University of Southern Queensland

Faculty of Health, Engineering and Sciences

Low-cost data logger for electrical respiration sensor

A dissertation submitted by

James Stuart Guthrie

in fulfilment of the requirements of

ENG4111 and 4112 Research Project

towards the degree of

Bachelor of Engineering (Honours) (Electrical & Electronic)

Submitted October, 2021

Abstract

The monitoring of the human respiration rate can provide crucial information for the early indication of physiological conditions such as hypoxia and hypercapnia as well as aid in the diagnosis and treatment of medical conditions such as asthma, chronic bronchitis, and emphysema.

By integrating electrical sensors, inside a face mask, with a low-cost data logging device it is then possible to have a more sophisticated, automated, and accurate means of monitoring and logging the respiration rate of the wearer in different environments and physiological states. This data can then be presented on its own or used alongside data provided by other breathing monitoring equipment and can be a vital asset to healthcare professionals by aiding in arcuate, reliable, and timely diagnosis.

The low-cost data logging system produced is based on the Arduino platform. Two different sensors were tested, a commercial off-the-shelve sensor and a hand drawn sensor that was made by graphite pencil drawn traces on standard printing paper.

The commercial sensor produced more stable, accurate and repeatable results compared to the hand drawn sensor. Given the low-cost of the commercial sensor and the better performance over the hand drawn sensor, the Arduino data logger paired with the commercially available sensor is shown to be the better complete overall low-cost respiration rate data logging system.

University of Southern Queensland

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ENG4111 & ENG4112 Research Project

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

James Stuart Guthrie
Student Number: [redacted]

Acknowledgements

I would like to thank my parents and friends for their ongoing support and encouragement over the journey of my engineering degree and this project.

Also, I would like to thank my work supervisors over the years for being accommodating and understanding in my management of working and studying concurrently.

And finally, thank you to my project supervisor, Dr Toan Dinh, for your guidance and support over the course of this project.

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Glossary of Terms

BPM	Breaths per Minute
CO2	Carbon Dioxide
DC	Direct Current
IDE	Integrated Development Environment
Li-ion	Lithium-ion
NTC	Negative Temperature Coefficient
SD	Secure Disk
SPI	Serial Peripheral Interface SPI
USB	Universal Serial Bus

1. Introduction

The monitoring of human respiration performance can provide crucial information for the early indication of physiological conditions such as hypoxia and hypercapnia as well as aid in the diagnosis and treatment of medical conditions such as asthma, chronic bronchitis, and emphysema. By using electrical sensors to monitor breathing, information can be obtained from breaths, including temperature, humidity, and flow rate. This data can be a vital asset to healthcare professionals by aiding in arcuate, reliable, and timely diagnosis. This project is focused on integrating respiration sensors with a data logging device, forming a complete low-cost system in the form of a wearable face mask. Having a low-cost system capable of capturing the signals, storing the data, and outputting meaningful information can allow patients to share this data, which has been collected outside the medical clinic environment, with healthcare professionals.

The remaining of this chapter outlines the background and aim of the project, and its objectives. Finally, section 1.4 - project outline, includes an outline of the remaining chapters of the project.

1.1 Background

The respiration rate is the one of the body's main four vital signs that are routinely monitored by medical professionals. The other three are body temperature, pulse rate and blood pressure. The Respiration rate is the number of breaths a person takes in a minute. At the most basic level, the respiration rate can be measured by simply counting the number of breaths a person takes in one minute by counting how many times the chest rises. *The Human Body Book* (2007, p. 136) defines the normal respiration rate for an adult at rest is between 12 and 17 breaths per minute.

By integrating electrical sensors (inside a mask) with a low-cost logging device that stores this data, it is then possible to have a more sophisticated, automated, and accurate means of monitoring and logging breathing activity. The respiration rate of the wearer can be continuously monitored in different environments and physiological states. This data can then be presented on its own or used alongside data provided by other breathing monitoring equipment or compared to the number of breaths counted in one minute by the chest rise and fall method.

For myself personally, as a keen mountain bike rider I'm interested in how controlling breathing or maintaining a certain breathing rhythm can increase physical performance, in a similar way to how consumer heart rate monitors are used to track fitness metrics. Therefore, a low-cost respiratory rate data logger could also be used to monitor breathing rates during physical exercise and the data later analysed in a sports science context to aid in improving performance.

1.2 Aim

The aim of the project is to develop a low-cost data logger that detects and logs breathing data from a sensor inside a face mask. The data logging system is based on the Arduino open-source platform. Two different sensors are used in the project. Sensor one is the off-the-shelf commercial DHT11 digital temperature-humidity sensor. Sensor two is a hand-made humidity sensor which is constructed by graphite pencil drawn traces on normal printing paper.

1.3 Objectives

The project hopes to achieve a self-contained low-cost wearable face mask that logs breathing performance. The project will focus on developing an Arduino based data logger that integrates with two different temperature-humidity sensors.

The objectives of the project

- Accurate and reliable data logging of breathing performance
- Low-cost complete system
- Practical usefulness

2. Literature Review

This chapter reviews literature on the following topics: Topic 1 – Breathing Monitoring Systems (section 2.1), this topic will explore some breathing monitoring systems; Topic 2 – The DHT11 Sensor (section 2.2), this topic will look at the DHT sensor and its uses as a breathing monitor sensor; Topic 3 – Arduino Data Logger (section 2.3), this topic will review the Arduino platform in the context of a data logging system. The summary will summarise this literature review and discuss the need for this project and the likelihood of obtaining meaningful results and an outcome that can be measured against the project objectives.

2.1 Breathing Monitoring Systems

This topic will explore some different devices that can be used for breath monitoring. Each device reviewed uses a different technique to the other. The first device is a tabletop capnography device, the second device is a wearable monitor, and the final device is a smartphone based breathing monitoring app.

Capnography is the monitoring of carbon dioxide (CO2) in the respiratory gases. In a medical context a capnography device, along with providing information about CO2 production and other diagnostic statistics, provides information on respiratory patterns and therefore respiration rate. The essential mechanism at play in a capnography device is that CO2 absorbs infrared radiation and this is the basis behind how the level of CO2 is measured. When a patient exhales, an infrared beam of light is passed over the gas sample on a sensor, the amount of or lack of CO2 is then inversely measured by the amount of light reaching the sensor. Figure 1 shows the display of the Medtronic Capnostream 20p bedside capnography.

