

PRIFYSGOL CYMRU
Y Drindod Dewi Sant
UNIVERSITY OF WALES
Trinity Saint David

Electric Motor Data Acquisition System

Author: Domenico Michael Francesco Todaro

Supervisor: Mr Gareth Jones
Second Marker: Dr Gary Jones

Project submitted as part of the requirements for the award of BEng (Hons) Electrical and Electronic Engineering

April 2018

Declaration Form

I, Domenico Michael Francesco Todaro declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not been previously been accepted as part of any other degree submission.

Signed:

Date:

Acknowledgments

Throughout the process of my part time study ranging from HNC to now the final year of my BEng degree, there are many people I would like to thank with the deepest gratitude.

Firstly, I would like to thank all of my supervisors and managers both at Valero oil Refinery, Pembroke and ExxonMobil, AES Newport for allowing me to pursue with my studies, also providing technical insight when asked upon.

I would like to thank Gareth and Gary Jones, my project supervisors within UWTSD for their help, guidance, time and patience throughout the final year of study.

Finally, and if not most importantly I would also like to thank my mother, father and three elder sisters for their positive encouragement when I've experienced both highs and lows throughout my study.

Abstract

The Electric Motor Data Acquisition System report was submitted as part of the requirements of the author studying a part-time Electrical and Electronic BEng (Hons) degree at UWTSD Swansea campus. The aim of this report was to design and produce a microcontroller based Electric Motor Data Acquisition System.

The following pages reflect the objectives established to produce this data acquisition system. This included a wide range of background research covering, AC and DC motors, identifying ways in which a motor could be monitored, as well as the design and build of a prototype acquisition system and gather data to reflect the performance.

There were a number of methods used to progress this project, these cover, SMART goals, Gantt charts reflecting time management, research onion to aid research methodology plus SWOT analysis to select applicable components.

The project was designed and tested successfully, although a number of faults became present which ultimately put a stop to the implementation of a structural prototype acquisition system. Investigations into these faults were on going whilst this report was submitted.

A number of improvements and recommendations were concluded as part of this report, with successful design outcomes being established.

Table of Contents

Declaration Form 1

Acknowledgments 2

Abstract 3

Table of Figures 11

Table of tables 17

Chapter 1 - Introduction 20

1.1 Project Overview 20

1.2 Project Aims and Objectives 21

1.3 Project Rational 22

1.4 Conclusion - Introduction 23

Chapter 2 – Research Methodology 25

2.1 Introduction – Research Methodology 25

2.2 Research Philosophy 25

2.3 Research approach 26

2.4 Research strategies 26

2.5 Time horizons 26

2.6 Data Collection methods 26

2.7 Conclusion – Research methodology 27

Chapter 3 – Planning 28

3.1 Introduction – Planning 28

3.2 Key Milestones 28

3.3 Milestone breakdown 29

3.4 Overall plan 29

3.5 Resources Required for Each Milestone 29

3.6 Conclusion – Planning 31

Chapter 4 – Background Research 33

4.1 Introduction - Background research 33

4.2 Extruder Main Drive Motor 33

4.3 Motors 34

4.3.1 AC Motors 34

4.3.2 DC Motors 37

4.3.3 AC and DC Motor Differences 37

4.3.4 Motor Failings 39

4.4 Data acquisition systems 42

4.4.1 How can Data acquisition systems be used? 42

4.4.2 Market research 44

4.5 Work Based Survey 45

4.6 Conclusion - Background research 50

Chapter 5 – Design Requirements/Specification 52

5.1 Introduction - Specification 52

5.2 Performance 52

5.2.1 Measurements 52

5.2.2 Data logging device 52

5.2.3 Logging time 52

5.2.4 Aesthetics - Display/Communication 53

5.2.5 Motor 53

5.2.6 Power 53

5.3 Target cost 53

5.4 Hardware/Software 53

5.5 Customers 54

5.6 Environment 54

5.7 Size/weight & Ergonomics 54

5.8 Quality and reliability 54

5.9 Testing 54

5.10 Safety 55

5.11 Conclusion – Specification 55

Chapter 6 – Design Research/Component Selection 56

6.1 Introduction - Component Selection 56

6.2 Motor selection 57

6.2.1 Brushed 57

6.2.2 Brushless 58

6.2.3 Market Research of Selected Motor 59

6.2.4 Selected Motor 60

6.3 Motor variable speed 60

6.3.1 Pulse Width Modulation 60

6.3.2 Flux Control Method 62

6.3.3 Armature Control Method 63

6.2.4 Market Research of Selected PWM Speed Controls 63

6.2.5 Selected Speed Control 65

6.4 Temperature sensors 65

6.4.1 Infrared 65

6.4.2 RTD 66

6.4.3 Thermocouple 67

6.4.4 IC (Integrated circuit) 68

6.4.5 Market Research of Selected IC Temperature Sensors 68

6.4.6 Selected Temperature Sensor 69

6.5 Speed sensors 70

6.5.1 Photo Electric – Beam Break 70

6.5.2 Photo Electric – Reflective 71

6.5.3 Hall-Effect 72

6.5.4 Market Research of Selected Photo Reflective Speed Sensors 72

6.5.5 Selected Speed Sensor 74

6.6 Vibration sensors 74

6.6.1 Gyroscope 74

6.6.2 Strain gauge 75

6.6.3 Proximity Probes 75

6.6.4 Market Research of Selected Gyroscopes 76

6.6.5 Selected Vibration Sensor 78

6.7 Battery 78

6.7.1 Lead Acid 79

6.7.2 Lithium 79

6.7.3 Mercury 80

6.7.4 Market Research of Selected Battery 80

6.7.5 Selected battery 81

6.8 Microcontroller Selection 82

6.8.1 Microcontroller requirements 82

6.8.2 Microcontroller Market research 84

6.8.3 Selected Microcontroller 84

6.9 Conclusion - Component Selection 84

Chapter 7 – Component Testing 86

7.1 Testing introduction 86

7.2 Temperature Sensor 86

7.2.1 Test procedure 87

7.2.2 Test analysis 88

7.3 Speed Sensor 90

7.3.1 Test procedure 90

7.3.2 Test analysis 91

7.4 PWM Controller 99

7.4.1 Test procedure 99

7.4.2 Test analysis 100

7.5 Battery Testing 103

7.5.1 Test procedure 103

7.5.2 Test analysis 104

7.6 Motor Testing 105

7.6.1 Test procedure 105

7.6.2 Test analysis 106

7.7 Conclusion – Component Testing 110

Chapter 8 – Design & Design Testing 111

8.1 Introduction - Design 111

8.2 Operational Flow Chart 112

8.3 Structure Diagram 113

8.4 Proteus Design 113

8.4.1 Overall Design 114

8.4.2 Speed Sensor 114

8.4.3 Vibration Sensor 115

8.4.4 Temperature Sensor 115

8.4.5 Power Supply 116

8.4.6 Microcontroller 116

8.4.7 Running Indication 117

8.4.8 RS232 117

8.5 Easy-PC design 118

8.5.1 Overall Design 118

8.5.2 Speed Sensor 119

8.5.3 Vibration Sensor 119
8.5.4 Temperature Sensor 120
8.5.5 Power Supply 120
8.5.6 Microcontroller 121
8.5.7 Running Indication 121
8.5.8 RS232 121
8.5.9 LCD 122
8.6 PCB Design 122
8.7 CCS Design and Testing 124
8.7.1 CCS Development 124
8.7.2 Temperature Sensor Testing 129
8.7.3 Vibration Sensor Testing 133
8.7.4 Speed Sensor Testing 135
8.7.5 On/Off button & Start button plus LED Testing 138
8.8 Structural Design of Prototype 139
8.9 Design - Conclusion 139
Chapter 9 – Implementation 140
9.1 Implementation – Introduction 140
9.2 Miscellaneous Components 141
9.3 Overall Costing's 142
9.4 Prototype Build 143
9.4.1 Stuctural Build 143
9.4.2 Software Build 145
9.4.3 Electronic Build & Testing 145
9.5 Conclusion - Implementation 152
Chapter 10 - Evaluation 154
10.1 Introduction – Evaluation 154

10.2 Project Aims 154

10.3 Project Objectives 154

10.4 Successful Aspects 155

10.5 Unsuccessful Aspects 157

10.6 What would be done differently? 157

10.7 Conclusion - Evaluation 158

Chapter 11 – Conclusion 160

Chapter 12 – Recommendations 166

Chapter 13 – Reflection 169

13.1 Learnings 169

13.2 Personal Development 170

Chapter 14 - References 171

Chapter 15 – Bibliography 178

Chapter 16 – Appendices 180

16.1 Milestone Breakdown 180

16.2 Gantt Chart - Proposal 187

16.3 Gantt Chart - Interim Viva 1 188

16.4 Gantt Chart – Interim Viva 2 189

16.5 Gantt Chart – Final 190

16.6 Survey Results 191

Table of Figures

Figure 1: Report Structure *24*

Figure 2: Research onion [3] *25*

Figure 3: Research onion route [3] *27*

Figure 4: Original Gantt chart 10/08/2017 ..... *29*

Figure 5: Project selection timescale Interim 1 – 19/01/17 ..... *31*

Figure 6: Project selection timescale Interim 2 – 25/01/18 ..... *32*

Figure 7: Project selected timescale 29/03/18 ..... *32*

Figure 8: Extruder, Main drive & Motor *34*

Figure 9: AC Motor Structure [6] *35*

Figure 10: AC Motor Magnet Field Structure [6] *36*

Figure 11: DC Motor Structure [7] *37*

Figure 12: Root Cause Motor Failure Analysis [9] *39*

Figure 13: Motor Stresses [9] *41*

Figure 14: Data Acquisition Layout [11] *42*

Figure 15: Survey Questions *46*

Figure 16: Survey question 1 results *47*

Figure 17: Survey question 2 results *47*

Figure 18: Survey question 3 results *48*

Figure 19: Survey question 4 results *48*

Figure 20: Survey question 5 results *49*

Figure 21: Survey question 6 results *49*

Figure 22: Survey question 7 results *50*

Figure 23: Layout of Microcontroller/electronics enclosure *53*

Figure 24: System function blocks *55*

Figure 25: Component selection process *56*

Figure 26: DC brushed Motor [20] *57*

Figure 27: DC Brushless Motor [20] *58*

Figure 28: Selected DC motor [23] 60
Figure 29: Pulse width Modulation [26] 60
Figure 30: PWM Block diagram 61
Figure 31: Flux Control [29] 62
Figure 32: Armature Control [29] 63
Figure 33: Selected PWM [33] 65
Figure 34: RTD [37] 66
Figure 35: Thermocouples [40] 67
Figure 36: Selected Temperature sensor [22] 70
Figure 37: Reflective sensors [50] 71
Figure 38: Selected speed sensor data [53] 74
Figure 39: Strain Gauge [58] 75
Figure 40: Selected Gyroscope [64] 78
Figure 41: Selected 2x12V Batteries 81
Figure 42: Process of testing components 86
Figure 43: LM35 testing layout 87
Figure 44: LM35 Test 1 88
Figure 45: LM35 Test 2 89
Figure 46: Temperature logger read out 89
Figure 47: LM35 Testing using a multi-meter 89
Figure 48: OPB740 Testing Layout 91
Figure 49: OPB740 Testing Setup 91
Figure 50: OPB740 Testing With Wood 91
Figure 51: Wood Testing Results 92
Figure 52: OPB740 Testing With Cardboard 92
Figure 53: Cardboard Testing Results 93
Figure 54: OPB740 Testing With Reflective Plastic 93
Figure 55: Reflective plastic Testing Results 94

Figure 56: OPB740 Testing With Paper 94
Figure 57: Paper Testing Results 95
Figure 58: OPB740 Testing With Clear Plastic 95
Figure 59: Clear Plastic Testing Results 96
Figure 60: OPB740 Testing with White plastic 96
Figure 61: White Plastic Testing Results 97
Figure 62: OPB740 Test Result Comparison 98
Figure 63: PWM Testing Layout 100
Figure 64: PWM controller, Motor and Oscilloscope Connected Together 100
Figure 65: PWM Controlling at Minimum Setting 101
Figure 66: PWM Controlling at 50% Speed 101
Figure 67: PWM Controlling at 100% Speed 102
Figure 68: Battery Testing Layout 103
Figure 69: Testing 12V Battery 104
Figure 70: Testing 24V Battery 104
Figure 71: Motor Testing Positions 106
Figure 72: Motor Testing 106
Figure 73: Motor Temperature Results 1 107
Figure 74: Motor Temperature Results 2 108
Figure 75: Motor Temperature Results 109
Figure 76: Designing process 111
Figure 77: Operational Flow Chart 112
Figure 78: Structure Diagram 113
Figure 79: Overall Proteus Design 114
Figure 80: Proteus speed sensor design 114
Figure 81: Proteus vibration sensor design 115
Figure 82: Proteus temperature sensor design 115
Figure 83: Proteus power supply design 116

Figure 84: Proteus microcontroller design *116*
Figure 85: Proteus indication *117*
Figure 86: Proteus RS232 ..... *117*
Figure 87: Overall Easy-PC design *118*
Figure 88: Easy-PC speed sensor *119*
Figure 89: Easy-PC vibration sensor *119*
Figure 90: Easy-PC temperature sensor *120*
Figure 91: Easy- PC power supply *120*
Figure 92: Easy-PC microcontroller *121*
Figure 93: Easy-PC indication *121*
Figure 94: Easy-PC RS232 ..... *121*
Figure 95: Easy-PC LCD connections *122*
Figure 96: PCB 3D design *122*
Figure 97: PCB 3D design - 0v copper pour *123*
Figure 98: PCB 0v and 5v copper pour *123*
Figure 99: Initial CCS set-up *124*
Figure 100: CCS to LCD connections and 'hello' display *125*
Figure 101: Proteus LCD communication *125*
Figure 102: Printing 'hello' for 1 second *126*
Figure 103: 'temp' defined *126*
Figure 104: Temperature sensor CCS set up *126*
Figure 105: 'rpm' defined *127*
Figure 106: RPM set up on CCS *127*
Figure 107: Gyroscope set-up on CCS *128*
Figure 108: Set up of the gyroscope on CCS, communication with the LCD *129*
Figure 109: Proteus Measuring Testing Points *130*
Figure 110: Proteus Temperature Testing *130*
Figure 111: Proteus Temperature Sensor Testing 1 ..... *132*

