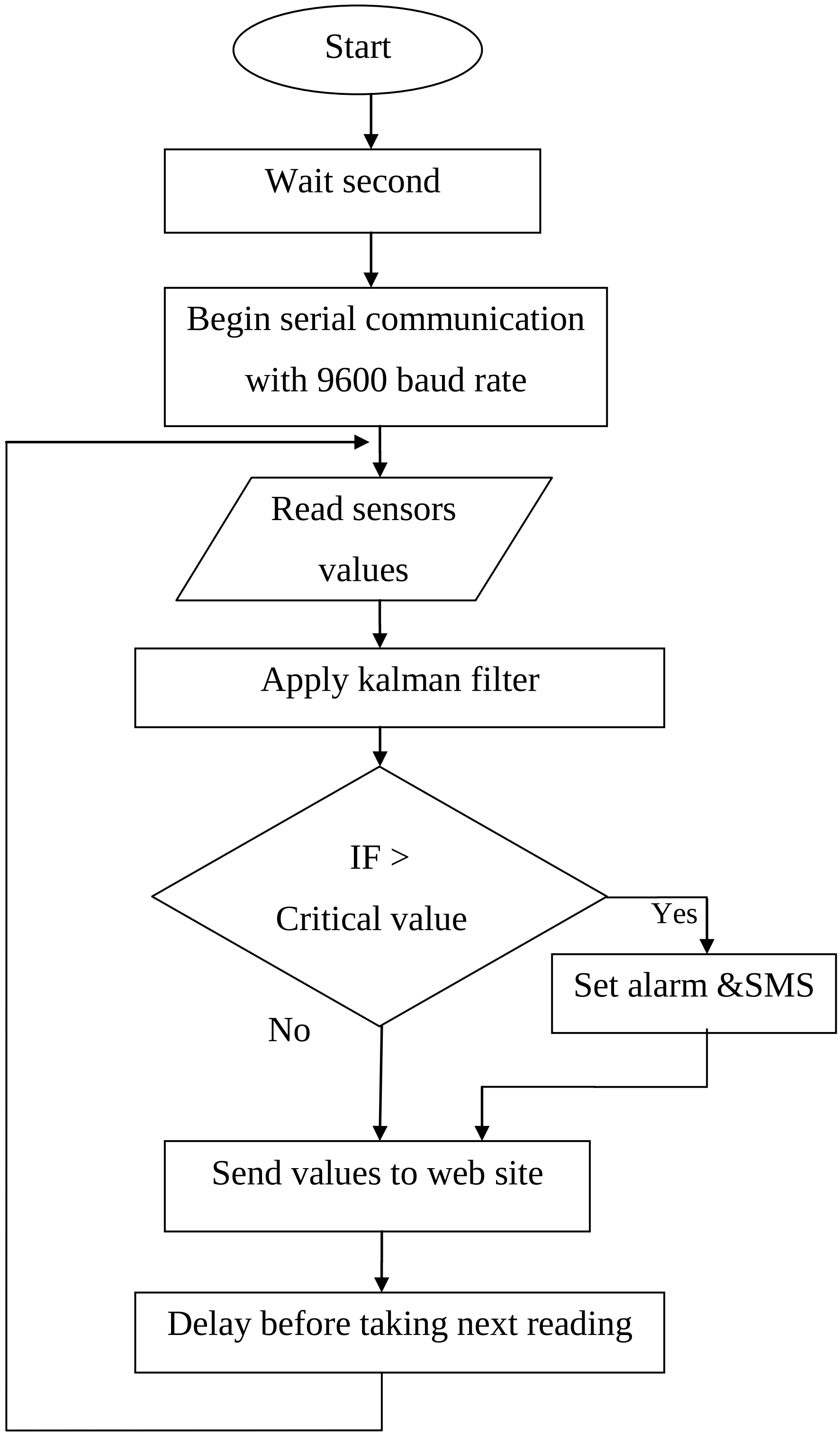

Figure 3-2: System flow chart

Here is the program algorithm, where the physical parameter is heart pluses, body temperature, and velocity angle to determine the infant's wellness and illness.

The middleware or Arduino Nano device takes the sensor's values and manipulates them according to a program that compares these values with a given threshold and determines if it normal or not. Kalman filter implements in this reading. An emergency alarm will set in abnormal values, and a warning SMS will be sent to the concerned person. Arduino Nano sends the reading values to the thing-speak website through an esp-01 WI-FI module.