Figure 1: The display of a capnography device by Medtronic (Medtronic 2021)

This capnography display is an example of typical capnography display, it shows the capnography waveform (bottom left) as well as other vital sign indicators. The respiration rate is shown in the bottom left-hand corner.

The respiration range of the Capnostream 20p is 0-150 Breaths per Minute (bpm) and the accuracy is:

0–70 bpm: ±1 bpm
71–120 bpm: ±2 bpm
121–150 bpm: ±3 bpm

A capnography device is not considered a consumer device, it is a professional piece of equipment that would be found in hospitals and clinical practices. Of note is the requirement for capnography machines to undergo regular calibration. As an example, the Capnostream 20p bedside capnography requires initial calibration after 1,200 operating hours, then once a year or after 4,000 operating hours, whichever comes first.

The wearable monitor. “Wearable” means that the device is to be worn on the subject while he or she goes about their daily activities with minimal restriction from the wearable device. There is a vast number of wearable devices, but not all of them are capable of measuring breathing performance and providing reliable results. Some studies have shown that microphones can be used to continuously monitor breathing by detecting the different sounds produced by inhaling and exhaling and using this information to calculate the respiratory rate. This method is more favourable with smartphone based applications due to the inbuilt microphone. Other studies have shown that by examining the movement of the chest cavity, for example by the use of accelerometers, the respiration rate can be calculated. Hung et al. (2008) concluded that accelerometer for use in measuring respiratory waveforms were not reliable in producing accurate results because of body movements and only provided suitable results when the subject was instructed to sit or lie down and minimise movement.

The American multinational technology company, Google, has introduced a feature that will allow users to take vital health measurements using just a smartphone camera. Initially only available on a Google Pixel phone but with plans for it to be offered on other Android devices in the future, users will be able to measure both heart and respiratory rate. Computer vision-based methods are used to take these measurements using only the smartphone camera. Google claims it can produce results that are comparable to clinical-grade measurements, however this is yet to be peer reviewed. Of note is the explicit warning by Google that these features are only intended for the use of tracking one’s own general wellbeing, i.e., it’s not meant to replace a professional diagnostic or medical tool.

2.2 The DHT11 Sensor

The DHT11 is a low cost digital temperature and humidity sensor. Inside the DHT11 is a capacitive humidity sensor and a thermistor to measure the surrounding air. It is powered by 3 to 5 volts and uses an 8-bit microcontroller to output a digital serial signal with a resolution of 16-bit and accuracy of ±5% relative humidity and ±2 degrees Celsius. Data can be refreshed from the sensor every 1 second.

2.3 Arduino Data Logger

Arduino is an open-source platform consisting of both a hardware programmable circuit board system, i.e., a microcontroller, and a piece of software or Integrated Development Environment (IDE) that runs on a computer and is used to develop and upload code to the physical device. Arduino is a popular platform due to the open-source licence and ease of uploading code, which basically requires running the IDE and connecting an Universal Serial Bus (USB) cable between the Arduino board and your computer. Arduino board designs use a variety of microprocessors and are equipped with sets of digital and analog input/output (I/O) pins that can be used to interface to various expansion boards, referred to as ‘shields’, to breadboards, other circuits, and sensors.

Arduino boards come in many different sizes and configurations with numerous different microprocessors, memory sizes, IO pins, physical size and etc. As of writing there is 17 different commercially produced Arduino boards.

Yearmwar, Mhetre and Patel (2018) showed that encouraging results can be obtained by using an Arduino Due to capture the results from a Negative Temperature Coefficient (NTC) type Thermistor and amplifier circuit that detects the vibration of the respiratory airways and converts this information into respiratory rate.

2.4 Summary

This literature review has looked at three different types of breathing monitoring systems, from high end machines found in hospitals, to innovative app-based solutions that can be run on smart phones. Each of these techniques has its advantages and usefulness in the targeted operating environment. The low-cost data logger presents an opportunity for a low-cost, stand-alone device that can be utilised in many different environments to obtain meaningful breathing rate information that be used in conjunction with existing devices or by itself.

3. Methodology

This chapter looks at the method of equipment selection (3.1), the mask, sensors, data logger. The software and programing requirements (3.2), examines the Arduino coding language and IDE. The prototyping (3.3), will detail the benchtop prototyping method. And finally the testing (3.4), that will be conducted to ensure correct operation.

3.1 Equipment selection

The mask selected was the 3M 8710 disposable particulate respirator (figure 2). This mask was selected due to the rigid structure, secure fitment and seal to the wearers face, room for fitment of sensor, and low cost.

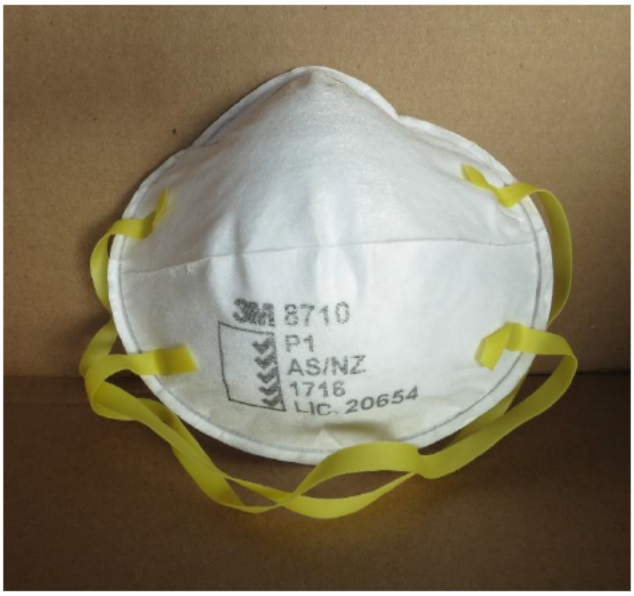

Figure 2: Digital camera picture of 3M 8710 mask

3M 8710 Specifications:

Parameter	Detail
Brand	3M
Exhalation valve	No
Natural rubber latex components	No
Product type	Dust and other particles
Protection level	P1
Respirator stlye	Cup
Size	Standard

Table 1 3M 8710 Mask Specifications

The DHT11 humidity and temperature sensor module from DFROBOT was selected as the digital sensor. The module package includes a filtering capacitor and pull-up resistor mounted on a printed circuit board with connector. The sensor has a full range temperature compensation, low power consumption, long term stability and calibrated digital signal