Figure 112: Proteus Temperature Sensor Testing 2 ..... *132*
Figure 113: Proteus Temperature Sensor Testing Comparison *133*
Figure 114: I2C sensor testing to RS232 communication *134*
Figure 115: Vibration sensor testing on CCS *134*
Figure 116: Vibration sensor testing on Proteus *134*
Figure 117: Speed Sensor Proteus Test *135*
Figure 118: Speed Sensor Proteus Signal Generator *135*
Figure 119: Speed Sensor Proteus Signal Generator Output *136*
Figure 120: Speed Sensor Proteus LCD Output *137*
Figure 121: Speed sensor Test on Proteus Comparison *137*
Figure 122: ON/Off & Start Proteus Test 1 ..... *138*
Figure 123: ON/Off & Start Proteus Test LED's *138*
Figure 124: Prototype layout *139*
Figure 125: Prototype base layout *143*
Figure 126: Motor and speed measurement point *143*
Figure 127: Motor base vibration softener *144*
Figure 128: Components soldered and sleeved *144*
Figure 129: Uploading CCS file to the Microcontroller *145*
Figure 130: Pickit 3 device [83] *145*
Figure 131: Process to implementing Electronics *145*
Figure 132: Voltage regulator implementation *146*
Figure 133: voltage regular layout on breadboard *147*
Figure 134: Voltage regulator error *147*
Figure 135: 7805 Voltage regulator pin layout [84] *147*
Figure 136: System start button implementation *148*
Figure 137: initial power up of Speed sensor *149*
Figure 138: Speed sensor functionality check *149*
Figure 139: Temperature sensor functionality *150*

Figure 140: Temperature sensor functionality 2 ..... *151*

Figure 141: LCD Error *152*

Figure 142: Survey Results *161*

Figure 143: OPB740 Testing Conclusion *162*

Figure 144: PWM Testing Conclusion *163*

Figure 145: Overall Proteus Design Conclusion *163*

Figure 146: PCB Design Conclusion *164*

Figure 147: Proteus Testing Results *164*

Table of tables

Table 1: S.M.A.R.T aims and objectives 22

Table 2: Project Rational 23

Table 3: Project milestones 28

Table 17: Recourses required for each milestone to be successful 30

Table 18: Different AC Motors 36

Table 19: Strengths & Weaknesses of AC & DC Motors 38

Table 20: Data Acquisition Systems comparison 44

Table 21: SWOT analysis of a brushed motor 57

Table 22: SWOT analysis of a brushless motor 58

Table 23: Market research of selected motor 59

Table 24: SWOT analysis of PWM 61

Table 25: SWOT analysis of Flux control 62

Table 26: SWOT analysis of armature control 63

Table 27: Market research of selected speed control 64

Table 28: SWOT analysis of Infrared temperature sensors 65

Table 29: SWOT analysis of RTD sensors 66

Table 30: SWOT analysis of Thermocouples 67

Table 31: SWOT analysis of Integrated circuit sensors 68

Table 32: Market Research of Selected Temperature Sensor 69

Table 33: SWOT analysis of Beam Break sensors 71

Table 34: SWOT analysis of Reflective sensors 72

Table 35: SWOT analysis of Hall-Effect sensors 72

Table 36: Market Research of Selected Speed Sensor 73

Table 37: SWOT analysis of Gyroscopes 75

Table 38: SWOT analysis of Strain gauges 75

Table 39: SWOT analysis of Proximity Probes 76

Table 40: Market Research of Selected Vibration Sensor 77

Table 41: Battery amperage rating requirements 78
Table 42: SWOT analysis of lead acid batteries 79
Table 43: SWOT analysis of Lithium batteries 79
Table 44: SWOT analysis of Mercury batteries 80
Table 45: Market Research of Selected Battery 81
Table 46: Microcontroller pin requirements 82
Table 47: Bit requirement 83
Table 48: Clock Cycle 83
Table 49: Microcontroller Selection 84
Table 50: Selected microcontroller 84
Table 51: Conclusion - Component Selection 1 85
Table 52: Conclusion - Component Selection 2 85
Table 53: Temperature Sensor Test Procedure 87
Table 54: Speed Sensor Test Procedure 90
Table 55: OPB740 Test Result Comparison 98
Table 56: PWM Module test procedure 99
Table 57: Battery Test procedure 103
Table 58: DC Motor Test Procedure 105
Table 59: Motor Temperature Results 109
Table 60: Proteus Temperature Sensor Results 131
Table 61: Proteus Speed Sensor Test Results 136
Table 62: Miscellaneous Components 141
Table 63: Overall costing 142
Table 64: Voltage Regulator implementation procedure 146
Table 65: System Start implementation procedure 148
Table 66: Speed implementation testing procedure 149
Table 67: Temperature implementation testing procedure 150
Table 68: LCD to Microcontroller implementation procedure 151

Table 69: Miss Order of PIC18F2458..... 153

Chapter 1 - Introduction

Within the oil, gas, chemical and manufacturing industry making a key decision or discovery on equipment operation is paramount in aiding the industries down time, safety, reliability and financial losses. Data acquisition Systems are a valued tool to aid these discoveries and decisions.

1.1 Project Overview

The author of this report is employed as an Electrical Process Technician within a chemical plant which produces Thermoplastic Elastomers. At the time of the major project, the chemical plant ran with four production lines all built to produce such products.

As a consequence of the growing industry, the plant was undergoing an expansion, installing two new production lines, subsequently doubling its capacity. Within a production line, the line operates with a main drive motor used to power an extrusion process of the plant. The existing four lines on site ran 600V DC main drives, and had done so for over 20 years. With modern technology and upgrades, the two new production lines will run with a main drive of 6.6KV AC. This is a major dynamic change for the plant moving forward, being a new process and a new way of operating the plant.

The four existing main drive motors have been maintained, monitored and controlled within the thermoplastic site for the past 20 years. The operation and maintenance activities/maintenance findings are known by both the operations and maintenance department. Introducing two new main drive motors of an AC supply is a new technology with unknown characteristics to control.

As the title of this Major Project suggests Electric motor data acquisition system, it was identified as a good target area to produce a data logging system that could measure key areas of the main drive motor. Not just compare the major differences within the AC and DC main drive motors performance, but to be used as a maintenance tool for both the operation and maintenance departments.

For the purpose of the Major Project in which this report is submitted for, a prototype data acquisition system was produced. The main findings and

learnings of the prototype could be adapted for a full scale Electric motor data acquisition system for further use. The prototype also suited the timescale of the major project submission.

1.2 Project Aims and Objectives

Aim: Design and produce a Microcontroller based Electric Motor Data Acquisition System.

Objectives:

- Research into AC and DC motors and identify their main characteristics
- Research into the major failings for AC and DC motors
- Identify a way in which the failings could be monitored via sensors
- Design and build a prototype data acquisition system
- Test the data acquisition system
- Gather data from the bench motor
- Evaluate and conclude the project
- Look at further opportunities for the system to be improved and produced as a usable system on site.

To ensure the aims and objectives of this major project were structured, the S.M.A.R.T goal technique was used. S.M.A.R.T standing for, Specific, Measureable, Attainable, Relevant and Time-bound. This technique is argued by 'Yourcoach' website as the most effective way of obtaining goals [1].

S.M.A.R.T	Action
Specific	Design and produce a Microcontroller based Electric Motor Data Acquisition System
Measureable	A Gantt chart will be produced to reflect the timescale of the project from start to finish. The Gantt chart shall be continuously updated throughout to reflect progress. A list of key milestones for the project will be set with due dates for completion, a number of activities will be listed within each milestone, which will need to be completed for a successful due date completion.
Attainable	Aims, objectives and plan will be agreed by university supervisor and site based supervisor.
Relevant	The project will be built and designed in such a way to cover the requirements of the major project for the Electrical and Electronic degree. SWOT analysis will be conducted throughout the component selection process.
Time-bound	All major dates will be identified along with major milestones throughout the project. All of these dates will be produced within a Gantt chart.

Table 1: S.M.A.R.T aims and objectives

1.3 Project Rational

It is felt that the scope of this project gave the opportunity to apply both work based, and University based learnings/applications. With the nature of the project predominately being designed and built outside of the author's place of work, the reasoning behind the project is derived from activities within author's work place, combining both work and academic based knowledge.

As highlighted in '1.1 Project Background' the site is undergoing a major change with the main drive being changed from Direct current (DC) driven, to Alternating Current (AC). This application leads too many mechanical and control changes within the two set ups, which will be discussed further within this report. One of the findings and concern of the workplace is the difference in performance of the equipment, and maintenance that will need to be performed. For this reason, it was seen beneficial for a Motor Data Acquisition that could be applied to either the DC Drive or AC Drive, to be produced measuring aspects of the motors performance.

Project Rational	
Reason	***Benefit***
Performance	The Motor Data Acquisition System would benefit the end users motor performance by measuring running failures of a given motor that could not be identified unless the motor was shut down and physically inspected.
Maintenance	The motor data acquisition system could identify when a motor would require maintenance prior to shut down – Not shutting the motor down where no failures have been identified.
Measurement/Accuracy	The motor data acquisition system will give the end user accurate measurement of the motors parameters. This could be used as a reference to ensure all the motors control were also measuring correctly and accurately.
Real-time display	The motor data acquisition system will provide the end user with real time display of any given motor parameters whilst in operation.

Table 2: Project Rational

1.4 Conclusion - Introduction

An overview of the Electric motor data acquisition system project was backed up with the main aim and objectives of the project. This was obtained by the SMART goals set and used throughout out the Major project period. The project rational justified the reasoning for this project, identifying the use for real-time display, maintenance, accurate measurements and performance based monitoring that could be used through the engineering industry as well as on the two new production lines within the thermoplastic site.

The following chapters will cover all of the methods, planning, research, design and implementation of design that was producing. Chapter two will discuss the research methodology used for the data gathering and research aspects before planning activities were conducted. The structure of the report can be seen on the following page.

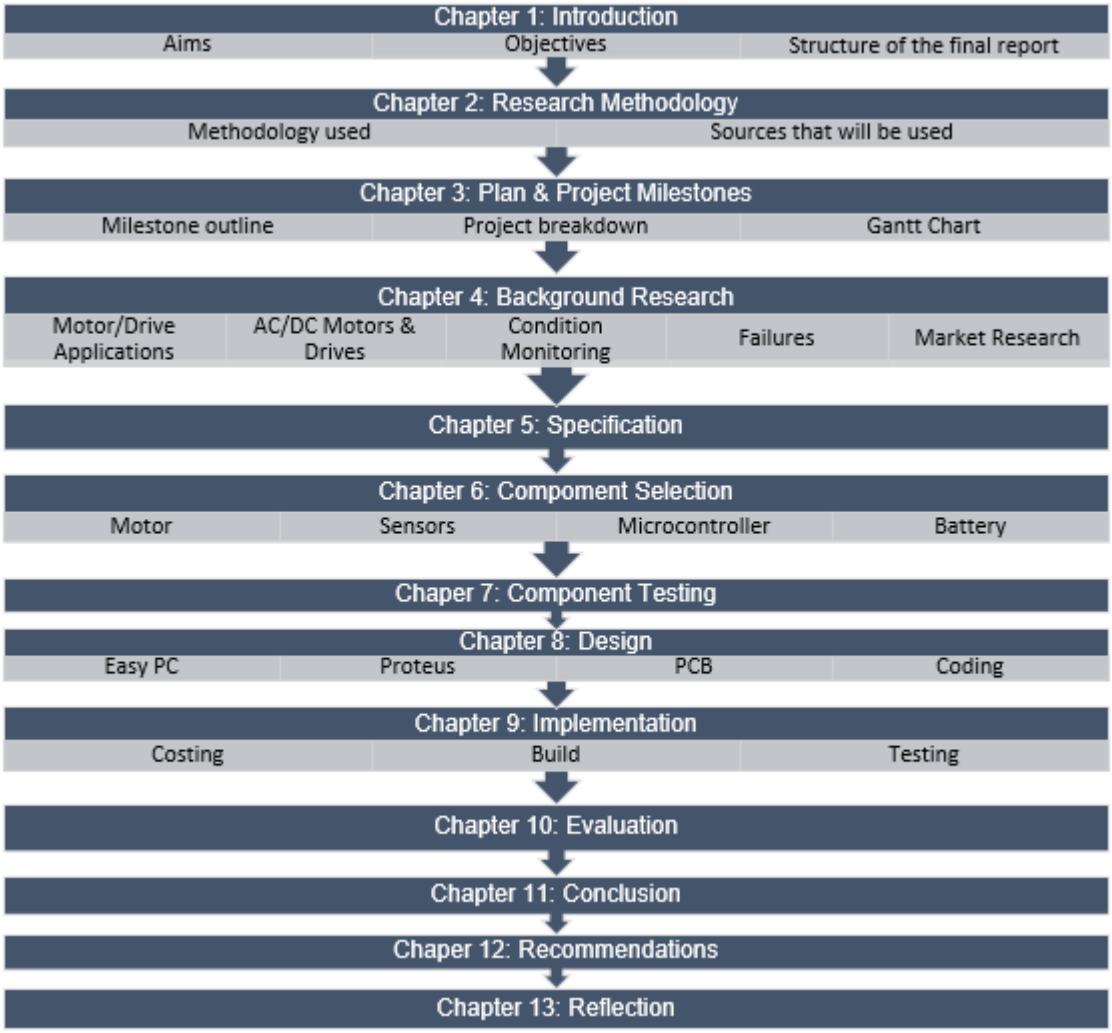


Figure 1: Report Structure

Chapter 2 – Research Methodology

2.1 Introduction – Research Methodology

The purpose of the research methodology chapter is to explain how the research was conducted throughout the major project. The research methodology is explained within the Write pass journal as '*an integral part of your study, and explains the methods you are planning to use to prove your thesis or answer your research question'* [2].