3.3.2 Kalman Filter Flow Chart

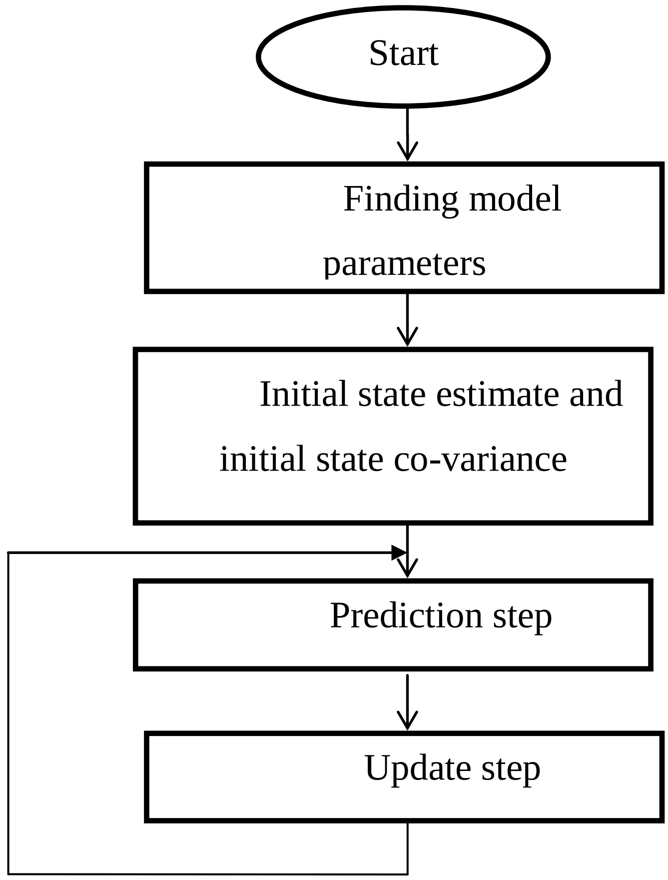

Figure 3-3: kalman filter flow chart

3.3.3 Thing-Speak Flow Chart

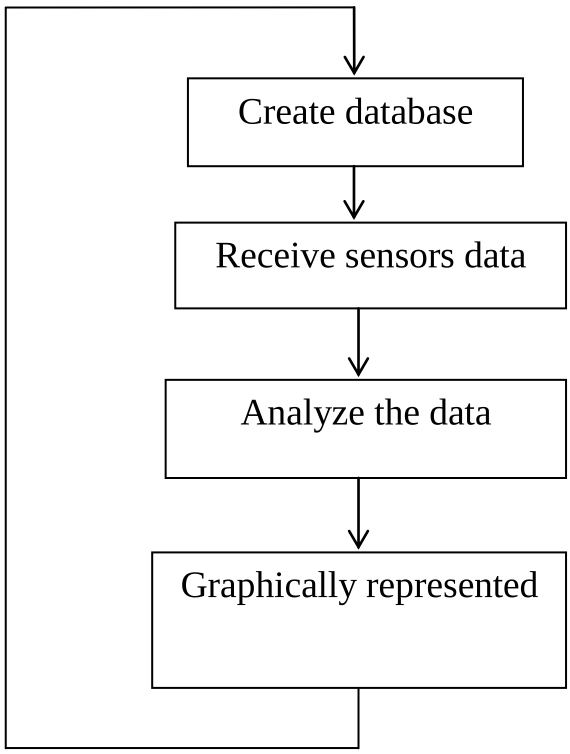

Figure 3-4: Things-speak flow chart

Before the infant monitoring device's actual design, the design's electronic circuit simulation is implemented using Proteus virtual system modeling.

3.4 Proteus Virtual System Modeling (VSM)

Proteus VSM integrated with schematic capture ISIS software [36] and ARES layout software [37] for PCB design. It includes a rich library of built-in for emulating various passive and active electronic devices as resistors, capacitors, transistors, operational amplifiers, etc. Circuit printouts for PCB design added.

Proteus also includes an impressive library of MCU from various manufacturers providing a universal development environment. Enough scope of Atmel's microcontrollers supported by Proteus VSM as well.