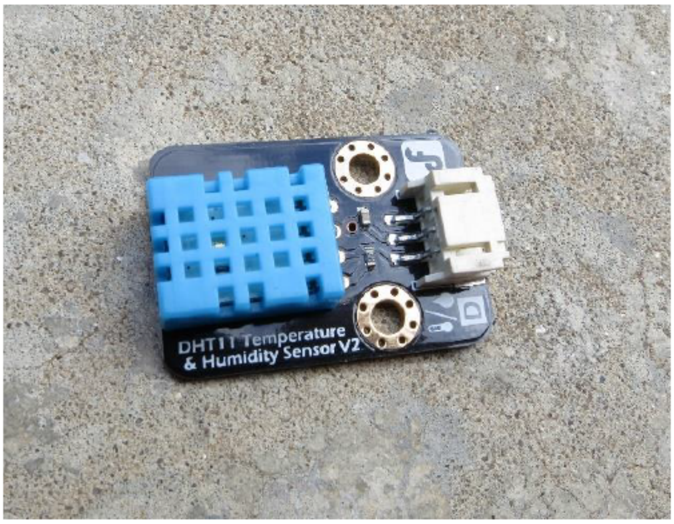

Figure 3: Digital camera picture of the DHT11 sensor

DHT11 Specifications:

Parameter	Detail
Sensor	DHT11
Temperature range	0 - 50 Celsius
Temperature measurement accuracy	+/- 5%
Humidity range	20 - 80%
Humidity measurement accuracy	+/- 2%
Sampling rate	1 Hz
Operating voltage	3 - 5 Volts
Current usage (operating)	2.5 mA
Current usage (standby)	60 uA
Body size	32 x 22 mm

Table 2 DHT11 Sensor Specifications

The Arduino Nano board has been selected as the suitable board for this project. The Nano board specifications are listed below, but the main reason the Nano board was selected was due to the boards small form factor, field proven and wide user base, low power consumption, and low-cost.

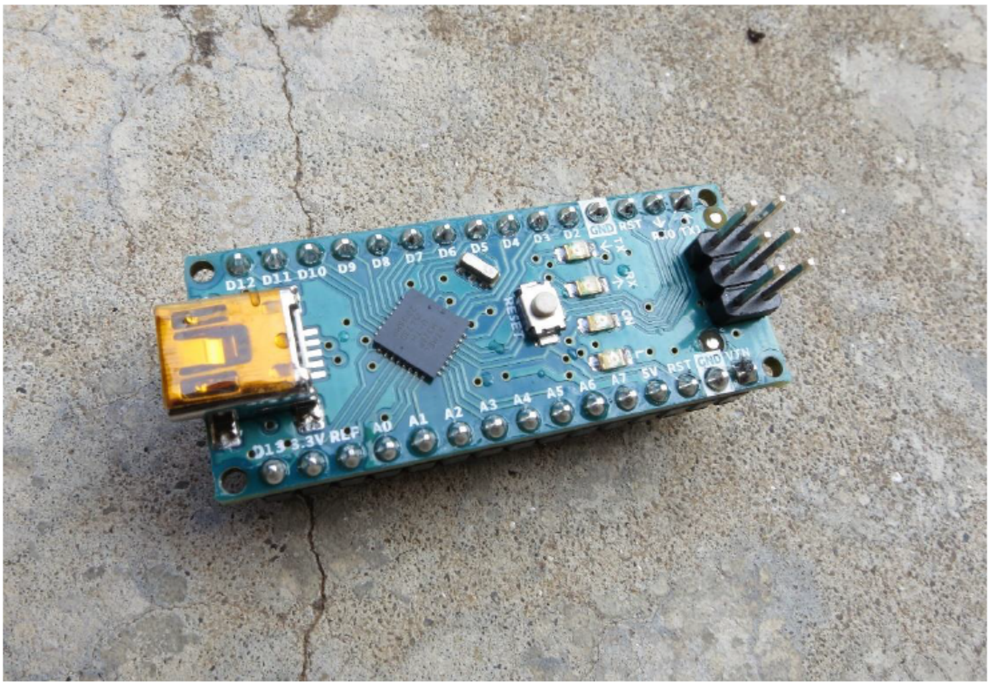

Figure 4: Digital camera picture of Arduino Nano board

Arduino Nano Specifications:

Parameter	Detail
Microcontroller	ATmega328
Architecture	AVR
Operating voltage	5 Volts
Clock speed	16 MHz
Flash memory	32 KB
Static RAM	2 KB
EERROM	1 KB
Analog I/O pins	8
Input voltage	7-12 Volts
Digital I/O pins	22
PWM output	6
Power consumption	19 mA
PCB size	18 x 45 mm
Weight	7 g

Table 3 Arduino Nano Specifications

3.2 Software and programing

The open-source Arduino software IDE makes it easy to write code and upload in to the Arduino board via an USB cable. The IDE runs on Windows, Mac OS X, and Linux. The IDE is a graphical user interface and is written in Java. A *sketch* is the name Arduino uses for a program. The Arduino IDE supports the programming language C and C++ and is supplied with a comprehensive software library, which provides many common input and output procedures. Arduino 1.8.15 is the current version of the IDE (August 2021). For the DHT11 sensor to communicate with the Arduino board it requires the Adafruit unified senor and DHT sensor library to be installed within the IDE and defined in the sketch.

3.3 Prototyping

Prototyping was conducted on a breadboard setup with the Arduino Nano board and two sensors, one for inside the 3M face mask and the other used as an ambient temperature reference sensor. For uploading of the sketch and monitoring the serial communications between the Arduino board and a personal computer a USB cable was used to make the connection and allow serial data to pass over the communication port. The Arduino IDE configures the transmission protocol used between board and computer and provides a serial monitor screen to display information when the sketch outputs serial data to the serial monitor.