As shown within the figure below, a research onion was used to identify the stages of the required research strategy. Each layer, from the outside working to the centre of the onion below, provides a route through the research methodology design [3]. Working through the layers of the research onion covers the following**:** research philosophy, approaches, strategies, time-base and data collection methods. The route used for this major project will be covered within this chapter.

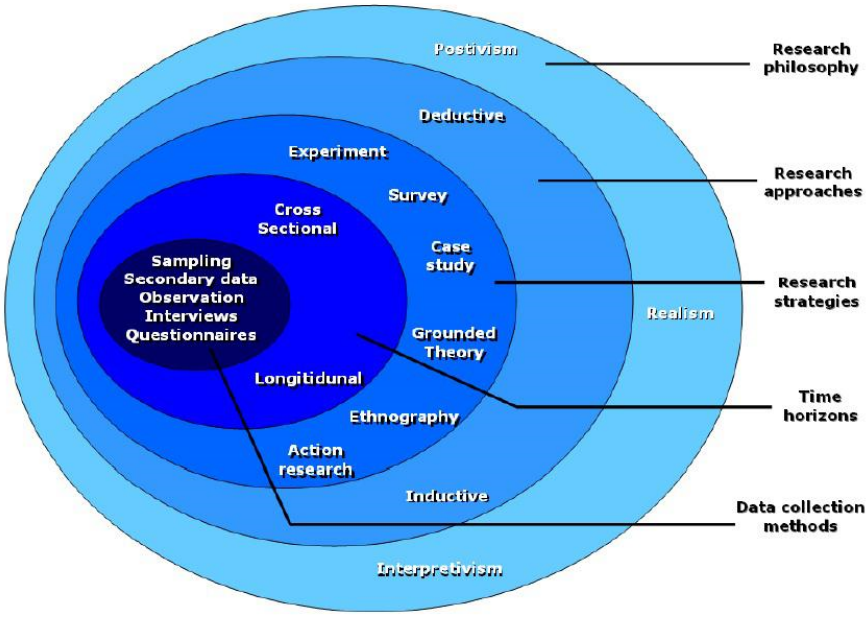


Figure 2: Research onion [3]

2.2 Research Philosophy

Within the research philosophy stage of this project the positivism approach was followed. This is because the objective is to design and install new equipment, and research will be needed to understand how the equipment theories work.

2.3 Research approach

For the research approach, the deductive approach was followed, as new equipment such as microcontrollers, sensors and hardware was used with a prototype being built. These applications were deigned and a prototype was built to aid the gap in measuring the different motor parameters on the authors work site, preventing unnecessary downtime on a production line.

2.4 Research strategies

For the research strategies, the ‘grounded theories’ was used as the project required the author to conduct research into theories and the operations of applications that will be used, also testing the theories and component operation. A survey was also produced and conducted to gain information from experienced personnel from the chemical plant of the authors work.

2.5 Time horizons

Longitudinal approach was used for the time horizon for this project. This was to ensure the project was evaluated over a period of time that allowed the operation to be proven. The actual time of evaluation will be implemented within the plan/Gantt chart.

2.6 Data Collection methods

Both primary and secondary data collection methods were used within this project. The author gathered secondary data from understanding the theory and principles behind technologies that were used. The primary data came from the actual motors control information and settings.

2.7 Conclusion – Research methodology

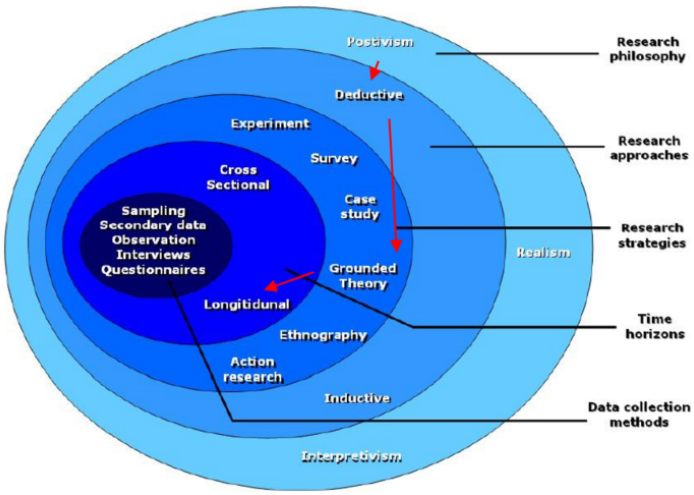


Figure 3: Research onion route [3]

Positivism, deductive, grounded theories and longitudinal was the approach used to peel back the layers of the research onion. This was due to the methods fitted the aims and objectives discussed within chapter 1 of this report.

The research onion was used to aid planning within the next chapter, it identified how research and planning was going to be approached. The onion also provides an outlook of how the content and findings of the major project were produced.

Chapter 3 – Planning

3.1 Introduction – Planning

After the research methodology was identified, the planning stage of the major project could be performed and outlined. Within this planning chapter, it will be shown how key milestones were identified with due dates to reflect when these milestones were required to be complete.

Once the milestones had been established, it enabled the activities that were required within each milestone to be segregated. Each activity was given a timescale based on the due date of the milestone. This allowed the activities to be scheduled with the correct amount of time to be performed. A Gantt chart was produced to reflect these dates. The Gantt chart was continuously updated where any defects occurred. The Gantt charts are shown within this chapter also.

3.2 Key Milestones

Milestone	*Due date*
Project chosen and agreed	10/08/2017
Research methodology	17/09/2017
Planning	05/10/2017
Interim viva Part 1	19/10/2017
Background Research	16/11/2017
Design Requirements/Specification	07/12/2017
Design Research	04/01/2018
Interim viva part 2	25/01/2018
Design	15/03/2018
Implementation	05/04/2018
Evaluations	26/04/2018
Report submission	26/04/2018
Final Viva	03/05/2018

Table 3: Project milestones

3.3 Milestone breakdown

Please refer to appendices 16.1 for breakdown of each milestone.

3.4 Overall plan

When the milestones and milestone activities were complete, a Gantt chart was produced to reflect the timescale that were given for the major project completion.

The Gantt chart was first devised by Karol Adamiecki, a Polish engineer running a steelworks in southern Poland in the mid 1890's [4]. It is also argued as '*one of the most popular and useful ways of showing activities (tasks or events) displayed against time'* [4]. The Gantt chart highlights a list of activities on the left column which are derived from the milestone and the milestone activities shown previously within this chapter. The top row of the chart identifies the timescale, this dated from 26th January 2017 to 26th April 2018. (Appendices 16.2, 16.3, 16.4, 16.5)

The Gantt charts were continuously updated throughout the progression of the project to reflect any changes in the original timescales set to the task breakdowns and milestones.

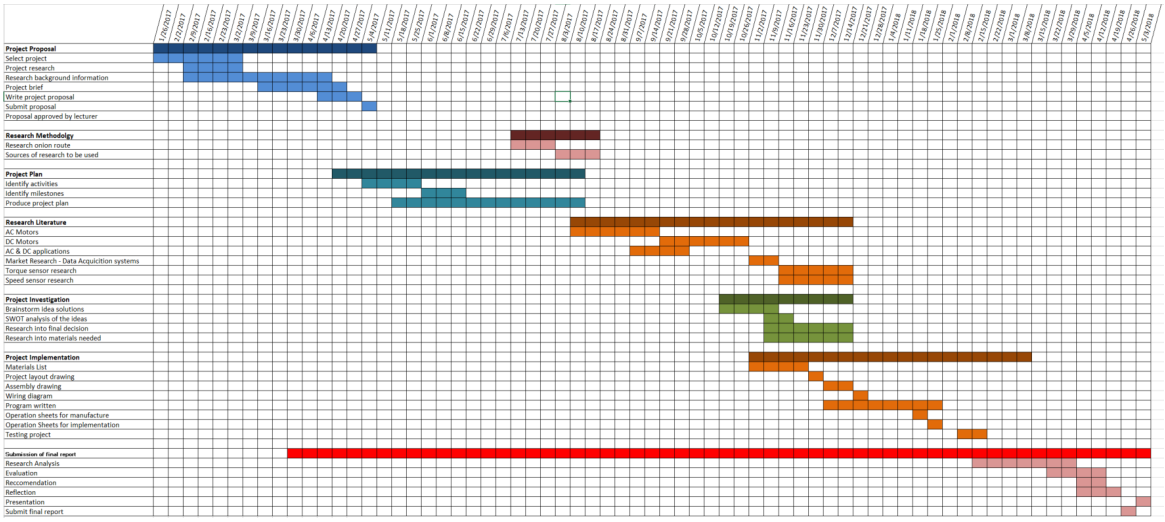


Figure 4: Original Gantt chart 10/08/2017

3.5 Resources Required for Each Milestone

Along with the milestone breakdown per task and the overall Gantt chart, it was identified there would be a number of sources used to understand theories,

principles and software packages. As shown within the table below, four sources were identified to focus on against each milestone. These include human, physical, software/hardware and journals/books.

The main disadvantage of using physical and human resources for knowledge based learning or feedback within the project is being reliant on someone who was not part of the project. To overcome this all human resources were targeted at a minimum, and being more reliant on controlled substances such as software/hardware and books/journals.

Objectives	Resources required			
	Human resource	**Physical resource**	**Software/ Hardware**	**Journals/ books**
Project selection	Yes – Feedback off University/work supervisors	No	Yes	Yes
Research methodology	No	Yes – Components/tools	Yes	Yes
Planning	No	Yes – Putting the plan together	No	No
Interim viva Part 1	Yes - University supervisors	Yes – Presenting the presentation	No	No
Background Research	No	No	Yes	Yes
Design Requirements/Specification	No	No	Yes	Yes
Design Research	No	No	Yes	Yes
Interim viva part 2	Yes - University supervisors	Yes – Presenting the presentation	No	No
Design	No	Yes	Yes	Yes
Implementation	No	Yes	Yes	No
Evaluations	No	No	No	Yes
Report submission	No	Yes	No	No
Final Viva	Yes - University supervisors	Yes – Presenting the presentation	No	No

Table 4: Recourses required for each milestone to be successful

3.6 Conclusion – Planning

The planning section of the major project was thoroughly assessed with a logical thought process to enable accurate scheduling of the major milestones required to be met. This thought process was reflected on by the S.M.A.R.T goals set out within chapter 1. Each activity within a milestone was **Specific** with a description ensuring it was **Measurable** with a completion date. All aspects were given a date which was **Attainable** to be produced. All activities had a direct **Relevance** to the milestones, reflecting the projects aims/objectives. As seen in section 3.4, all activities were scheduled into a Gantt chart which reflects the **Time** scale that was available over the academic year.

The Gantt chart produced within section 3.4 were updated throughout the academic year as some milestone dates changed throughout four stages of the project. This was a consequence of the final project proposal took longer than first expected meaning the overall plan shifted with the end date being fixed. The original timescale for project selection was nominally planned for 15 weeks dated 19/01/17, but ended up being overdue by 25 weeks dated 25/01/17. This was due to the outcome of the interim viva determining that the original selected project was not practical. The Gantt chart changed again, dated 29/03/18 as a consequence of a wrong Microcontroller being ordered. This lead to downtime due to the reordering of this component, this is also reflected within the below snippets. Design and implementation was extended by 3 weeks as a consequence of this. (Gantt chart produced and updated – refer to appendices 16.2, 16.3, 16.4, 16.5)

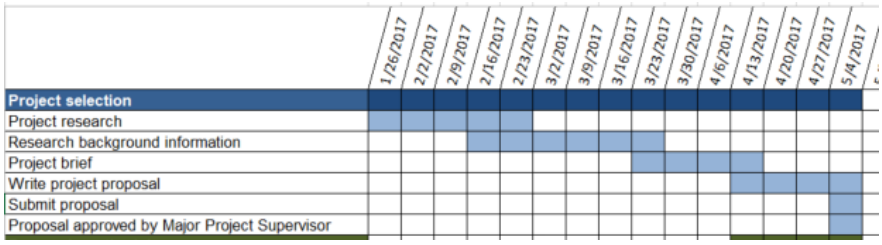


Figure 5: Project selection timescale Interim 1 – 19/01/17

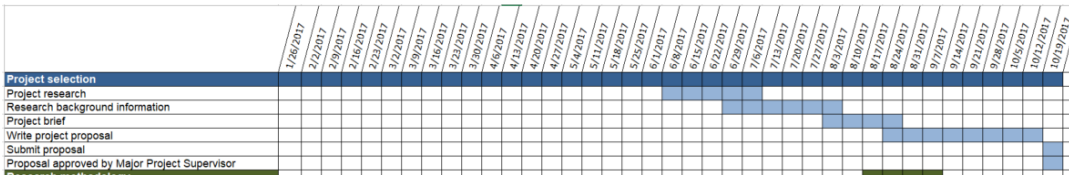


Figure 6: Project selection timescale Interim 2 – 25/01/18

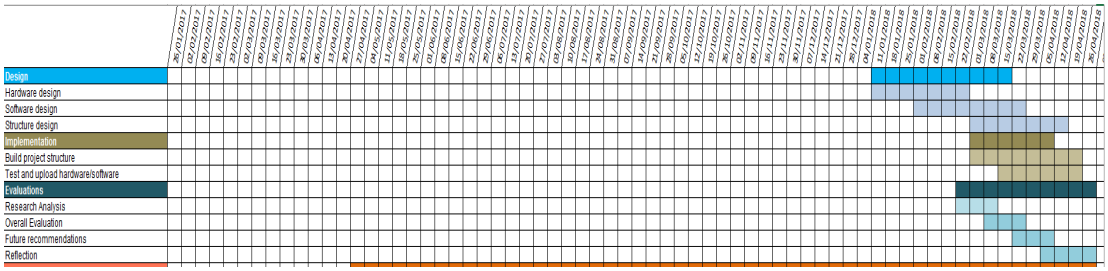


Figure 7: Project selected timescale 29/03/18

As well as key milestones, milestone activities and Gantt charts, the resources required to successfully reach each milestone were assessed. No specific dates were given to these resources, but an indication prior to starting activities and what was required within the respect of human, physical, software/hardware, and books/journal resources was given.