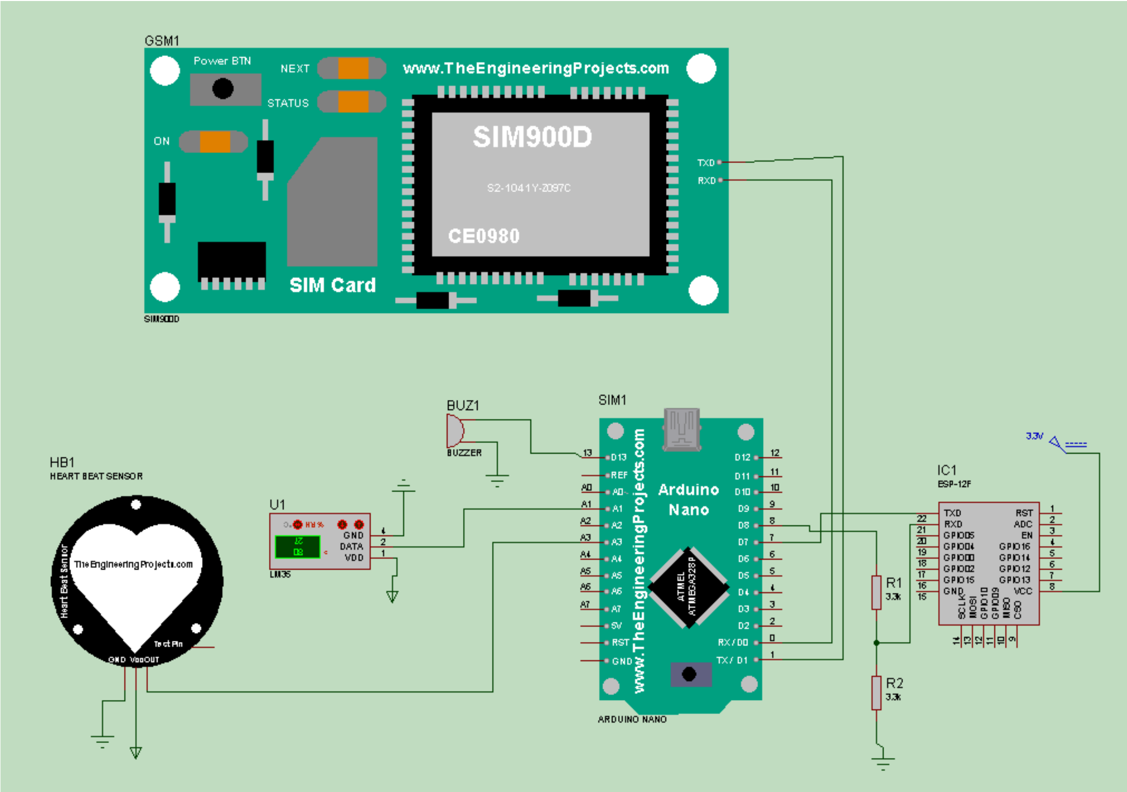

Figure 3-5: Proteus simulation

The above figure is a prototype model for baby vital sign measurement based on temperature monitoring and pulse rate monitor; our system gives peace of mind to loved ones when they are away from their infant.

3.5 System Implementation

The figure below presents the general scope of the system, focusing on the integration model. In the figure, it is possible to observe that the health state has a mechanism of wireless communication to send the data that have been read from sensors to the thing-speak website.

The integration of this data with the Internet happens through Wi-Fi communication.

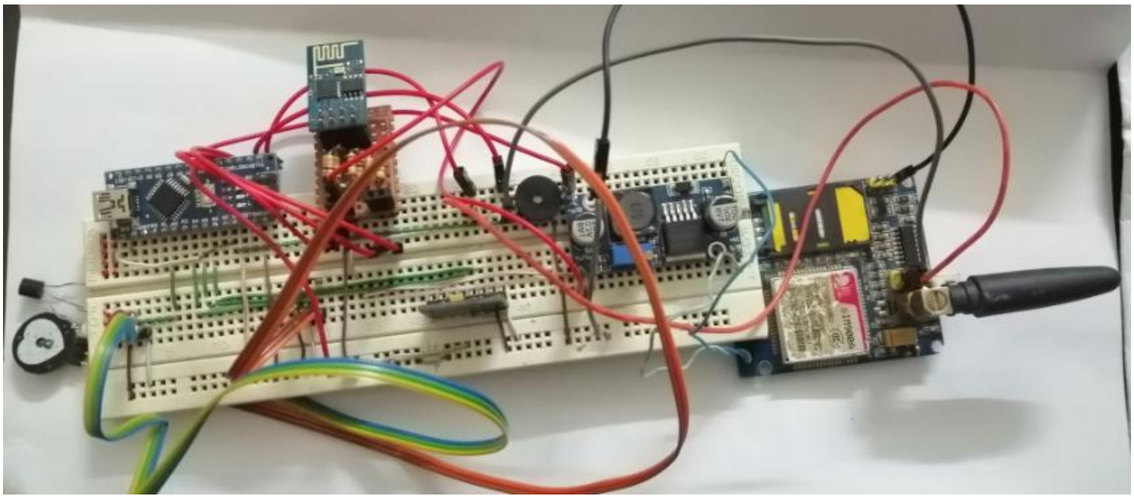

Figure 3-6: Implementation of the Overall System

When the system is powered, the sensors measured the physical parameters and sent them to Arduino nano, which acts as the middleware device, received the measurements, and deal with them by the conditional program implemented to perform tasks.

This project has four sections. Firstly sensors set for measuring; LM35 sensor senses the temperature of the baby and SEN-11574 sensor measures the heart pluses, and MPU-6050 measure velocity angle, Secondly Arduino nano reads the LM35 sensor output by using a single wire protocol and SEN-11574heart rate sensor's output by data using I2C protocol to get a data comes from the sensor also read the MPU-6050 data using I2C protocol. Thirdly, these values are manipulated on Arduino-nano and finally send to the thing speak web site by using esp-01. It allows access to the infant data easily through any browser.

The following are detailed about the components that are part of the system overview

3.5.1 Temperature Measurement

Since the output voltage (Vout) of LM35 is connected to ADC channel (A1), the ADC converts the analog readings into digital values according to the following formula:

$$\text{ADC value} = \text{sample} * 1024/\text{Reference Voltage} \quad (3\text{-}1)$$

The algorithm for measuring temperature is:

1. Initialize Arduino configurations.

-Baud Rate = 9600.