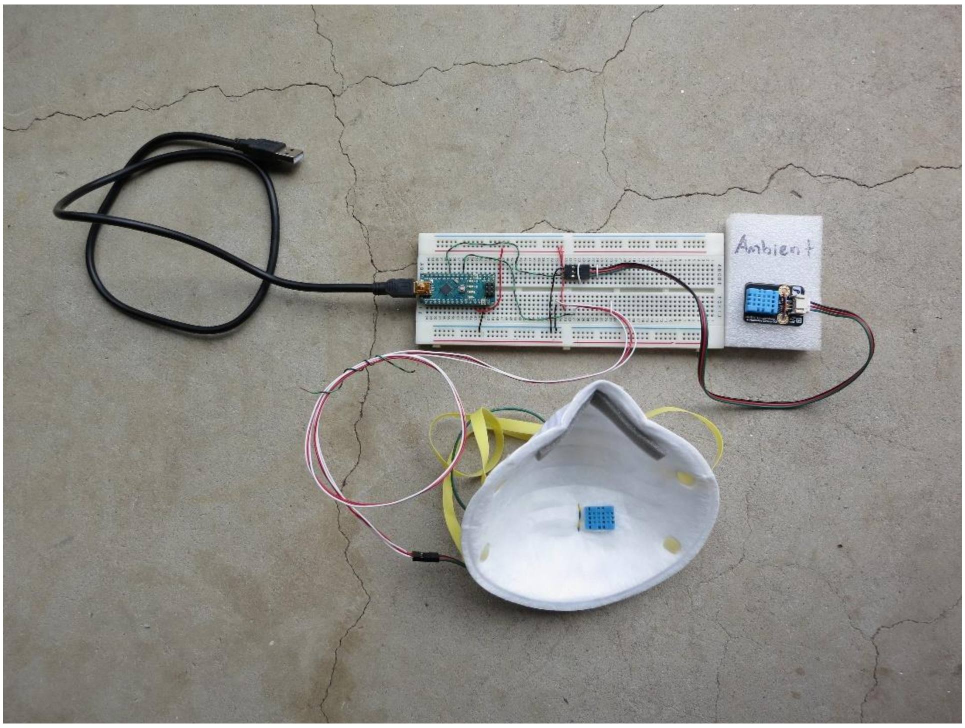

Figure 5: Digital camera picture of prototyping setup

4. Design and Implementation

4.1 Pencil Drawn Sensor

Electrical sensors based on using pencil drawn (graphite) techniques have been shown to produce low-cost, highly sensitive and stable performance for use in monitoring the respiration rate. Balakrishnan, et al. (2019) produced a sensor using manual drawing and printing techniques that were based on graphite trace and silver nanoparticles that were drawn on printing paper.

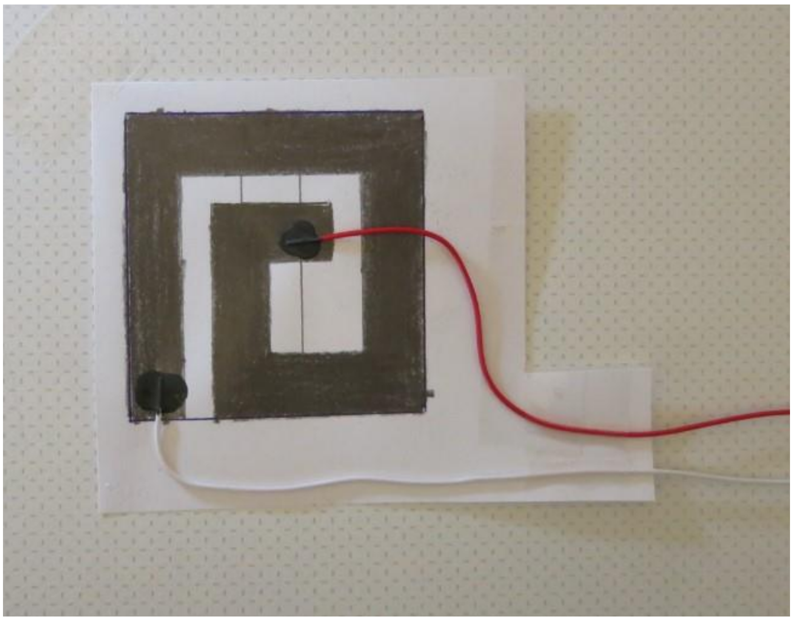

Figure 6: Digital camera picture of hand drawn sensor

Figure 6 shows the hand drawn sensor that is constructed on plain printing paper. The tracks are drawn with a Staedtler HB graphite pencil. The wires are attached using Idolon Technologies electrically conductive glue. Outside the face mask (room temperature and humidity) the resistance of the sensor is measured at 152 kilo Ohms.

The application of the hand drawn sensor, in this case, is to function as a variable resistor that reacts to changing humidity levels inside the face mask as the wearing breathes in and out. This changing resistance will be converted to a voltage through the use of a simple voltage divider circuit, which will be supplied to the Analogue to Converter input of the Arduino to produce a dataset that can evaluated to obtain the BPM of the mask wearer.

4.2 Memory Module

The Arduino Nano only has a small amount of on-board memory available for data storage. To eradicate this issue, a memory card module will be added, to not only substantially increase the amount of data that can be retained, but to also aid in the ease of transferring data off the device for analysing. Figure 7 shows the Iduino HW-203 Secure Digital (SD) memory card module. This memory card module accepts standard size SD cards and interfaces with the Arduino Nano through the Serial Peripheral Interface (SPI) protocol. To use this module with the Arduino Nano, the SD library is needed (this library is installed by Arduino IDE by default).

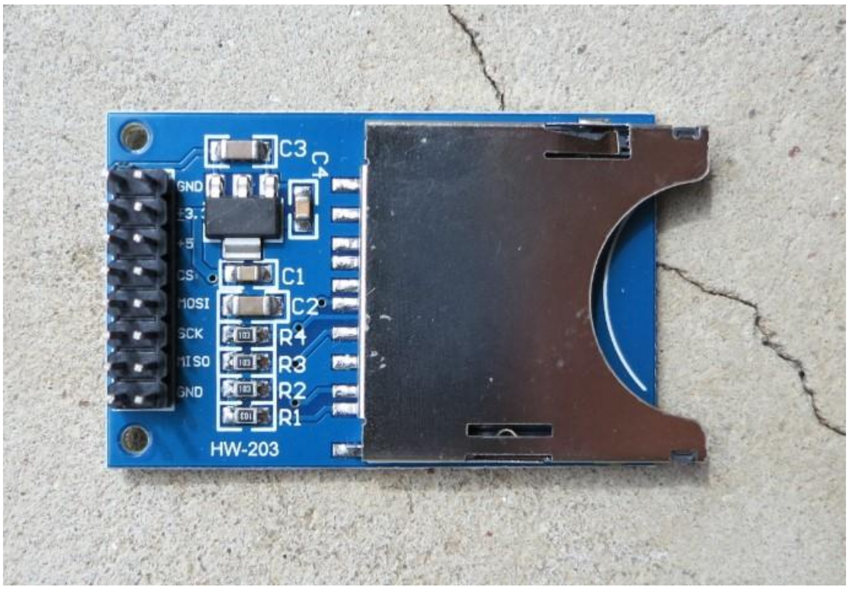

Figure 7: Digital camera picture of HW-203

4.3 Complete System

A complete and functioning system using the DHT11 sensor and constructed on a prototyping breadboard is shown in figure 8. The system consists of an Arduino Nano microprocessor, ambient DHT11 sensor, SD card module, and mask with DHT11 sensor in-built. The Arduino Nano and DHT11 sensors both require 5 Volt (V). The Iduino HW-203 system is powered by 5V Direct Current (DC), but also requires 3.3V DC – this can be obtained from the 3.3V output supplied on the Arduino Nano board. For battery powered 5V operation, a convenient method is to use a 5V DC to DC converter module that has an input Voltage range of 2.5-5V DC. This way either two size AA 1.5V batteries or a single size 18650 Lithium-ion (Li-ion) battery can be used to supply power to the system.