The next chapter discusses the background research carried out with major findings being highlighted prior to outlining a design specification and researching components.

Chapter 4 – Background Research

4.1 Introduction - Background research

For the purpose of this report the research has been split up into two sections. This chapter will contain background research on the application of motors, AC motors, DC motors, motor failings, condition based monitoring, data acquisition systems on the market and a survey carried out on twenty colleagues with vast experiences within the chemical plant of the authors work. The background research is laid out in such a way that will be used as a criterion for the specification in Chapter 5, leading onto the second research section ‘Design research’ in chapter 6.

4.2 Extruder Main Drive Motor

In context of which this major project was selected, the first section of the literature review was to research the application on which the main drive motor was used. As discussed within chapter 1, the chemical plant was undergoing a major expansion, almost doubling the capacity to the site. To do this, two new main drive motors were being installed to drive the extrusion process of the plant. The extrusion process is key to obtaining good, quality and sellable product.

The purpose of the main motor and drive for the extruder is to convert electrical energy into rotational mechanical energy. Controlling the RPM of the motor to provide the required speed of the extruder screws, dependant on the speed requirements of the grade of product that is being produced. Another main characteristic is to protect the motor from overheating, avoiding premature failure of the motor and ensuring the motor is not loaded above its nameplate power rating. The information related to the main drive and extruder was gathered from the onsite specialist with 20+ years’ experience. Unfortunately there was no literature information obtainable about the on sites process to publish within this report, as this information is proprietary to the company. For this reason, a survey was produced within this chapter to reflect user/experienced personnel’s feedback.

Below is an overall layout of the extruder illustration how motor drive and motor drive ties in with the extruder itself.

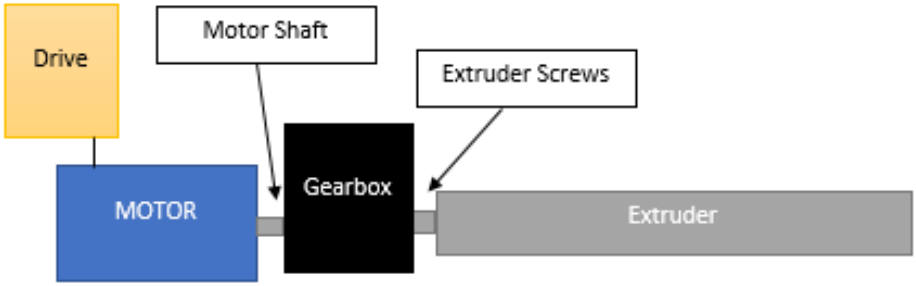


Figure 8: Extruder, Main drive & Motor

4.3 Motors

Motors were chosen to be included within the background research as a basic understanding would be required to understand the failings of motors and in what context these failings could be measured. AC and DC motors are discussed but it is noted, this is an overview of their general structure and applications. Individual motors were not researched in detail as this was not an essential part of research for building a prototype data acquisition system.

4.3.1 AC Motors

AC motors play a vital role within industry and everyday use, with the wide range of applications in which they can be applied to. Two examples of the use of AC motors are pumping crude oil down a pipeline within an oil refinery to driving a robot within the manufacturing industry. AC motors are used due to the flexibility and its diversity, matching any kind of demand it is argued [5].

There are many types of AC motors, ranging from synchronous and asynchronous motors which can be either single phase or three phase. Before looking at the make-up, differences and the uses of these types of motors, it is essential to investigate how the basic operation of AC motors operate.

There are two basic components that make up an AC motor, these are the rotor and stator, these can be seen within the below figure.

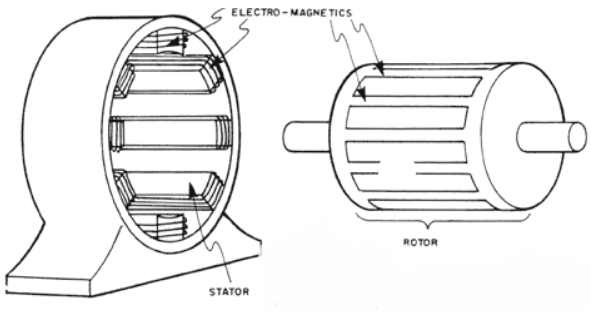


Figure 9: AC Motor Structure [6]

The stator gets the name from ‘stationary’ as it is the stationary part of the motor set up. It is made up of a group of electro-magnets that are arranged in a way that form a cylinder. With the cylinder type arrangement set by the electro magnets, each pole of the magnet is facing into the centre [6].

The rotor acquired its name from ‘rotating’ as this is the rotating component of the motor set up. Like the stator, the rotor is also made up of electro-magnets arranged in a cylinder type structure. The rotor is placed inside the cylinder set up of the stator, being mounted on the motors shaft. Instead of the magnets pointing inwards to the centre of the cylinder structure like the stator, the rotor magnets point outwards, towards the stator magnets [6].

The rotation of an AC motor is produced by sending voltage into the stator, this produces a magnetic field around the stator. Due to the AC voltage being applied to the stator, the laws of magnetism apply, inducing an electric current into the rotor magnets [5]. The stator and rotor magnet coils attract to each other and repel, producing the rotation of the rotor which is as discussed, attached to the motor shaft. This is illustrated within the figure on the following page.

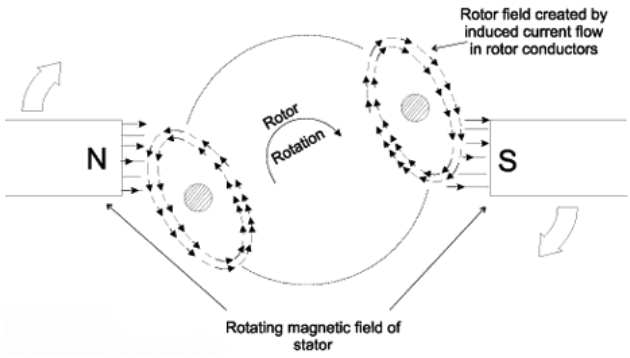


Figure 10: AC Motor Magnet Field Structure [6]

Now the understanding of how an AC motor has been researched, the below table outlines the different synchronous and asynchronous motors available.

Synchronous	Asynchronous
Plain	**Induction motors:** Squirrel Cage, Slip-ring
Super	**Commutator motors**: Series, Compensated, shunt, repulsion, repulsion-start induction, repulsion induction

Table 5: Different AC Motors

Synchronous motors are mainly used within applications requiring high precision. The reasoning behind this is the rotor rotates at the same speed as the stator current, allowing this type of motor to be one speed.

Asynchronous motors as seen within the table above, have many more variants compared with synchronous. The asynchronous motor can come in single phase or three phase set up, dependant on the application and drive it is being used with. Single phase asynchronous motors can be found within low power tools or domestic appliances. Three phase motors can be found within industry such as refineries and chemical plants which require high power to be produced. The asynchronous motor can also be used with a constant, variable or adjustable speed if required, making this type of motor flexible for its end user [5].

4.3.2 DC Motors

As well as AC motors, DC motors also play a vital role within industry and every uses. DC motors are produced in two forms, these are brushed DC motors and brushless DC motors.

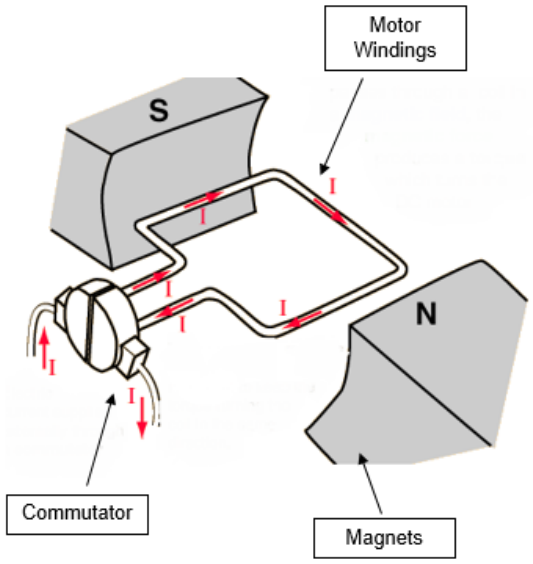


Figure 11: DC Motor Structure [7]

As seen within the above figure, the basic DC motor consists of a commutator, magnet and motor windings. The magnets make up the stator, which is the stationary part of the motor. The motor windings is the rotating part of the motor, making up the rotor. The rotor sits with the stator, like on an AC motor but in the instance of a DC motor, the rotor is the conductor carrying the voltage/current and not the stator. The same principle applies with the laws of magnetism, with the voltage within the windings creating a magnetic field also, enabling the motor to rotate [5].

DC motors shall be discussed in more depth further on in this report.

4.3.3 AC and DC Motor Differences

When trying to compare AC and DC motors, finding the strengths and weaknesses of both, it can be difficult because they both serve purposes in different areas dependant on the application in which they are being used.

The principles in which the stator and rotor of the AC and DC motors are constructed are similar, with both the stators being the stationary part of the motor and the rotor being the rotating components. The theory behind their operation however is different. As discussed, the AC motors stator carries the voltage and induces voltage to the stator creating a rotating magnetic field, the DC motors rotor induces the voltage creating the magnetic field with the stator.

AC and DC motors can also vary the speed but require external electronics to do so. It is discussed within '*precision-electric'* that DC motors are being replaced with AC motors with external electronics to aid speed control because it is seen as more economical and less expensive. It is also discussed that the reasoning behind this is due to the DC motor having more moving parts which are inevitably more expensive [8].

It is also noted that all DC motors are single phase where AC motors can be both single phase and three phase supplied. The below table highlights both the strengths and weaknesses of AC and DC motors.

Strengths		**Weaknesses**	
DC motors	**AC motors**	**DC motors**	**AC motors**
Speed control over a wide range	Controlled acceleration	Only single phase	Require external electronics to vary speed
Speed and torque curve is linear	Torque limit is adjustable	Many moving parts	Inability to operate at low speeds
Forward and reverse control	Efficient	High maintenance	Positioning control is poor
Quick starting and stopping	Forward and reverse control	Not suitable where dust is present	Produces back EMF
Simple design	Single phase and three phase		
High accuracy	Low cost		
	High power factor		
	AC power supply is ready available within industry		

Table 6: Strengths & Weaknesses of AC & DC Motors

As seen within the above table, it is highlighted that there is numerous strengths and weaknesses to both AC and DC motors. The AC motor being highlighted as having more strengths than the DC motor. As discussed, within industry DC motors are being replaced with AC motors and the reasons for this can be seen within this table. The strengths of the AC motor include, good power factor rating, low costing components with AC supply being readily available are the main factors for this. It is noted that within some applications such as, high precision packages, DC motors would be more suitable as their strengths include both quick starting/stopping and high accuracy.

High maintenance cost, moving parts and not suitable where dust is created are the major weaknesses related to the DC motor.

With the inability to operate at low speeds, external electronics to vary the speed and back EMF being the major weaknesses of the AC motor.

4.3.4 Motor Failings

As with any piece of equipment, if an electric motor is worked to its absolute maximum limit on an hourly basis without adequate maintenance it is susceptible to failure. Some motors will be supplied with a run time from the manufacture, indicating its lifetime before failure or before general maintenance is require. Others will not. This is where a Data Acquisition would monitor the ongoing running of the motor.

The below pie chart was extracted from the *'EC&M paper'* which reflected a root cause motor failure analysis.

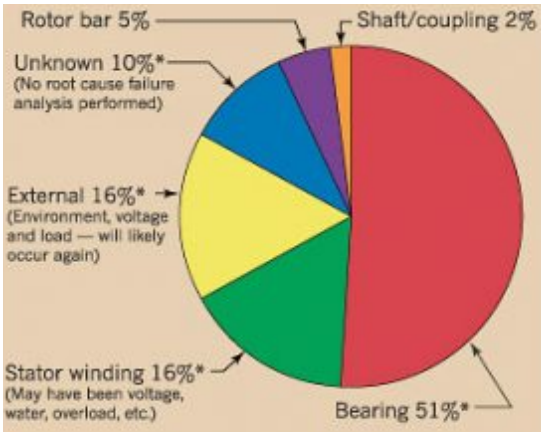


Figure 12: Root Cause Motor Failure Analysis [9]

It is noted that the pie chart is reflected from a root cause failure analysis carried out on a squirrel cage motor which is a common motor within the industry, it is still valued information for motors in general and this report. It is also noted that the geographical location these testing's are not stated within the report produced, and the results could vary.

The above chart highlights that just over half of failings are bearing failure which is at 51%, stator windings and external both at 16% of the cause. 5% from the rotor bar, a small 2% being derived from the shaft/coupling and 10% coming from unknown failure. To analyse these results, the 10% of unknown failures is highlighted as quite high as this could cause significant financial losses.

Although *EC&M* states a percentage of 51% of bearing failures, it is noted that another source found '*Processing Magazine'* states:

'*Research shows that up to 50 percent of damage to rotating machinery is a consequence of misalignment*.' [10].

Although these facts are slightly different, the over 50% misalignment failures stated within the Processing Magazine could possibly be a knock on effect of the bearing failures stated within the EC&M paper – Misalignment causing the bearing failures.

The EC&M paper, also discusses stresses occurring when the equipment/motor is not kept within its design limits meaning that more than one aspect of equipment is worked beyond the design capacity [9]. The paper also provides a table which summaries the pie chart previously shown within this section. The table breaks down the failure components into stress type and stress damage. This is reflected on the following page.