2. Apply input signals to A1.

3. Obtain data by reading A1.

4. Perform Calculations on the data.

5. Print it to the Serial Monitor.

6. Wait 1000ms until the next reading.

7. Repeat from step 3.

The digital output values were printed to the Serial Monitor of the Arduino IDE.

3.5.2 Heart rate Measurement

The heart pulse sensor breadboard to ground and DC power supply outputting 5V on the Arduinonanopin, and connect the pulse sensor analog output pin or the data pin to the pin (A3).

Measuring BPM:

The algorithm for measuring BPM and IBI is:

1. Initialize Arduino configurations.

-Baud Rate = 9600.

2. Apply input signals to A3.

3. Obtain data from reading A3.

4. Perform Calculations on the data.

5. Print it to the Serial Plotter.

6. Wait 1000ms until the next reading.

7. Repeat from step 3.

3.5.3 Position Measurement

The position of the baby can be monitored through Accelerometers.

Accelerometers measure acceleration (Acceleration is the rate of change of velocity, regardless of whether the acceleration is produced by gravity or any other force.

The mpu-6050 measures a velocity angle to determine the horizontal site of a baby. The sensor connected with DC power, ground, Arduino pin (A4) with mpu-6050 SDA and Arduino pin (A5) withmpu-6050 SCL, the signal from the three axes(x,y,z) of the accelerometer, and in the right it can be seen the frequent composition of the signal x (the one with more breath rate signal consistently through the different activities).

3.5.4 Node MCU

An esp-01 powered from direct current to direct current converter and connect Tx and Rx with Arduino nano.

3.5.5 Alarm System

The alarm function has to be set in an abnormal condition. Two types of alarms are represented here in this project; the buzzer connects with the Arduino pin (A13).

And GSM Module powered by using an adapter with generates 5v with 2A.

3.6 Software

3.6.1 The Filter at Work

The filter converges relatively quickly, depending on the choice of initial conditions. After much iteration, the variance is already very low, so the filter is confident on its estimated and updates states. [38]

The mean is the average you’re used to, where you add up all the numbers and then divide by the number of numbers

.

Variance is a sigma square.

In Kalman filters, we iterate measurement (measurement update) and (prediction). And the update will use Bayes rule, which is nothing else but a product or a multiplication. In prediction, we use total probability which is a convolution or simply an addition.

Implementation of measurement cycle and then the prediction cycle is as follows: [38]

The mean shift

1. Suppose we have a prior distribution; it is a very wide Gaussian with the mean.
2. The final mean gets shifted which is in between the two old means, the mean of the prior, and the mean of the measurement

The parameter update

1. Suppose we multiply two Gaussians, as in Baye's rule, a prior and a measurement probability. The prior has a mean of Mu and a variance of Sigma square, and the measurement has a mean of Nu, and covariance of r-square.
2. Then, the new mean, Mu prime, is the weighted sum of the old means. The Mu is weighted by r-square; Mu is weighted by Sigma square, normalized by the sum of the weighting factors. The new variance term would be Sigma square prime.
3. Clearly, the prior Gaussian has a much higher uncertainty, therefore, Sigma square is larger and that means the nu is weighted much larger than the Mu. So, the mean will be closer to the nu than the mu. Interestingly

enough, the variance term is unaffected by the actual means, it just uses the previous variances.

$$\mu' = \frac{r^2\mu + \sigma^2 v}{r^2 + \sigma^2} \quad (3\text{-}2)$$

$$\sigma^{2'} = \frac{1}{\frac{1}{r^2} + \frac{1}{\sigma^2}} \quad (3\text{-}3)$$

The Gaussian sensor data implement

1. A new mean is your old mean plus the sensor data often called u. So, and you knew sigma square is your old sigma squared plus the variance of the sensor data Gaussian.
2. The resulting Gaussian in the prediction step just adds these two things up, mu plus u and sigma squared plus r squared. The motion updates/ predicts function are:

$$\mu' \longleftarrow \mu + u \quad (3\text{-}4)$$

$$\sigma^{2'} \longleftarrow \sigma^2 + r \quad (3\text{-}5)$$

The Kalman Filter Limitations

The KF is a stochastic filtering process that recursively estimates the state of a dynamic system in the presence of measurement noise and process noise by minimizing the means squared error. [39] The KF consists of a discrete state-space model describing the evolution of a process given by

$$X_t = A_{t-1}\, x_{t-1} + q_{t-1} \quad (3\text{-}6)$$

$$y_t = H_t\, x_t + r_t \quad (3\text{-}7)$$

Where X_t is the true but hidden state of the system and y_t is the observable measurement of the state. The KF assumes a linear system dynamics and all noise follows a Gaussian distribution A is the fundamental matrix describing the system dynamics and H is the measurement matrix. $q_{t-1} \sim N(0, Q_t)$Is the process noise and $r_{t-1} \sim N(0, R)$is the measurement noise. The KF estimates the value of x_t given the measurement, $y_t$by filtering out the noise. This is carried out using the ‘‘Prediction’’ and ‘‘Update’’ steps equations [40] as follows:

Prediction step:

Predicted stat estimate: $\mathrm{x\hat{}_t = A_t x_{t-1}}$ (3-8)

Predicted estimate covariance: $\mathrm{p\hat{}_t = A_t P_{t-1} A_t^T + Q_t}$ (3-9)

Update step:

Measurement residual:$\mathrm{v_t = y_t - H_t x\hat{}_{t\,|t-1}}$ (3-10)

Residual covariance:$\mathrm{C_t = H_t P\hat{}_t H_t^T + R_t}$ (3-11)

Kalman gain: $\mathrm{k_t = p\hat{}_t H_t^T C_t^{-1}}$ (3-12)

Updated state-estimate: $\mathrm{x_t = x\hat{}_t + K_t v_t}$ (3-13)

Updated state-estimate covariance: $\mathrm{p_t = (1 - K_t H_t) p\hat{}_t}$ (3-14)

3.6.2 Arduino IDE (Integrated Development Environment) Software

Arduino programs, called “sketches”, are written in a programming language similar to C and C++. Every sketch must have two functions a setup () function (executed just once) followed by a loop () function (potentially executed many times); add “comments” to code to make it easier to read. Many sensors and other hardware devices come with prewritten software line for sample code, libraries (of functions). Libraries are a collection of code that makes it easy for you to connect to a sensor, display, module, etc. [41]

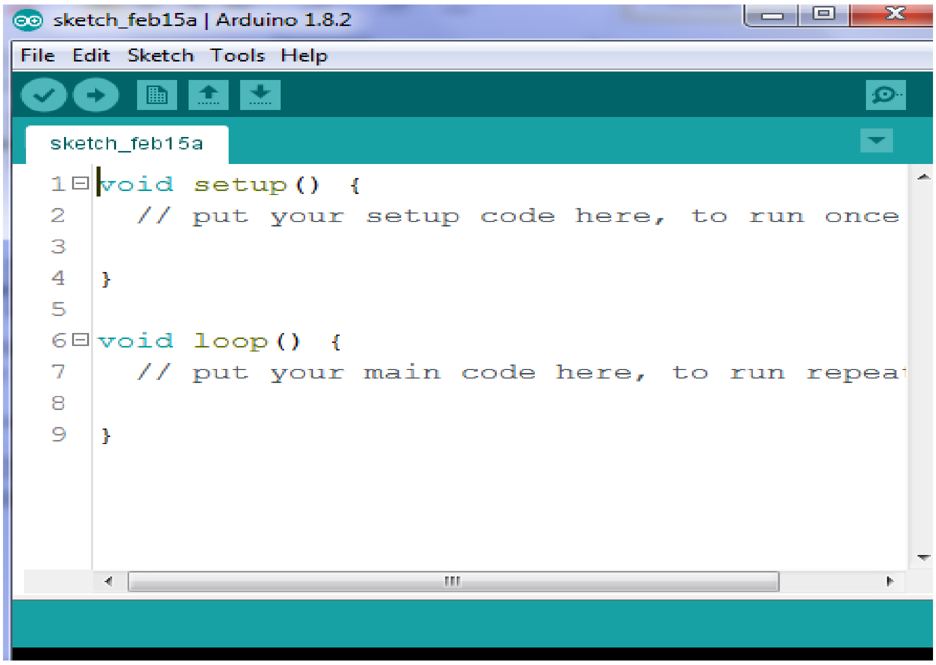

Figure 3-7: Arduino IDE software

3.6.2.1 Connecting the Sensor to an Arduino

The algorithm for Arduino Software is as follows:

- Initialize the sensor variables

-Declare and initialize power supply pins and ground pins

-Declare all variables related to arduino hardware

void setup()

{Serial transmission rate take place.

-Declare and initialize output pins

-Declare and initialize high and low pins for power and ground Values Set the type of host node and station node with integer value.

3.6.2.2 Thing-Speak

Thing-Speak are an Internet of Things (IoT) platform that helps to monitor, collect, and store sensor data in the cloud and develop IoT applications.

The Thing Speak IoT platform provides apps that let to analyze and visualize data in MATLAB and then act on the data. Sensor data can be sent to Thing-Speak from Arduino.

Thing-Speak provide many key attributes, including real stream data handling, static and dynamic data processing. The core part of Thing-Speak is its Communicating Thing-Speak channel. It allows users to send and receive data from the stored place. Each channel supports a maximum of 8 fields of different data types. [42]

3.6.2.3 Setup Thing-Speak

To perform operations in the Thing-Speak tool, a user account and a channel have to be set. In Thing-Speak, a channel is treated most important because only sensor data is sending and storing. For every 15 seconds. [42]

- Firstly open the https://thingspeak.com website for registration and signup.
- Channel created by selecting Channels, next click My Channels, and then NewChannel
- API Key and Channel ID Write down separately write for coding purposes.
- Thing Speak Communication Library Installed for Arduino

3.6.2.4 Setup Arduino Sketch

On the Arduino IDE software the Channel Number will configured and API Key variables.