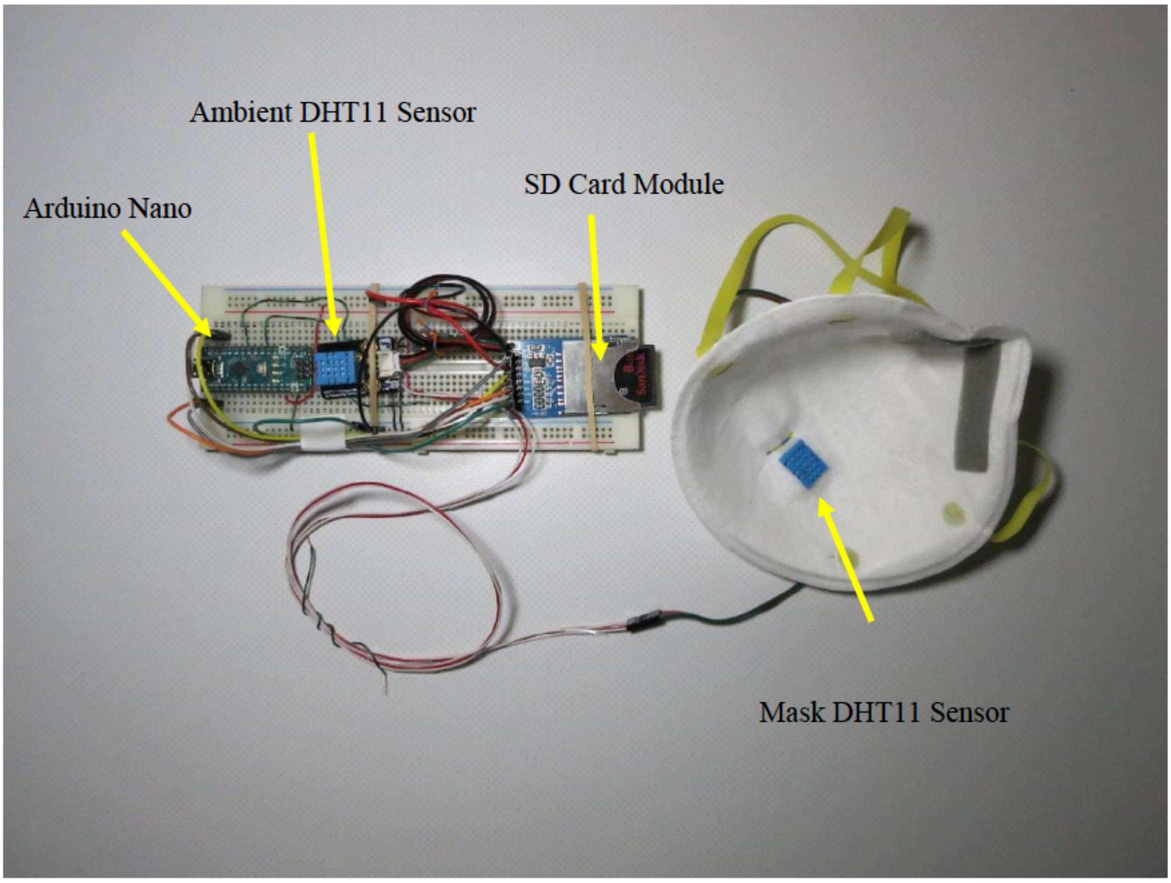

Figure 8: Digital camera picture of complete data logging system

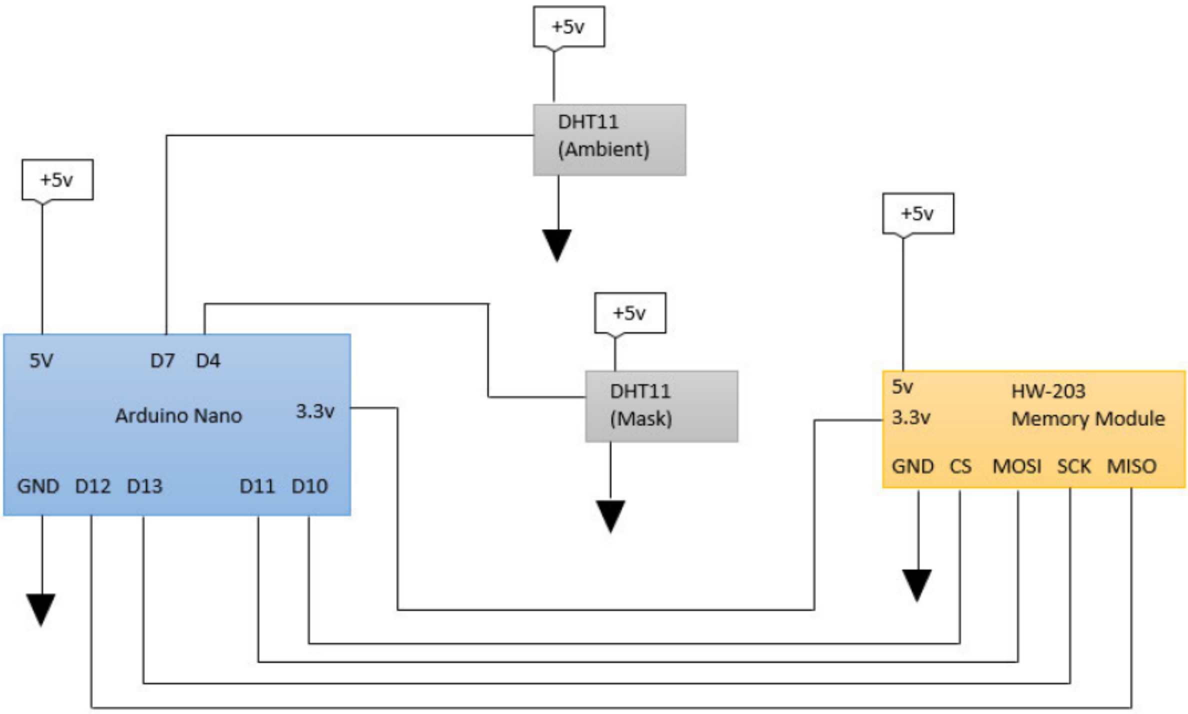

Figure 9: Circuit diagram of complete system

5. Testing and Evaluation

5.1 Results from DHT11 Sensor

The temperature of breaths vs samples chart shown in figure 10 shows the output data from the DHT11 sensor that is fixed inside the 3M face mask. The temperature is fluctuating as samples are taken from the sensor. The rise and fall of the temperature correlates to the mask wearer breathing in and out, as exhaled air is warmer than inhaled air by around 2-3°C. It is this difference in temperature that is used as the data metric to capture and measure the wearers breathing rate.

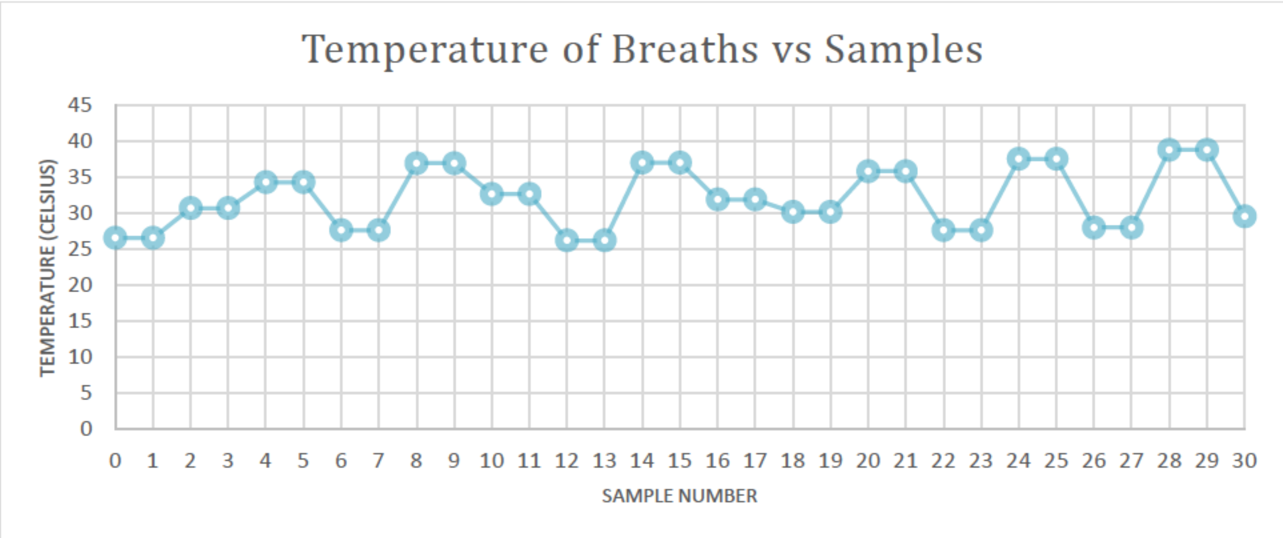

Figure 10: DHT11 Sensor results

The DHT11 sensor is connected to one of the digital input pins on the Arduino Nano. The DHT sensor has an 8-bit microcontroller that handles the output digital serial signal and therefore the Arduino Nano only needs to poll this input connection to capture the data. Inside the Arduino Nano the sketch (program) captures the data and stores the sample temperatures in an array before running a peak detection algorithm to calculate the number peaks in the dataset. The number of peaks over a 60 second time period is what is used to determine the breathing rate in BPM of the mask wearer.