Detailed Summary of Motor Stresses		
Motor component	**Stress type**	**Actual stress or damage**
Bearings	Thermal	Friction, lubricant, ambient
	Dynamic and static loading	Radial, axial, preload, misapplication
	Vibration and shock	Rotor, driven equipment, system
	Environmental	Condensation, foreign materials, excessive ambient, poor ventilation
	Mechanical	Loss of clearances, misalignment, shaft and housing fits
	Electrical	Rotor dissymmetry, electrostatic coupling, static charges, variable-frequency drives
Stator	Thermal	Thermal aging, thermal overload, voltage variation, voltage unbalance, ambient, load cycling, starting and stalling, poor ventilation
	Electrical	Dielectric aging, transient voltages, partial discharge (corona), tracking
	Mechanical	Winding movement, damaged motor leads, improper rotor-to-stator geometry, defective rotor, flying objects
	Environmental	Moisture, chemical, abrasion, poor ventilation, excessive ambient
Rotor	Thermal	Thermal overload, thermal unbalance, excessive rotor losses, hot spots/sparking, incorrect direction of rotation, locked rotor
	Dynamic	Vibration, loose rotor bars, rotor rub, transient torque, centrifugal force/overspeed, cyclical stress
	Mechanical	Casting variations/voids, loose laminations and/or bars, incorrect shaft-to-core fit, fatigue or part breakage, improper rotor-to-stator geometry, material deviations, improper mounting, improper design or manufacturing practices
	Environmental	Corrosion, abrasion, foreign materials, poor ventilation, excessive ambient temperature, unusual external forces
	Magnetic	Rotor pullover, uneven magnetic pull, lamination saturation, noise, circulationg currents, vibration, noise, electromagnetic effect
	Residual	Stress concentrations, uneven cage stress
	Miscellaneous	Misapplication, effects of poor design, manufacturing variations, inadequate maintenance, improper operation, improper mounting
Shaft	Dynamic	Cyclic loads, overload, shock
	Mechanical	Overhung load and bending, torsional load, axial load
	Environmental	Corrosion, moisture, erosion, wear
	Thermal	Temperature gradients, rotor bowing
	Residual	Manufacturing processes, repair processes
	Electromagnetic	Excessive radial load, out-of-phase reclosing

Figure 13: Motor Stresses [9]

When analyzing the table above from the EC&M paper it in necessary to pick out the common accusing stress type, identifying a sequence. As seen above, thermal stress is identified in every component and so is mechanical. This is a clear indication that measuring temperature aspects of a motor would be beneficial to aiding motor failure.

Another source used when researching motor failures was the '*Processing Magazine'*, an article from John Bernet discussing 'How to prevent motor failure', who stated:

'Several studies over the past 25 years show that vibration testing programs come with a 20-to-1 benefit-to-cost ratio.' [10].

The reasoning behind this statement he explains was that most common faults on rotating equipment is susceptible to imbalance, misalignment and wear [10].

4.4 Data acquisition systems

A Data Acquisition System, also known as ‘DAQ’ is a system that collects information from a specific devise to obtain the measured variable, producing adequate and accurate data. The system logs the data in a way it can be read and logged for monitoring purposes.

The below figure shows a typical layout of a Data Acquisition System.

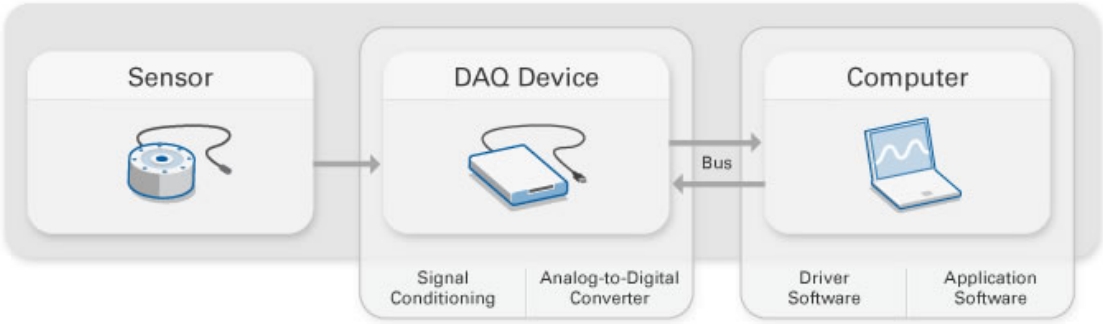


Figure 14: Data Acquisition Layout [11]

4.4.1 How can Data Acquisition Systems be used?

Within industry there are many ways in which maintenance activities are conducted. This can vary from lessons learned with experience of dealing with certain equipment, producing a planned maintenance schedule, or techniques such as Condition Based Monitoring (CBM) which is discussed within this section of research.

CBM is used as a tool to provide maintenance to applications on an as-needed-basis. Variables of the equipment will be monitored and assessed, when maintenance is required based on its limits and tolerances given by the manufacturer, maintenance will be performed. The equipment can be monitored and assessed by visual inspections, non-contact sensors, scheduled tests or performance output with fixed measurement devices being retrofitted to equipment [12].

‘*Fiix*’ argues the goal of condition based monitoring is to spot upcoming equipment failures so maintenance can be scheduled when it is needed and not before [12]. ‘*Fiix’* also discusses there are many advantages, disadvantaged and challenges of CBM. The advantages discussed are equipment reliability, reduced failure costs, minimised labor costs, minimized downtime and improves

equipment safety. With the disadvantages covering some failures that are harder to monitor than others; requirement to train staff to analyse the data gathered and that the system of this maintenance tool could be expensive as a whole as there would be a need to change the whole organization potentially [12]. The disadvantages are also reflected with the challenges faced when trying to use CMB, with having trained personnel and measurement equipment able to both obtain the data and then read the data - being able to accomplish when maintenance would be required.

David Manning-Ohren discusses ten rules required for CBM within the '*Plant&works'* journal [13]. One of the rules that was highlighted for this Major project when reading this section was:

'Rule 5 - Keep a vibration database Vibration is a key part of a strong condition monitoring regime. A good vibration database will include three types of vibration reading, trend, spectrum and time waveform. Trend records the overall vibration parameter value and details the date and time of the reading. Spectrum measures the amplitude of the vibration parameter with respect to its frequency and the time waveform measures the raw vibration signature without filtering or processing. Vibration checks every 4-8 weeks is a good starting point.' [13].

This rule was highlighted because it was the only rule that stated a physical variable of an equipment attribute that must be measured. The remaining 9 rules covered cost and personnel variables, indicating vibration was a key area within industry in which failures/performance can be detected.

4.4.2 Market research

The below table compares different Data Acquisition Systems on the market for different applications.

System	VBOX 3i  [14]	DL1 Sport  [15]	HOBO UX90  [16]	OM-VIB-101  [17]
Application	Vehicle	Vehicle	Motor	Motor
Voltage	7V -30V	12v	0V – 3V	3.6V
Cost	-	£599	-	£114
Measurement	-	GPS RPM Gyroscope Lap time	Runtime On/off	Three accelerometers
Inputs	4	2	1	3
Outputs	2	1	1	1
Accuracy	+/-1.5mS	-	+/- 1 minute	+/-0.5g
Communication	USB Serial Bluetooth	USB	LCD screen USB	USB
Storage	Memory card	Memory card	-	16MB Flash memory
Sample rate	100HZ	100HZ	1HZ	60HZ

Table 7: Data Acquisition Systems comparison

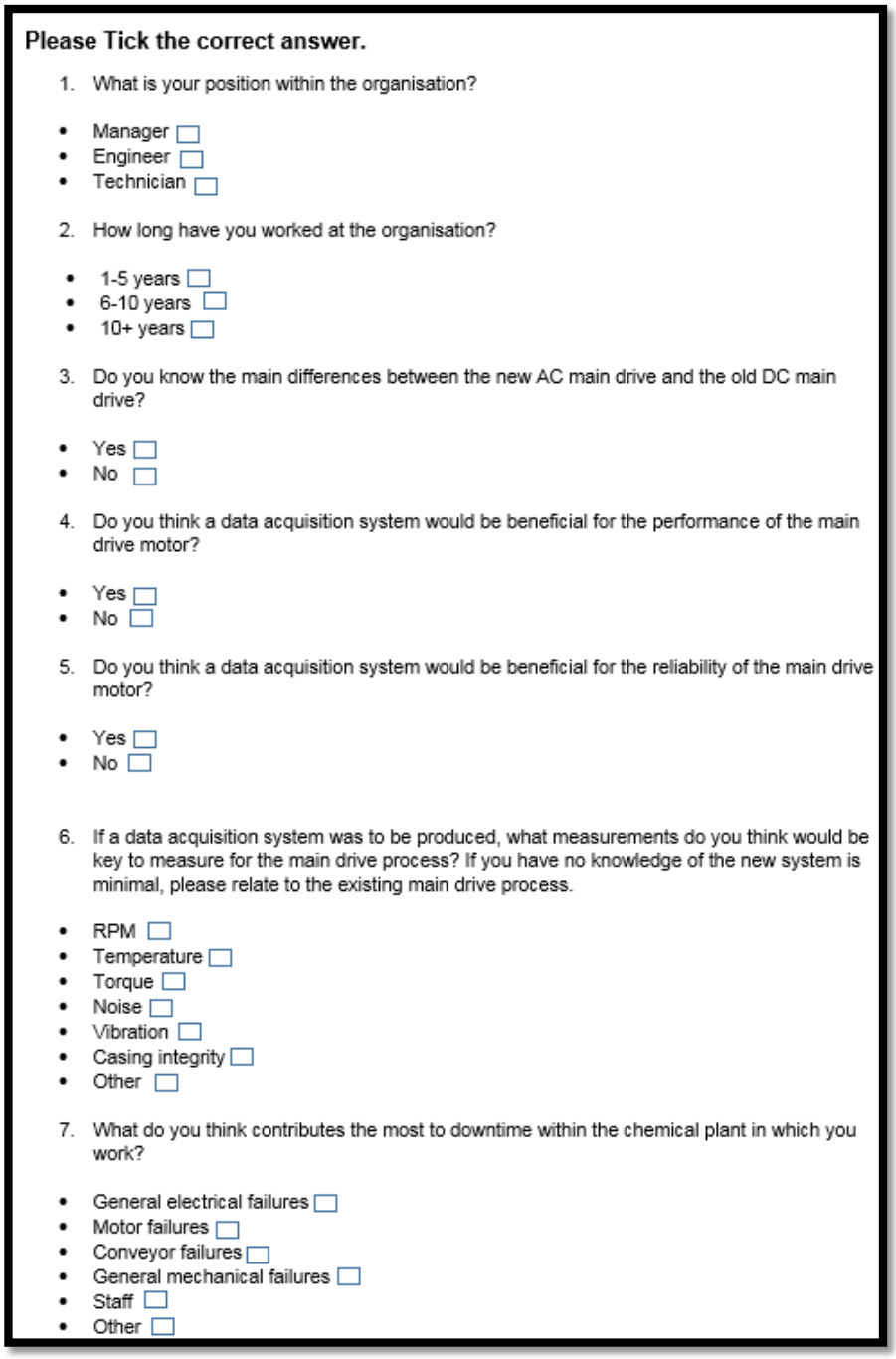
As seen in the above table, four data Acquisition Systems were analysed and compared from the market research. Vehicle acquisition systems were analysed as well as basic motor system. This was to obtain a greater understanding of different ways of gather information, what can be measured and the communication aspect of a Data Acquisition System. As seen in this table,

almost all systems researched used USB as a way of communication, with the HOBO UX90 also using an LCD screen. The VBOX 3i being the most advanced also having Bluetooth communication. This also aided with the design of the Electric Motor Data Acquisitions design process.

4.5 Work Based Survey

As the Data Acquisition System was to be based on a work based principle, a user survey was produced to obtain the thoughts of experienced work personnel based at the chemical plant. The reasoning behind producing a survey was also to obtain information from managers, engineers and technicians on their experiences, obtaining a conclusion to what the system should measure and whether the system would be beneficial to the site. The limited access to literature of the work based process was difficult to obtain as it was propriety information, this way the survey was based on personnel's views and experience only. (Refer to appendices 16.6 for survey results)

Below is the figure of questions asked to fifteen workers within the chemical plant to aid the background research.



Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☐

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☐
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☐
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☐
- Temperature ☐
- Torque ☐
- Noise ☐
- Vibration ☐
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Figure 15: Survey Questions

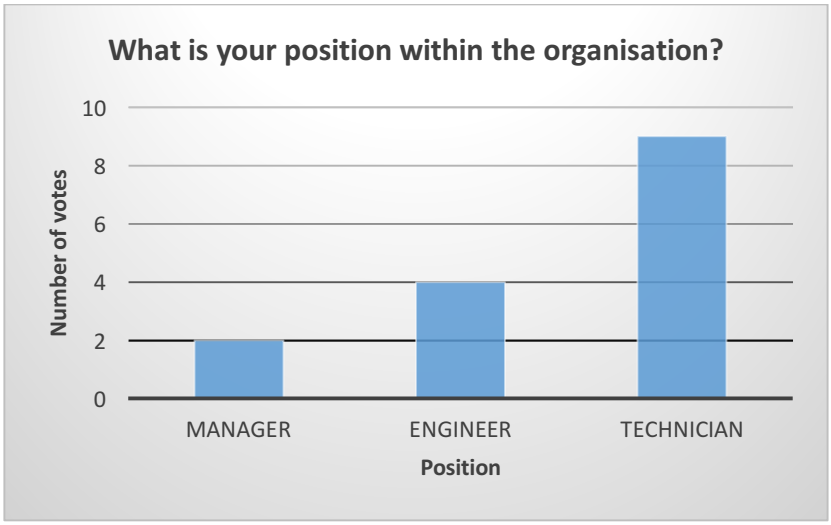


Figure 16: Survey question 1 results

The results of question one are reflected within the above figure. As seen, the majority of information gathered was obtained from technicians, at a total of nine. Four engineers and two managers also conduct the questionnaire.



Figure 17: Survey question 2 results

As a reflection of the results obtained from question two, it is clearly evident that the information was gathered from personnel with vast experiences and knowledge in the industry. Ten of with having 10+ years site experience.