CHAPTER FOUR

RESULT AND DISCUSSION

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Result

After wiring and writing the code, the program was run. The performance characteristics of the using Arduino nano-based on temperature sensor, heart rate sensor and 3-axis accelerometer and gyroscope, and esp-01 WI-FI module the test was done in two different conditions. The first test was done by dealing with sensors reading directly. The second test passed the sensor reading through the Kalman filter to create a different temperature and heart rate and position sensor and fuse sensor data. The result has been a more accurate and reliable use for other users and decision making.

The web browser displays the readings are shown the result of each sensor.

Observation of Sensor Data in Website

This thesis uses an open Thing-Speak IOT platform for displaying the different sensor data that the receivers received from the mobile phone. It even stores the data in the cloud. The data can have both public and private access. Data can be observed either through the mobile application by authorized persons with user id and password or in the web browser. Data that has been received by Thing-Speak could be analyzed and graphically represented.

This project uses six fields. Field 1 is used for displaying the body temperature, field 2 for filtered temperature, field 3 for heart rates and field 4 for filtered heart rate and field five for a position, and field six for filter position measurement.

In all fields, the X-axis represents the measuring date, and the Y-axis represents the value of the vital sign.

Figure 4-1: Observation of sensors data in Thing-Speak website

The figure below is a screenshot of the alert message the SMS send to the phone in an emergency case.

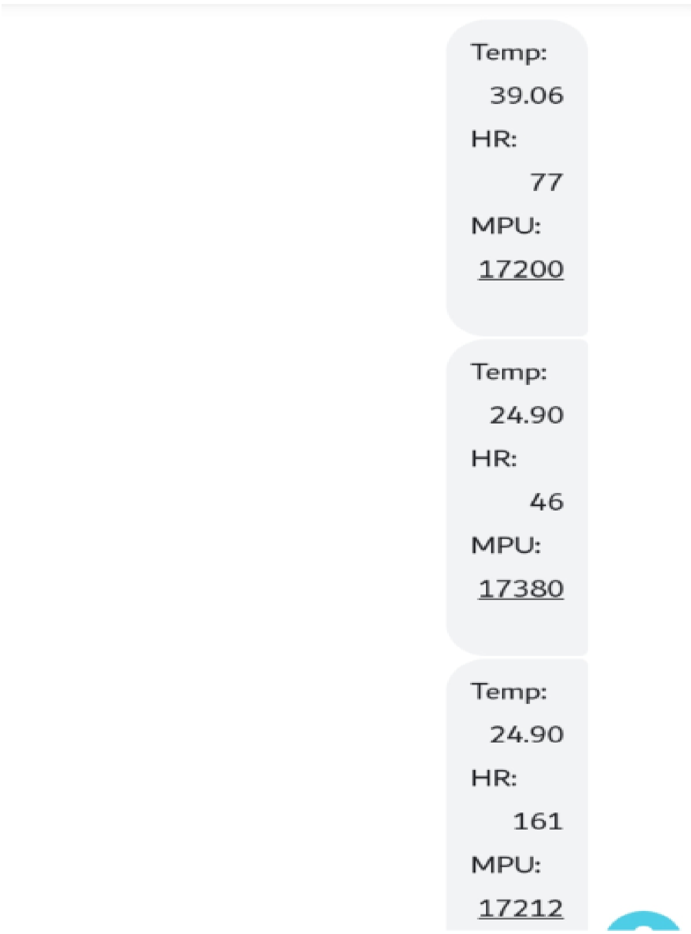

Figure 4-2: Screen shot from SMS alarming

4.2 DISCUSSION

This system has been compared with the hospital system by taking ten readings from both systems for the same infant at the same time. The mean value and the standard deviation have been calculated.

The real reading takes from different ills babies from the hospital of Ibrahim-Malik with doctor Mohsin's help.

The table below shows the heart rate, temperature, and accelerometer data sensor from my system compared with hospital measurement.

Table 4-1: for Result of the hospital's systems

NO.	Infant / month	HR bpm	Temp (°C)
1	4.5	110	37.4
2	11	113	36.8
3	9	101	34
4	8	116	37.2
5	6	117	37
6	10	123	38
7	4	104	36.2
8	9	100	35
9	7.5	106	36
10	5	116	38.2

Table 4-2: Result of the designed system

NO	Infant/ month	Temp (°C)	KF-Temp (°C)	HR bpm	KF-HR bpm	Mpu Ax	filtered Mpu Ax
1	4.5	33.2	32.0	130	129.90	120	120.24
2	11	31.74	32.18	102	101.78	164	164.23
3	9	34.18	34.00	129	129.52	144	144.66
4	8	38.5	39.01	106	105.78	-344	-343.77
5	6	41.02	40.6	126	126.3	-160	-160.28
6	10	37.11	37.88	160	159.8	20	19.2
7	4	41	40	131	130.63	-32	-32.2
8	9	33.20	32.88	130	129.9	-456	-456.47
9	7.5	33.69	32.93	121	120.01	120	120.24
10	5	42.48	42.57	90	89.4	-280	-279.35

Table 4-3: Comparison Result of the heart rate

	Hospital HR-bpm	**Designed System**	**Designed System with kalman**
Mean $\bar{x}$	110.6	122.5	122.3

Tale 4-4: Comparison Result of the temperature

	Hospital Temp	**Designed System**	**Designed System with kalman**
Mean $\bar{x}$	36.5°C	36.6°C	36.4°C

After designing and implementing the project, the previous results were obtained. From results we can found an Accuracy using the equations below:

$$\text{Error ratio} = {(\text{actual value} - \text{measured value})}\big/{(\text{actual value})} \quad (5\text{-}1)$$

$$\text{Accuracy} = 1 - \text{error ratio} \quad (5\text{-}2)$$

Measured value = the value obtained from designed system.