The DHT11 sensor paired with the Arduino Nano produced encouraging result and could be further refined to produce a stable and consistent complete low-cost respiration rate data logger.

5.2 Results from Paper Drawn Sensor

The circuit in figure 11 shows the design of the variable resistor paper based sensor. This graphite pencil drawn sensor provided inconsistent results and it was unable to be used to obtain a meaningful BPM value. More work and testing on this sensor design is needed before it can implemented. Another design of a paper based pencil drawn sensor could provide better results. The method of using a pencil drawn sensor that is meant to function as a variable resistor might not be the best approach and other methods, such as, a paper based thermistor design could be investigated as a more suitable design approach.

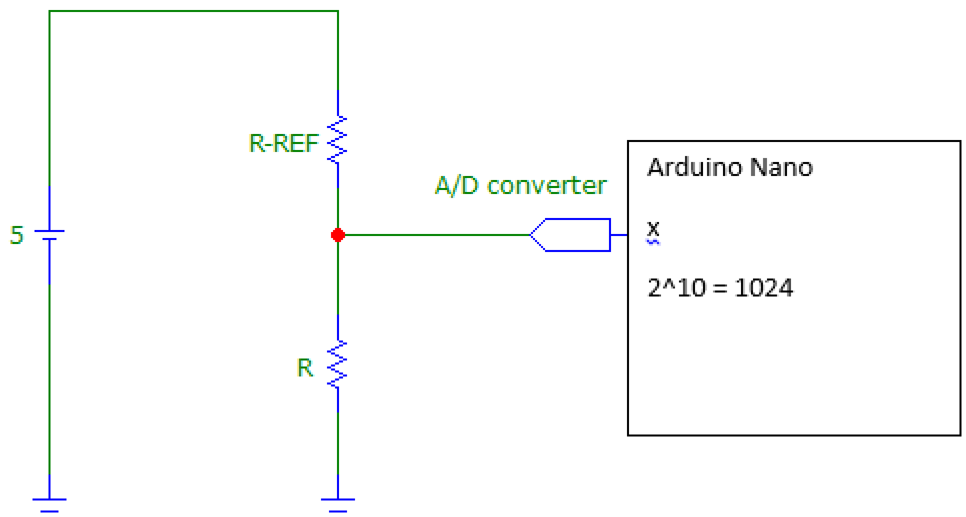

Figure 11: Circuit diagram of paper based sensor

6. Conclusion

6.1 Conclusion

The components used to construct a low-cost data logger for electrical respiration sensor, as of 2021, is under $30 Australian dollars. The DHT11 sensor was shown to produce better results than the hand drawn pencil on paper sensor design that was chosen in this project. This is not a decisive conclusion that a DHT11 sensor is the better sensor when compared to a pencil drawn paper based sensor as there is a vast amount of different techniques and designs of these sensor types, and it is outside the scope of the project to be able to compare them all.