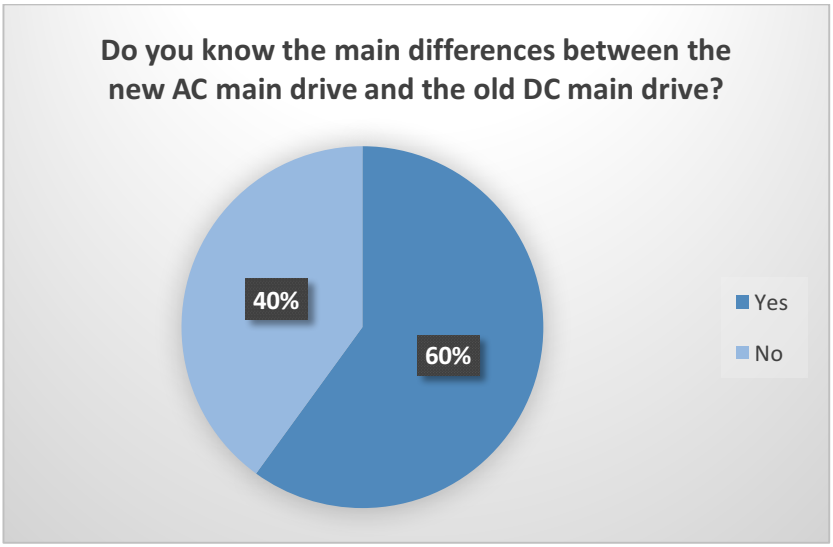


Figure 18: Survey question 3 results

To understand the base line knowledge of the personnel completing the questionnaire, they were asked to indicate whether they were familiar with the main differences of the old and new main drive system. This came out at a 40/60 split, with 60% of the workers indicating they did know.

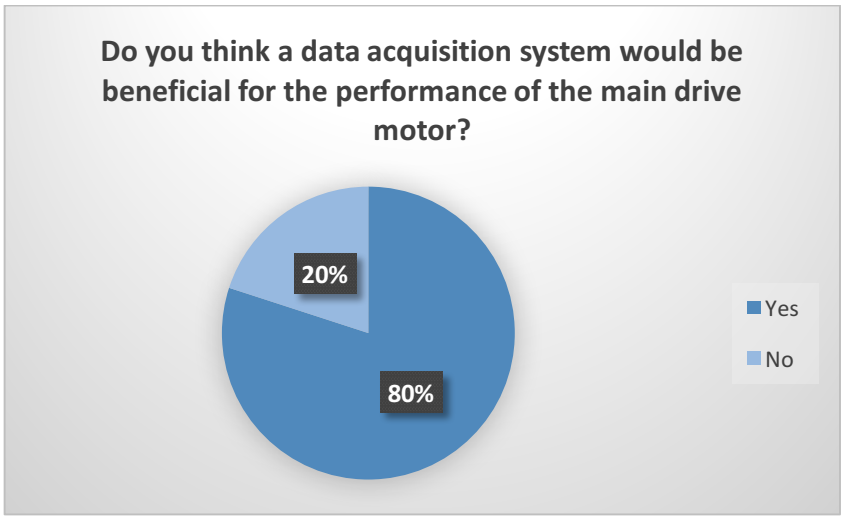


Figure 19: Survey question 4 results

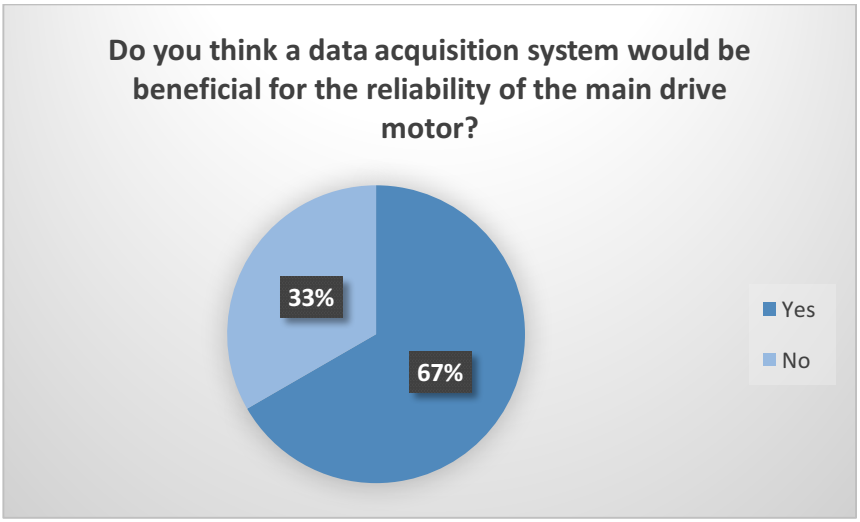


Figure 20: Survey question 5 results

Questions four and five were both pointed purely on the person's interpretation of whether a Data Acquisition System would be beneficial, both for the performance and reliability. Results from both responses indicating that the majority believed it would be beneficial, with 80% and 67% saying yes.

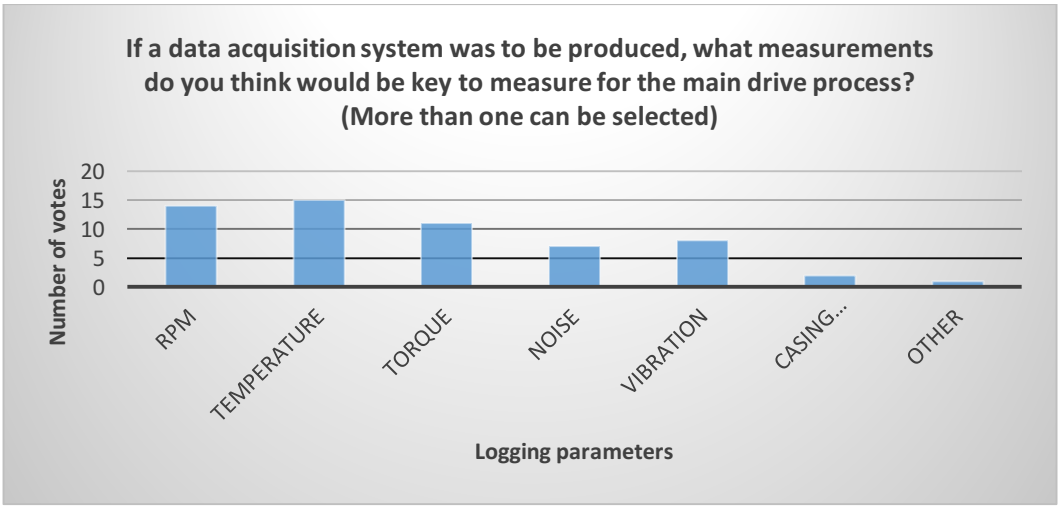


Figure 21: Survey question 6 results

Question six was a multi choice question the system being produced could measure more than one aspect of a motor. RPM and temperature were the highest selected, with fourteen and fifteen persons selecting this area. Torque, noise and vibration coming closely after.

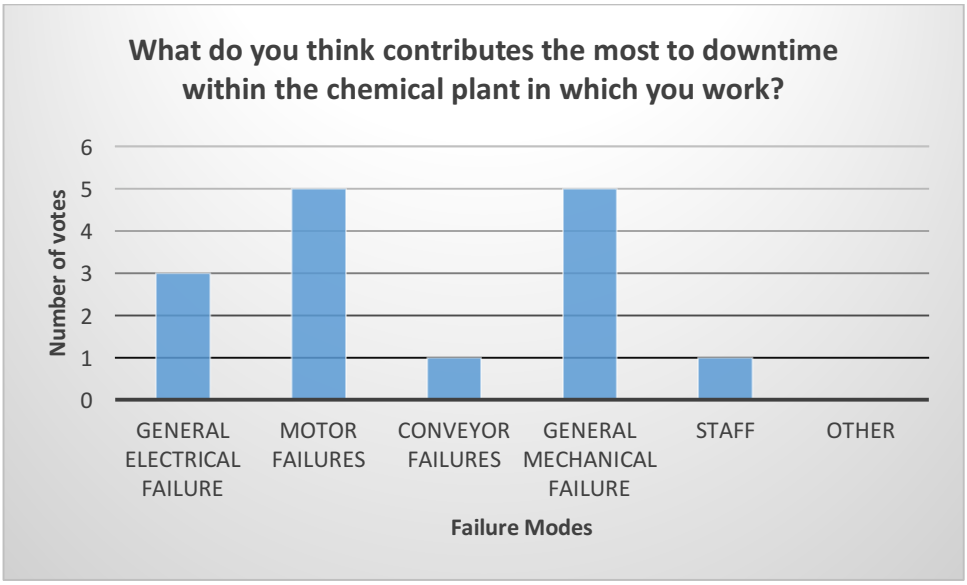


Figure 22: Survey question 7 results

The final question asked was an open question to gain personal views on what caused the most down time. Motor failures and general mechanical failures coming out top, with general electrical failures closely behind.

4.6 Conclusion - Background research

The background research conducted was justified by the knowledge gained from each topic area that was researched. Applications of both AC and DC motors were identified, comparing the strengths and weaknesses of both. The common failures of motors were also reflected upon, with 51% of motor failings being stated as bearing failure is most beneficial when justifying what should and could be measured on the prototype design.

Market research of different general Data Acquisition Systems was seen as a task to obtain an understanding of how other systems and principles operate. Ensuring a broad spectrum of applications were covered, ultimately obtaining ideas from each.

CBM was researched as this is an area in which the chemical plant company operate. The organisation run equipment either to failure or where the performance is not adequate before maintenance is obtained. A Data Acquisition System was targeted because it was seen as a good tool to aid with the CBM process. The acquisition system could not only be used within the main drive motor as this report is targeting but also, other smaller motors or

pieces of equipment across the site. Motor failings were also identified as a bad actor across the site, with mechanical failings being highlighted throughout site as a major factor of downtime. This is also reflected within question 7 of the survey conducted, with the motor failures, and general mechanical failures being highlighted as a major attribute to downtime within the chemical plant.

The survey conducted was seen beneficial to the background research conducted. To use onsite experience was relevant, as seen by the results from question two, ten out of the twenty people surveyed had ten plus years' experience on site.

Motor failings, market research of other systems and the survey conducted lead the author to conclude the requirements of the prototype design being produced as part of this major project. A specification was outlined before any components were researched or designs were produced. This can be seen within the next chapter of this report.

Chapter 5 – Design Requirements/Specification

5.1 Introduction - Specification

After carrying out background research in chapter 4, a greater understanding was obtained of the Electric motors application, operation, common failures and a section of work force experience, all aiding the selection of the Data Acquisitions specification.

The specification was carried out before any work was produced in relation to the Data Acquisition System prototype design research. The specification laid a basis for design requirements to aid component selection. It also reflected the aims and objectives that were set within chapter one and could be used as an evaluation basis when the prototype was produced.

5.2 Performance

5.2.1 Measurements

- Speed
    - Measure a minimum of 1500RPM
- Vibration
    - Measure a minimum of 10 rads/second
- Temperature
    - Measure a minimum temperature range -10°C to 100°C

5.2.2 Data logging device

- Microcontroller

5.2.3 Logging time

- Must be able to log data for 1 hour
- Speed Sensor
    - Read per RPM
    - Read every 0.5 seconds
- Vibration Sensor
    - Read every 0.5 seconds
- Temperature Sensor
    - Read every degree

- Read every 0.5 seconds

5.2.4 Aesthetics - Display/Communication

- LCD Display
- RS232 Communication

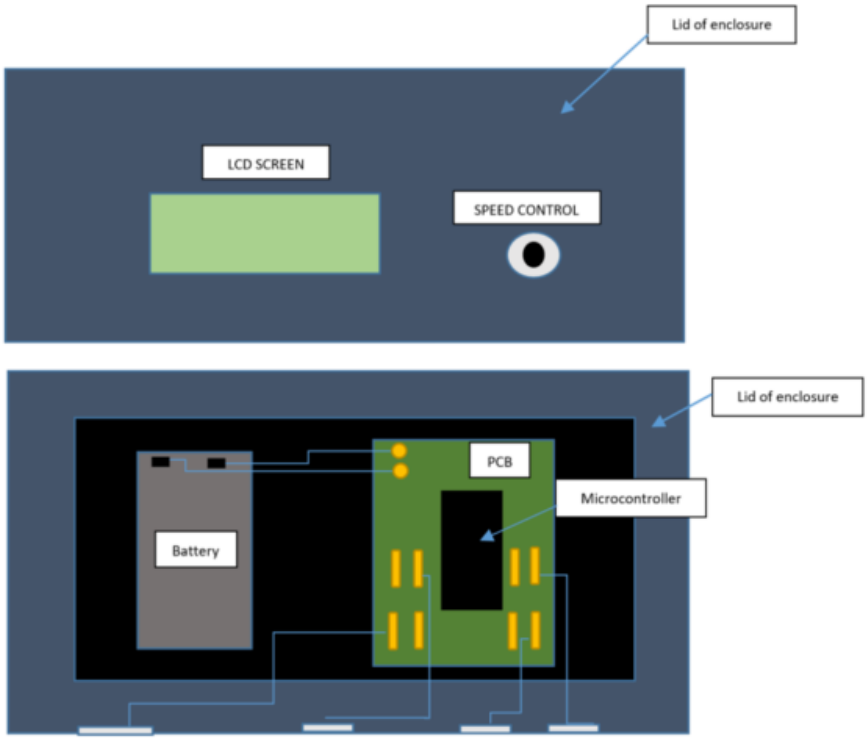


Figure 23: Layout of Microcontroller/electronics enclosure

5.2.5 Motor

- 24VDC
- Variable Speed
- Minimum 1500RPM

5.2.6 Power

- 24Volt battery / Two 12V batteries
- Amp/hour to reflect components selected

5.3 Target cost

- Prototype to cost a maximum of £100

5.4 Hardware/Software

- Proteus –Circuit build & Testing

- Easy – PC – PCB design
- CCS –Coding & Testing
- Microsoft word – Project report
- Microsoft Excel – Producing tables, Graphs & Gantt charts

5.5 Customers

- University of Wales Trinity Saint David's Major Project criteria
- Project supervisor
- Authors place of work

5.6 Environment

- Prototype to be used at University at Swansea for practical demonstration only

5.7 Size/weight & Ergonomics

- Bench prototype to be no heavier than 20KG
- All components and parts must be fixed on a board so that it can be moved by hand at ease.
- System must be easy to operate
- Speed of motor must be easy to adjust
- Data logged must be readable to the user

5.8 Quality and reliability

- The information gathered must be accurate
- The speed control must be accurate and obtainable with the selected motor

5.9 Testing

- All measurement components must be tested
    - Data to be gathered from components within a table or graph and compared with data sheet
- Proteus design to be tested continuously throughout design

5.10 Safety

- No 240V mains supply used
- No exposed sharp rotating parts
- No exposed live electrical wiring
- All components fixed on a solid base

5.11 Conclusion – Specification

The above specification was produced based on the background research conducted, the availability of components and the academic timescale of the major project. The specification provided a clear understanding of how the Data acquisition system was going to be produced including how it was going to be run, what it would measure, timescale in which the system was going to measure for and the safety aspects of the main product along with a number of other attributes.