Actual value = the value obtained from hospital's device.

Tale 4-5: Accuracy Error Ratio

	Temp Sensor	**K-Temp**	**Heart Rate**	**K-Heart Rate**
Accuracy	-0.0005%	0.004%	-0.107%	-0.105%
Error Ratio	1.0005	0.996%	1.107	1.105%

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

Conclusion

The designed system is integrated using low-cost hardware and software to detect a problem of sudden death and assist parents in monitoring the newborn vital sign data.

This study's result was done by using Arduino-Nano in which a baby’s vital signs were conditioned and transmitted to the thing-speak web site by an esp-8266 WI-FI module. Vital signs can display on any browser easily. The buzzard alarm will set, and an emergency SMS sent on the emergency case.

According to the analysis, the measurements from the filter system using Kalman are less Error ratio than from the sensor system. And have more accuracy.

Future work

This wearable system was done with low cost and a few sensors; the sensor's number should be increased in the future. These can include Blood Pressure, Respiratory Rate, and other parameters. The measurement vital signs need to be shared with near hospital and make a database for each kid save on hospital server to simplify monitoring of baby health at the early age and also the GPS technique may use to immediately handle a baby position in an emergency case to send an ambulance even there is no one near the baby.

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APPENDIX

Appendix of the Sensors Codes with Arduino Nano and ESP8266

In this section of the appendix we list the codes we used. Here, we tested each sensor's compatibility with the Arduino Nano board.

```
#include <SoftwareSerial.h>
SoftwareSerialser(7, 8);
#include <stdlib.h>

#include <SimpleKalmanFilter.h>
SimpleKalmanFiltersimpleKalmanFilter(2, 2, 0.01);

#define USE_ARDUINO_INTERRUPTS true
#include <PulseSensorPlayground.h>

constintPulseWire = A3;
int Threshold = 550;

PulseSensorPlaygroundpulseSensor;
#include "Wire.h"
//#include "I2Cdev.h"
#include "MPU6050.h"
#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
   #include "Wire.h"
#endif
MPU6050 accelgyro;
String apiKey = "SUT5F7N66T64LRBZ";  //api key
//const char* ssid = "HUAWEI-B315-DF75"; //my Network SSID
//const char* password = "0JMMAFEQDFF"; //my Network Password
```

```
int16_t ax, ay, az;
int16_tgx, gy, gz;
floatdiff,temp,hum;
int alarm;
void setup()

{

Serial.begin(9600);
ser.begin(9600);
ser.println("AT+RST");
pinMode(13,OUTPUT);
pinMode(A1,INPUT);
pinMode(A3,INPUT);
delay(10);
//digitalWrite(13,HIGH);
//delay(500);
pulseSensor.analogInput(PulseWire);
pulseSensor.setThreshold(Threshold);
pulseSensor.begin();

 #if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
Wire.begin();
#elif I2CDEV_IMPLEMENTATION == I2CDEV_BUILTIN_FASTWIRE
Fastwire::setup(400, true);
  #endif
accelgyro.initialize();

//WiFi.begin(ssid, password);
```

```
//ThingSpeak.begin(client);

}

void loop()

{
//*********************LM35****************************
int t = analogRead(A1);
temp = ((t /1024.0)*500);
Serial.print("Measured:      ");Serial.print("TEMP: ");
Serial.print(temp);



delay(100);

//*******************HeartRate****************************
//TIM2_EN();
pulseSensor.begin();
intmyBPM = pulseSensor.getBeatsPerMinute();
//if (pulseSensor.sawStartOfBeat()) {
Serial.print("            ♥ BPM: ");
Serial.print(myBPM);
delay(20);
// if (myBPM> 90){
//  //############################
// }

//}
```

```
//*******************                                    MPU
**************************************************
accelgyro.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);
Serial.print("          AX :      ");
Serial.println(ax);
delay(100);

//******************Kalman*****************************
Serial.print("Kalman      ");
floatmeasured_T = temp + random(-100,100)/100.0;
floatestimated_value_T = simpleKalmanFilter.updateEstimate(measured_T);
diff = temp - measured_T;
  //Serial.println(diff,4);
Serial.print("TEMP: ");
Serial.print(measured_T);
delay(100);

//if (myBPM> 0 &&myBPM<   100){
floatmeasured_BPM = myBPM + random(-100,100)/100.0;
floatestimated_value = simpleKalmanFilter.updateEstimate(measured_BPM);
diff = myBPM - measured_BPM;
  //Serial.println(diff,4);
Serial.print("        ♥ BPM: ");
Serial.print(measured_BPM);
delay(100);
//}
floatmeasured_AX = ax + random(-100,100)/100.0;
```

```
floatestimated_value_AX =
simpleKalmanFilter.updateEstimate(measured_AX);
diff = ax - measured_AX;
  //Serial.println(diff,4);
Serial.print("                AX :          ");
Serial.println(measured_AX);
Serial.println(" ");
delay(100);

//*******************************ALARM_TEMP***********
if ((temp > 37) || (myBPM> 160 ) || (ax > 17300)){
tone(13,1000) ;
alarm++;
if (alarm == 1){
alarm++;
Serial.println("AT");
delay(500);
Serial.println("ATD+ +249129043773;");
delay(500);
delay(15000);
Serial.println("ATH");
delay(500);
Serial.println("AT+CMGF=1");
delay(1000);
Serial.println("AT+CMGS=\"+249129043773\"\r");             //+249129043773
+249990499722
delay(1000);
Serial.println("Temp:");
delay(100);
```

```
Serial.println(temp);
delay(100);
Serial.println("HR:");
delay(100);
Serial.println(myBPM);
delay(100);
Serial.println("MPU:");
delay(100);
Serial.println(ax);
delay(100);
Serial.println((char)26);
delay(500);
  }
}

if ((temp < 37) || (myBPM> 80 &&myBPM<160) || (ax < 17000)){
noTone(13);
alarm = 0;
}
//********************************IoT********************
char buf2[16];
charbuf[16];
char buf3[16];
 String strTemp = dtostrf(temp, 4, 1, buf);
 String strBPM = dtostrf(myBPM, 4, 1, buf);
  String strAY = dtostrf(ay, 4, 1, buf);

String strmeasured_T = dtostrf(measured_T, 4, 1, buf);
String strmeasured_BPM = dtostrf(measured_BPM, 4, 1, buf);
```

```
  String strmeasured_AX = dtostrf(measured_AX, 4, 1, buf);

  String cmd = "AT+CIPSTART=\"TCP\",\"";
cmd += "184.106.153.149"; // api.thingspeak.com
cmd += "\",80";
ser.println(cmd);

if(ser.find("Error")){
Serial.println("AT+CIPSTART error");
return;
  }



  String getStr = "GET /update?api_key=";
getStr += apiKey;
getStr +="&field1=" + strTemp;
getStr +="&field2=" + strmeasured_T;
getStr +="&field3=" + strBPM;
getStr +="&field4=" + strmeasured_BPM;
getStr +="&field5=" + strAY;
getStr +="&field6=" + strmeasured_AX;
getStr += "\r\n\r\n";

  // send data length
cmd = "AT+CIPSEND=";
cmd += String(getStr.length());
ser.println(cmd);

if(ser.find(">")){
```

```
ser.print(getStr);
Serial.println("send");
  }
else{
ser.println("AT+CIPCLOSE");
   // alert user
   //Serial.println("AT+CIPCLOSE");
  }

delay(100);
}
```