Further work is recommended to fine tune the DHT11 based low-cost data logger, in particular, more reliable results when the respiration rate of the wearing is subject to sudden and abrupt changes in a very short period of time.

Overall the low-cost data logger for electrical respiration sensor produced a functioning unit that is able to produce meaningful and useful respiration rate data.

Appendices

Appendices A: Project Specification

ENG4111/4112 Research Project

Project Specification

For: James Guthrie

Title: Low-cost data logger for electrical respiration sensor

Major: Electrical Engineering

Supervisor: Toan Dinh

Enrollment: ENG4111 – EXT S1, 2021

ENG4112 – EXT S2, 2021

Project Aim: To develop a low-cost data logger, based on an Arduino system, to monitor electrical signals form a human respiration sensor in real time.

Programme: Version 1, 14th March 2021

1. Conduct background research on human respiration sensors, in particular senors that monitor physiological signals from breaths, including temperature, humidity and flow.
2. Review the two assigned sensors.
   a. Commercialised DHT11 for humidity and temperature monitoring.
   b. Hand-made humidity sensor.
3. Research and select a suitable Arduino based data logging system.
4. Assess hardware interfacing requirements between sensors and data logging system.
5. Construct data logging system and interface with sensors.
6. Select a suitable software development environment and develop code for data collection and logging.

7. Field testing of prototype system.
8. Process and evaluate experimental data.

If time and resource permit:

9. Refinement of prototype system, depending on performance in field testing and evaluation.
10. Further testing with larger test group.

Appendices B: Risk Assessment

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland Offline Version

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Building, fault finding and testing Arduino based Low-cost data logger for electrical respiration sensors	Assessment Date:	20/04/2021
Workplace (Division/Faculty/Section):	Faculty of Health, Engineering and Sciences	Review Date:(5 Years Max)	Click here to enter a date.

Context			
Description:			
What is the task/event/purchase/project/procedure?	Use of electronic equipment		
Why is it being conducted?	Completion of final year engineering project		
Where is it being conducted?	Home work spaces		
Course code (if applicable)	ENG4111 & ENG4112	Chemical name (if applicable)	Electrically Conductive Carbon Adhesive
What other nominal conditions?			
Personnel involved	James Guthrie		
Equipment	Basic consumer electronic equipment and low voltage Arduino development board		
Environment	Home work spaces		
Other			
Briefly explain the procedure/process	Designing, building, fault finding, and testing an Arduino based Low-cost data logger for electrical respiration sensors as part of ENG4111 and ENG4112 towards the completion of the final year engineering project.		
Assessment Team - who is conducting the assessment?			
Assessor(s)	Toan Dinh		
Others consulted:			

Eg 1. Enter Consequence

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Eg 2. Enter Probability

Recommended Action Guide

- **E**=Extreme Risk – Task ***MUST NOT*** proceed
- **H**=High Risk – Special Procedures Required (See USQSafe)
- **M**=Moderate Risk – Risk Management Plan/Work Method Statement Required
- **L**=Low Risk – Use Routine Procedures

Eg 3. Find Action

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Using electronic equipment	Contact with exposed live parts causing eletrical shock	Moderate	No access to live high voltage parts - Equipment is double insulated or earthed. Residual-Current Device (RCD) is fitted at premises.	Rare	Low	Yes or No	Test fitted RCD. Measurement of parts on deleveoplment board with multimeter and dissconnection of mains powered equipment before placing or removing components.	Moderate	Rare	Low	Yes
Hazards while constructing test circuits and etc	Nicks and cuts to fingers.	Minor	Use appropriate tools and PPE when required.	Possible	Moderate	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Use of Arduino battery power supply	Short circuit	Moderate	Battery power supply will be fitted with a fuse	Rare	Low	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Faulty development board or electrical sensors	Injury or damage to property from faulty components and/or parts	Minor	Exercise caution when operating system for first time/performing new measurments.	Unlikely	Low	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Construction of electrical sensor with wire glue	Fumes and contact with chemical - Electrically Conductive Carbon Adhesive.	Minor	Use in well ventilated area and use PPE.	Unlikely	Low	Yes or No	Consult product MSDS before use for extra safety precautions.	Select a consequence	Select a probability	Select a Risk Level	Yes or No

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
Test fitted RCD. Measurement of parts on deleveoplment board with multimeter and dissconnection of mains powered equipment before placing or removing components.	Multimeter	James Guthrie	20/04/2021
Consult product MSDS before use for extra safety precautions.	Anders Products Wire Glue Material Safety Data Sheet	James Guthrie	20/04/2021
			Click here to enter a date.
			Click here to enter a date.
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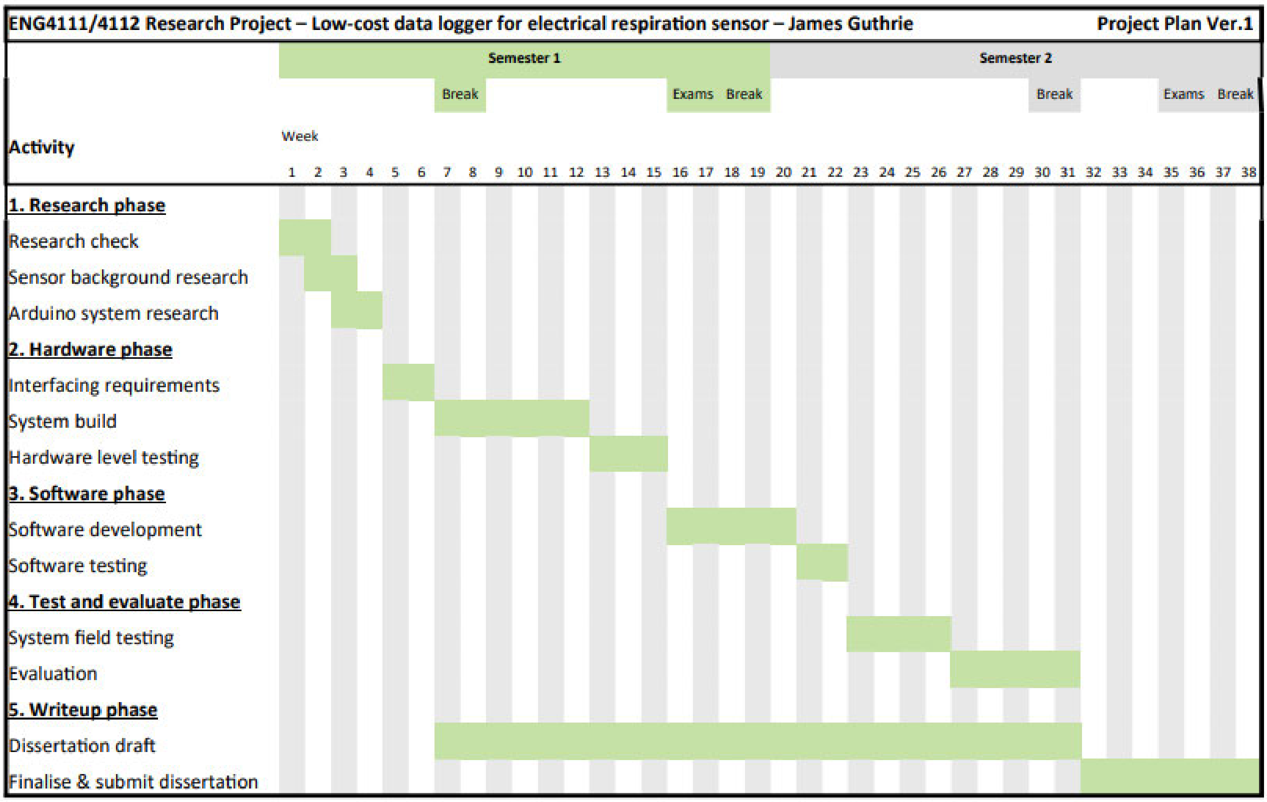
			Click here to enter a date.
			Click here to enter a date.