To summarise the specification on how the system would run, the below function blocks show simplistic requirements of the system. Each step labelled with ‘operator’ to indicate a physical operator requirement and ‘system’ is what the internal programming is required to do. This was used as a base design of the microcontroller and final flow chart.

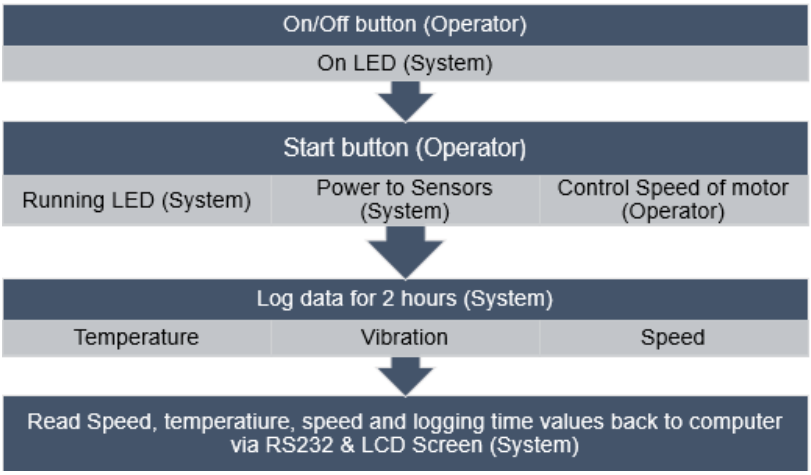


Figure 24: System function blocks

Once the specification was produced with the functionality and budget costing’s, market research of key components required to produce the system specified was conducted. This can be seen within the next chapter.

Chapter 6 – Design Research/Component Selection

6.1 Introduction - Component Selection

Using the specification set out within chapter 5, this section selects the key components that were used for the end prototype. The key components were identified to be the motor itself, the speed control for the motor, speed sensor, temperature sensor, vibration sensor, battery and a data logging components. Different variants of these components were looked at, with components being selected by the practicality of use for a prototype in relation to the specification.

S.W.O.T analysis technique of identifying the strengths, weakness, opportunities and threats of different variants of components to enable justification of specific component selection.

The S.W.O.T analysis tool was developed in the 1960s by Albert S. Humphreys [18]. SWOT is mainly used and established for business owners investigating future projects or strategies, but it also has the capability to be used in almost any situation in which a discussion making process has to be accurate and specific. This relating to the SMART goal set out within chapter 1 of this report. '*The balance'* argues that *'When conducted thoroughly, a SWOT analysis can uncover a wealth of information and can be useful in a number of situations'* [19].

Once a component type was selected within each area via SWOT analysis, market research was carried out to choose products for prototype purchase.

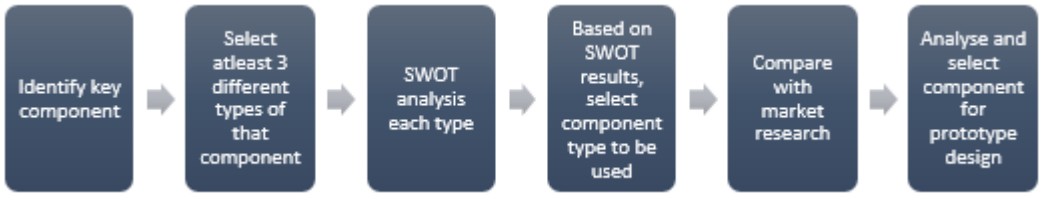


Figure 25: Component selection process

6.2 Motor selection

As per the specification outlined in chapter 5, the requirements for the motor were as follows:

- 24v DC
- 1500RPM minimum

6.2.1 Brushed

A brushed DC motor consists of a rotating armature and a stationary stator as shown in the below figure.

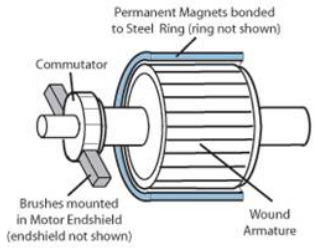


Figure 26: DC brushed Motor [20]

The armature, which is also known as the rotor contains windings wrapped around a soft iron core. The windings are connected electrically to the commutator, and the stator enclosed the rotor which contains permanent magnets, enabling a magnetic field to be generated. The DC power is connected to the brushes which are in contact with the commutator, energizing the armature coils. This causes the commutator and armature coils to rotate [21].

Strengths	**Weakness**
- Reliable - Inexpensive - No control required for single speed	- Periodic maintenance required - Heat dissipation
Opportunities	**Threats**
- Good area to measure heat on the prototype design - Similar to what is used at the authors place of work - Can be used with speed control	- Not reliable where high torque is required - With increased speed the friction of the bushes increase [22]

Table 8: SWOT analysis of a brushed motor

6.2.2 Brushless

The brushless motor works in a similar way to the brushed DC motor. The difference is, the permanent magnets are mounted on the brushless motors rotor and the stator contains winding coils. The brushless motors do not use brushes or a commutator, the rotation of the motor is now achieved by applying DC voltage to the winding coils on the stator [20].

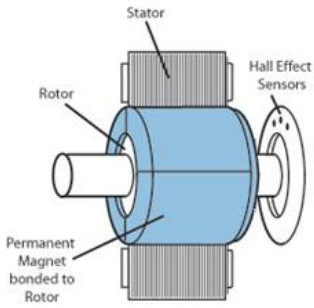


Figure 27: DC Brushless Motor [20]

Strengths	**Weakness**
- Less internal resistance - Better heat dissipation - More efficient - Quieter than a brushed motor - Hall effect sensors are used for detecting position of rotator	- Expensive
Opportunities	**Threats**
- Stator can be arranged in either a star or delta connection [20] - Lower inductance with higher speeds [20] - Greater flux density	- Can only be used in environments where there is no magnetic field in the proximity of the motor. As this will cause errors

Table 9: SWOT analysis of a brushless motor

6.2.3 Market Research of Selected Motor

The chosen motor type that was brought forward for market research was the brushless DC motor. The reasoning for this was the SWOT analysis shows opportunity to control the speed of this type of motor whilst also being efficient with lower resistance than the brushed DC motor produces. It was felt that this type of motor was also adequate for a bench prototype and would provide the requirements for this project. The below table shows some of the motors looked at on the market that could have been applied to the prototype design.

Selection					
Motor	**Price**	**Power**	**Voltage**	**RPM**	**Amps**
Electric E-Scooter Motor  [23]	£26.99	300watts	24V	2650RPM	16.5A
GM2 BLF 40-240  [24]	Information not given	26 watts	24v	4000rpm	1.8
Crouzet DC Geared motor  [25]	£612.94	30 watts	24v	7rpm	Information not given

Table 10: Market research of selected motor

6.2.4 Selected Motor

The selected motor was the Electric E-scooter motor, the reasoning behind this choice was due to the physical size of the motor enabling an adequate motor for a bench prototype. As seen in table 21, it was also noted the price of the motor was good value for money. The RPM of 2650 also provided a sufficient RPM for the prototype as per the specification set earlier in this report.



Figure 28: Selected DC motor [23]

6.3 Motor variable speed

The requirement for the motor speed controller is to be able to operate the selected motor sufficiently, for this reason it must operate within/at the following parameters:

- 24V
- >16.5A

6.3.1 Pulse Width Modulation

Pulse width modulation (PWM) works on the principle of varying the duty cycle with a fixed frequency with ‘on’ and ‘off’ pulses of voltage. The time in which the ‘on’ pulse is operated will an output average voltage compared to the ‘off’ pulses. This is shown within the figure below [26].

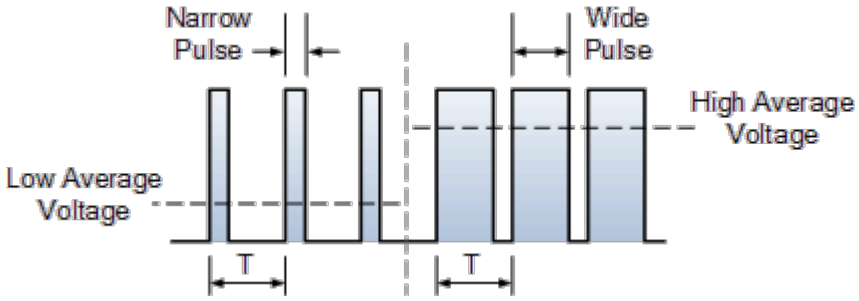


Figure 29: Pulse width Modulation [26]

The PWM system generates an analogue signal using a digital source. As discussed, the duty cycle and frequency are two main attributes to this system. The duty cycle is defined as the amount of time the ‘on’ pulse is on and the frequency determines how fast the system completes the ‘on’ ‘off’ cycle [27].

PWM can also be used from AC voltage input, as seen in the below block diagram showing how this would work.



Figure 30: PWM Block diagram

Strengths	Weakness
- Low heat generation - Fast operation - Low power loss on smaller applications - Minimum noise	- Energy loss due to constant switching ‘on’ and ‘off’
Opportunities	**Threats**
- Increased efficiency - Effective at controlling motors at a low RPM speed - Motor is always at full strength due to the voltage remaining constant when ‘on’	- Expensive

Table 11: SWOT analysis of PWM

6.3.2 Flux Control Method

With the flux control method of varying the speed of a DC motor, a variable resister is added in series with the field circuit, as shown below. The variable resistor varies the resistance within the field circuit which means the current through the windings of the DC motor can also be varied which will control the speed [28].

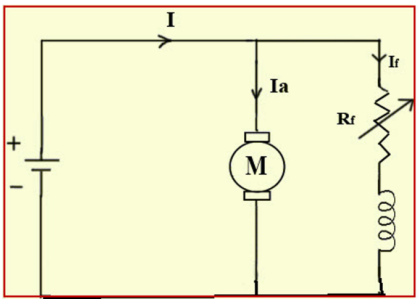


Figure 31: Flux Control [29]

Strengths	Weakness
- Increases the torque characteristics of the motor - Efficient - Cheap	- Large amount of power lost [30] - Speed control below the rated speed is not possible [31]
Opportunities	**Threats**
- Practically able to build one of these systems within the timescale of the major project - Different application of this method, Tapped, parallel, diverter.	- Can only be used on small motors [30] - Unreliable

Table 12: SWOT analysis of Flux control

6.3.3 Armature Control Method

Unlike the flux control connecting a variable resister in series with the field circuit, the armature control method adds a variable resister in series with the armature of the DC motor. This method is dependent on the back EMF and the DC motor speed is directly proportional. When the supply voltage and the armature resistance is at a constant the speed is proportional to the current. Adding the variable resister in series with the armature will decrease the armature current, meaning the speed will also decrease [29].

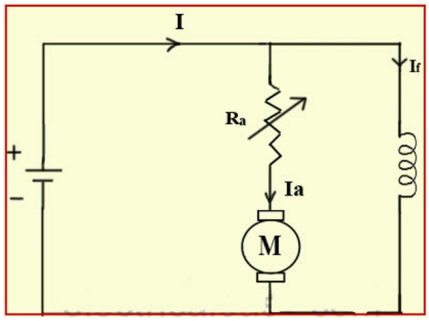


Figure 32: Armature Control [29]

Strengths	Weakness
- Complexity - Smooth speed control	- Large amounts of power lost [32]
Opportunities	**Threats**
- No opportunities could be found with this method which could be applied to the prototype design	- Not applicable to the chosen motor - Unreliable - Can be expensive [32] - Requires heat dissipation arrangements

Table 13: SWOT analysis of armature control

6.2.4 Market Research of Selected PWM Speed Controls

PWM, Flux and Armature methods of controlling the speed of the motor were reflected upon after conducting SWOT analysis on each technique. The outcome was to use PWM as the final method when controlling the motor speed due to its efficiency and ability to operate at low speeds. PWM was also a topic

of study at the time and of interest. Market research was carried out of PWM systems that could be used for this project within the below table.

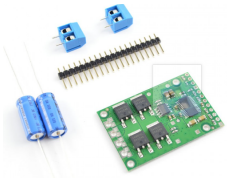
Selection				
Controller	**Price**	**Measurement range**	**Voltage**	**Time response**
PWM Step less Variable Speed regulator  [33]	£5.46	20A	9V to 60V	Information not available
Cytron 30A 5-30V DC  [34]	£32.66	30A	5-30V	1 second
Pololu  [35]	£57.73	20A	5.5 - 50V	Information not available

Table 14: Market research of selected speed control

6.2.5 Selected Speed Control

The below PWM Step-less Variable Speed regulator was selected for use within the prototype due to its design, the main reason for this is it aligned with the set requirements for the speed controller and the price of £5.46 suited to budget.