Kalman filter code

```
/* A simplified one dimensional Kalman filter implementation - actually a single variable low pass filter ;

*/

#ifndef _Kalman_h

#define _Kalman_h

class Kalman {

private:

/* Kalman filter variables */

double q; //process noise covariance

double r; //measurement noise covariance

double x; //value
```

```
double p; //estimation error covariance

double k; //kalman gain

public:

Kalman(double process_noise, double sensor_noise, double estimated_error, double intial_value) {

/* The variables are x for the filtered value, q for the process noise,

r for the sensor noise, p for the estimated error and k for the Kalman Gain.

The state of the filter is defined by the values of these variables.

The initial values for p is not very important since it is adjusted

during the process. It must be just high enough to narrow down.

The initial value for the readout is also not very important, since

it is updated during the process.

But tweaking the values for the process noise and sensor noise

 is essential to get clear readouts.

For large noise reduction, started from

q = 0.125

r = 32

p = 1023 //"large enough to narrow down"

e.g.

myVar = Kalman(0.125,32,1023,0);

*/
```

```
this->q = process_noise;

this->r = sensor_noise;

this->p = estimated_error;

this->x = intial_value; //x will hold the iterated filtered value

}

double getFilteredValue(double measurement) {

/* Updates and gets the current measurement value */

//prediction update

//omit x = x

this->p = this->p + this->q;

//measurement update

this->k = this->p / (this->p + this->r);

this->x = this->x + this->k * (measurement - this->x);

this->p = (1 - this->k) * this->p;

return this->x;

}

void setParameters(double process_noise, double sensor_noise, double estimated_error) {

this->q = process_noise;

this->r = sensor_noise;

this->p = estimated_error;
```

```
}

void setParameters(double process_noise, double sensor_noise) {

this->q = process_noise;

this->r = sensor_noise;

}

double getProcessNoise() {

return this->q;

}

double getSensorNoise() {

return this->r;

}

double getEstimatedError() {

return this->p;

}

};

#endif
```