Step 6 - Approval			
Drafter's name:	James Guthrie	Draft date:	20/04/2021
Drafter's comments:			
Approver's name:		Approver's title/position:	
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.

Appendices C: Project Timeline



Appendices D: References

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Appendices E: Arduino code

DHT11 sensor code

```
/*-----( Import libraries )-----*/
#include <DHT.h>
#include <SPI.h>
#include <SD.h>
#include <Adafruit_Sensor.h>

/*-----( Declare Constants and Pin Numbers )-----*/
#define DHT1_PIN 4 // Define Mask sensor on pin 4
#define DHT2_PIN 7 // Define Ambient sensor on pin 7
#define DHTTYPE DHT11 // Define type of sensor
#define samples 60 // Define number of samples

/*-----( Setup Files )-----*/
File myFile;

/*-----( SD Card Module Pin Numbers )-----*/
int CS_PIN = 10;

/*-----( Initialise DHT11 sensors )-----*/
DHT dht1 = DHT(DHT1_PIN, DHTTYPE);
DHT dht2 = DHT(DHT2_PIN, DHTTYPE);

/*-----( Declare Variables )-----*/
int counter = 0;
int breathCount = 0;
float diffArray[samples];
float diffArrayMax = 0;
float diffArrayMin = 100;
float diffArrayHOLD = 0;
float h;
float t;
float hic;
float h2;
float t2;
float hic2;
//float diff;
int diff;
int threshold = 15;
bool flag = false;

/*-----( Declare objects )-----*/

/*-----( Run SETUP )-----*/
void setup()
{
  Serial.begin(9600); // Begin serial communication at a baud rate of 9600
  Serial.println("DHT11 Breathing Monitor - JS GUTHRIE");
  Serial.println();

  // Setup SD card
  Serial.print("Initialising SD card...");
  Serial.println();
  if (!SD.begin(10))
    {
     Serial.println("initialisation of SD card failed!");
     while (1);
    }
```

```
  Serial.println("Initialisation of SD card done.");

  // Setup sensors:
  Serial.println("Initialising sensors...");
  dht1.begin();//for first DHT module
  dht2.begin();//for second DHT module
  Serial.println("Initialisation of sensors done.");
  Serial.println("Commence capturing breathing rate...");
}

/*-----( Run LOOP )-----*/
void loop()
{
  delay(1000); // Wait a second between measurements

  // Sensor 1
  h = dht1.readHumidity(); // Read the humidity in %:
  t = dht1.readTemperature(); // Read the temperature as Celsius:

  // Check if any reads failed and exit early (to try again):
  if (isnan(h) || isnan(t))
    {
     Serial.println("Failed to read from DHT Mask sensor!");
     return;
    }
  hic = dht1.computeHeatIndex(t, h, false); // Compute heat index in Celsius:

  // Sensor 2
  h2 = dht2.readHumidity(); // Read the humidity in %:
  t2 = dht2.readTemperature(); // Read the temperature as Celsius:

  // Check if any reads failed and exit early (to try again):
  if (isnan(h2) || isnan(t2))
    {
      Serial.println("Failed to read from DHT Ambient sensor!");
      return;
    }
  hic2 = dht2.computeHeatIndex(t2, h2, false); // Compute heat index in Celsius:

  diff =  abs(hic-hic2); // Calculate the difference between sensor 1 & 2
  diffArray[counter] = diff; // Store difference value in array
  counter ++; // Increment counter

  // After 60 samples, do this
  if (counter == samples)
    {
       // Iterate through whole array and print values
       for (int i = 0; i < sizeof(diffArray)/sizeof(diffArray[0]); i++)
         {
          Serial.println(diffArray[i]);
         }

       // Find peaks (cycles) in diffArray
       for ( int i = 0; i < sizeof(diffArray)/sizeof(diffArray[0]); i++ )
         {
          if ( diffArray[i] > threshold && !flag ) // diffArray greater than threshold and flag is false then this is a
breath
           {
             breathCount++;
             flag = true;
           }
```

```
        if ( diffArray[i] < diffArray[i+1] )  // Get the next drough and reset the flag
         {
           flag = false;
         }
       }
      Serial.println();
      Serial.print("The BPM is: ");
      Serial.print(breathCount);
      Serial.println();

     // Write data to SD card
     myFile = SD.open("data.txt", FILE_WRITE);
     // if the file opened okay, write to it:
     if (myFile)
       {
        Serial.println();
        Serial.println("Writing data to SD card...");
        myFile.println(breathCount);
        myFile.close(); // close the file:
        Serial.println("Done writing data to SD card");
        Serial.println("Continue capturing breathing rate...");
       }
     else
       {
        // if the file didn't open, print an error:
        Serial.println("error opening data.txt");
       }
     counter = 0; // Reset counter
     breathCount = 0; // Reset breathCount
   }
}
```