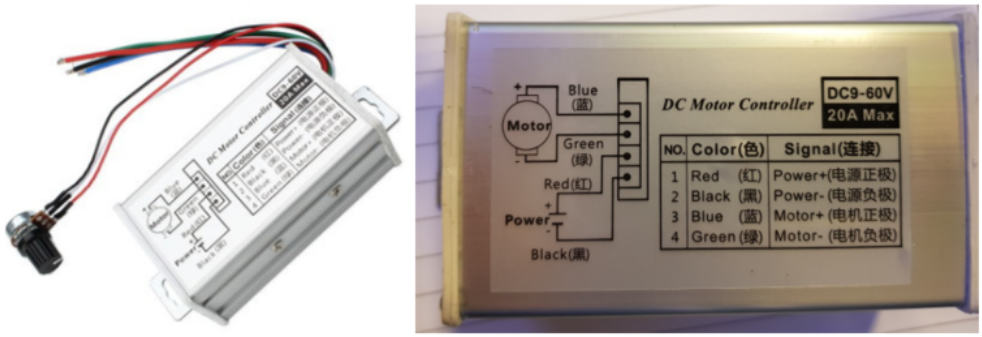


Figure 33: Selected PWM [33]

6.4 Temperature sensors

As per the specification outlined in chapter 5, the requirements for the temperature sensor were as follows:

- Minimum measurement range of -10°C to 100°C

6.4.1 Infrared

Infrared sensors use a lens to focus on infrared heat of an object required to be measured. The energy from the heat is passed through a detector which converts the heat energy into electrical energy [36].

Strengths	Weakness
- Fast response - Can be used in many different applications	- Expensive
Opportunities	**Threats**
- Measurements can be taken on moving parts - Compact and lightweight	- Measurements could be effective if the environment is wet/dusty

Table 15: SWOT analysis of Infrared temperature sensors

6.4.2 RTD

RTDs operate by the temperature in question being measured by the surface of the RTD. The RTD is made of a metal conductor, when heat is applied to the metal conductor the resistance measured in ohms increases. RTDs can be purchased in 2, 3 or 4 wire configuration [37].

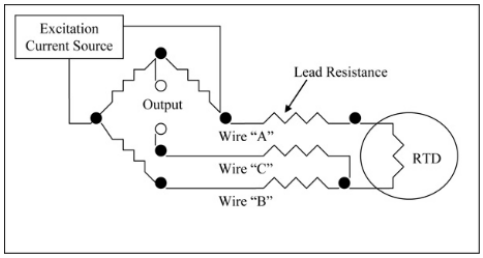


Figure 34: RTD [37]

Strengths	**Weakness**
- High accuracy - Linear output - No specific wire arrangement/installation	- High initial price - Limited temperature ranges - Self-heating
Opportunities	**Threats**
- Small base resistance - Suitable for precision applications [38]	- Slower response time than other temperature measuring devices

Table 16: SWOT analysis of RTD sensors

6.4.3 Thermocouple

Thermocouples are made up of two dissimilar metals connected together which produces what is called a ‘Thermo-electric’ effect. This effect produces a potential difference between the two dissimilar metals when any heat is applied. Voltage is created via the EMF of the two Thermo-electric effect with this output voltage being proportion to the temperature reading [39].

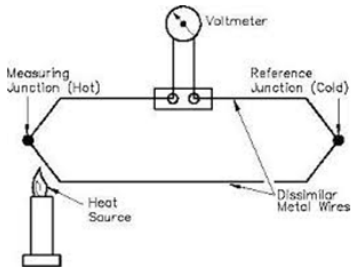


Figure 35: Thermocouples [40]

Strengths	Weakness
- Wide temperature range - Low cost - Durable	- Decreased accuracy compared to RTDs [41]
Opportunities	**Threats**
- Fast response time - Wide temperature range	- Difficult read - Requires recalibrating which can be difficult - Results can be unstable

Table 17: SWOT analysis of Thermocouples

6.4.4 IC (Integrated circuit)

IC (Integrated circuits) sensors hold circuitry within the sensor mostly with an analogue output current/voltage output. Some IC sensors combine analogue and digital circuitry. IC sensors are used largely with microcontroller based application [42].

Strengths	Weakness
- Inexpensive - Linear	- Power supply needed - Self-heating
Opportunities	**Threats**
- No additional circuitry required - Easily applied to a microcontroller type project - Analogue and digital outputs [43]	- Maximum output temperature of 150ºC - Potential of slow operation

Table 18: SWOT analysis of Integrated circuit sensors

6.4.5 Market Research of Selected IC Temperature Sensors

The IC temperature sensor was the application to be brought forward for market research. The justification for this choice was the IC circuit was the most simplistic application that could be used to measure temperature with an accurate output. The low cost of IC sensors could also be justified due to the overall prototype cost being relatively low.

If this was to be the design for the finished Data Acquisition System and not a prototype, it could be argued that the infrared temperature sensor would be the most accurate and suitable application to be used.

Selection				
Sensor	**Price**	**Measurement range**	**Voltage**	**Accuracy**
LM35  [44]	£1.40	-55ºC to 150ºC	4V – 30V	+/- $\frac{1}{4}$ ºC
AD590 Series  [45]	£17.25	-55ºC to 150ºC	4V – 30V	+/-0.1ºC
Integrated Circuit IC Temperature Probe  [46]	£36.50	-25ºC to 105ºC	4V – 30V	+/-0.1ºC
TMP36GT9Z  [47]	£1.10	-40ºC to 125ºC	2.7V to 5.5V	+/-3ºC

Table 19: Market Research of Selected Temperature Sensor

6.4.6 Selected Temperature Sensor

The selected sensor for the prototype was the LM35. The justification for this choice is focused on the criteria shown above and the criteria set within chapter 5, the specification. The cost of the LM35 is relatively low, with the temperature measurement range well within the specified range for the end design. The

operating voltage of this device could also be applied within the low voltage microcontroller design.



PARAMETER	TEST CONDITIONS	LM35A			LM35CA			UNIT
		TYP	TESTED LIMIT(1)	DESIGN LIMIT(2)	TYP	TESTED LIMIT(1)	DESIGN LIMIT(2)	
Accuracy(3)	T_A = 25°C	±0.2	±0.5		±0.2	±0.5		°C
	T_A = −10°C	±0.3			±0.3		±1	
	T_A = T_{MAX}	±0.4	±1		±0.4	±1		
	T_A = T_{MIN}	±0.4	±1		±0.4		±1.5	
Nonlinearity(4)	$T_{MIN} \le T_A \le T_{MAX}$, −40°C ≤ T_J ≤ 125°C	±0.18		±0.35	±0.15		±0.3	°C
Sensor gain (average slope)	$T_{MIN} \le T_A \le T_{MAX}$	10	9.9		10		9.9	mV/°C
	−40°C ≤ T_J ≤ 125°C	10	10.1		10		10.1	
Load regulation(5) 0 ≤ I_L ≤ 1 mA	T_A = 25°C	±0.4	±1		±0.4	±1		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$, −40°C ≤ T_J ≤ 125°C	±0.5		±3	±0.5		±3	
Line regulation(5)	T_A = 25°C	±0.01	±0.05		±0.01	±0.05		mV/V
	4 V ≤ V_S ≤ 30 V, −40°C ≤ T_J ≤ 125°C	±0.02		±0.1	±0.02		±0.1	
Quiescent current(6)	V_S = 5 V, 25°C	56	67		56	67		µA
	V_S = 5 V, −40°C ≤ T_J ≤ 125°C	105		131	91		114	
	V_S = 30 V, 25°C	56.2	68		56.2	68		
	V_S = 30 V, −40°C ≤ T_J ≤ 125°C	105.5		133	91.5		116	
Change of quiescent current(5)	4 V ≤ V_S ≤ 30 V, 25°C	0.2	1		0.2	1		µA
	4 V ≤ V_S ≤ 30 V, −40°C ≤ T_J ≤ 125°C	0.5		2	0.5		2	
Temperature coefficient of quiescent current	−40°C ≤ T_J ≤ 125°C	0.39		0.5	0.39		0.5	µA/°C
Minimum temperature for rate accuracy	In circuit of Figure 14, I_L = 0	1.5		2	1.5		2	°C
Long term stability	T_J = T_{MAX}, for 1000 hours	±0.08			±0.08			°C

Figure 36: Selected Temperature sensor [47]

6.5 Speed sensors

As per the specification outlined in chapter 5, the requirements for the speed sensor were as follows:

- Minimum measurement of 1500RPM

6.5.1 Photo Electric – Beam Break

Beam break photo electric sensors consist of an emitter and receiver which sit opposite one another. A light from the emitter is received by the receiver, once an object breaks the emitted light it reduces the light entering the receiver [48]. The reflected sensors are prodominatly anaologue with a 4-20mA output with the break of light generating a switch signal generated by the receiver [42].

Strengths	Weakness
- Fast response time - High resolution - Non-contact - Colour identification	- Expensive - Could receive ambiguous output readings if there were other moving parts within the area of measurement
Opportunities	**Threats**
- Non-contact - Long distance measuring - Can be applied to different applications	- Needs to be permanently fixed within a location it can be directed at the object being measured

Table 20: SWOT analysis of Beam Break sensors

6.5.2 Photo Electric – Reflective

A reflective sensor operates by using a transmitter and receiver located within the same enclosure. When there is no object/reflective material present the receiver will not record the received light from the transmitter. Reflectors are used to reflect light transmitted that is produced by the emitter/transmitter from the sensing object and back to the receiver. Reflective are also available with or without polarisation filters, this will only allow light from set phase angles be received leading to no false readings [49]. The reflected sensors are prodominatly anaologue with a 4-20mA output.

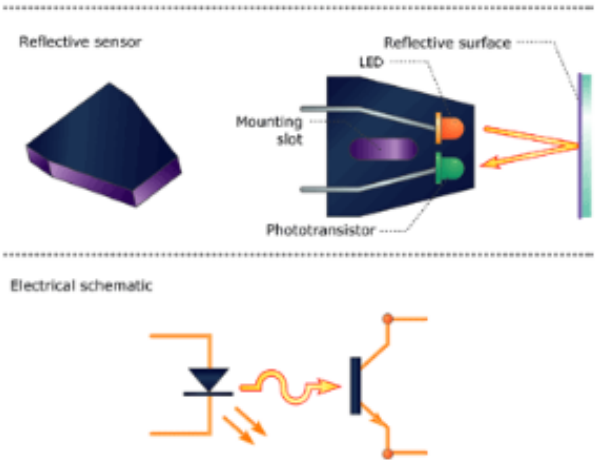


Figure 37: Reflective sensors [50]

Strengths	Weakness
- Fast response time - Low cost - Reliable	- If there are other moving objects in the area it could result in ambiguous readings.
Opportunities	**Threats**
- Senses a wide range of material - Long sensing range	- Results could become faulty if lenses became dirty through dust build up etc.

Table 21: SWOT analysis of Reflective sensors

6.5.3 Hall-Effect

The hall-effect principle of operation was named after its founder, Edwin Hall [51] Hall-effect sensors operate with the use of magnetic field flux (B) both north and south polarity. An output signal from Hall Effect sensors is generated by the magnetic flux density that surrounds the measuring object/device. Hall Effect sensors will have a threshold of flux density, when the external density exceeds this threshold the sensor will generate an output voltage, normally millivolts, this is also known as hall voltage (VH) [52].

Strengths	Weakness
- Not effected by dust or humidity - Reliable - Sensitive - Long life span	- Temperature could affect the resistance element of the sensor - Would not be effected if applied to an application with an external magnetic field
Opportunities	**Threats**
- Displays low carrier density - Output voltage would be simple to measure	- Distance of measurement is limited

Table 22: SWOT analysis of Hall-Effect sensors

6.5.4 Market Research of Selected Photo Reflective Speed Sensors

Photo reflective sensors were the chosen technique to be used to measure the speed of the motor. The reasoning behind this decision was due to the accuracy and practicality that this form of sensor could provide the prototype system being produced. Below, market research was conducted to select a sensor to be used on the final prototype.

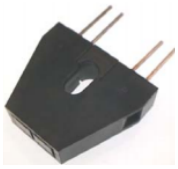
Selection				
Sensor	**Price**	**Measurement range**	**Voltage**	**Time response/Accuracy**
OPB740  [53]	£1.58	2.04mm to 7.62mm	3V to 5V	850nm
LS-S50MLR  [54]	$295.00	0.5mm to 170mm	10V to 30V	400nm
MCS-655M  [55]	$165.00	400mm	10V to 30V	0.5ms
OMRON E3ZLT81D2M  [56]	$79.64	60m	12V to 24V	Information not available

Table 23: Market Research of Selected Speed Sensor

6.5.5 Selected Speed Sensor

The OPB740 photo reflective sensor was selected as the speed sensor to be used within the prototype. This sensor was considered due to it fitted the specification price budget and also provided the necessary requirements that allowed the speed of the bench motor to me measured sufficiently and correctly.

Electrical Characteristics (T_A = 25° C unless otherwise noted)

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
645 nm LED (See OVLAS6CB8 for generic information — for reference only)						
V_F	Forward Voltage	-	-	2.6	V	I_F = 20 mA
I_R	Reverse Current	-	-	100	µA	V_R = 2 V
890 nm LED (See OP265 for additional information — for reference only)						
V_F	Forward Voltage	-	-	1.8	V	I_F = 40 mA
I_R	Reverse Current	-	-	100	µA	V_R = 2 V
935 nm LED (See OP165 for additional information — for reference only)						
V_F	Forward Voltage	-	-	1.7	V	I_F = 40 mA
I_R	Reverse Current	-	-	100	µA	V_R = 2 V

Absolute Maximum Ratings (T_A = 25° C unless otherwise noted)

Operating and Storage Temperature Range OPB708, OP709, OPB740, OPB741, OPB742, OPB743, OPB744, OPB745	-40° C to +85° C
OPB741WZ, OPB742WZ, OPB743WZ, OPB744WZ, OPB745WZ, OPB746WZ, OPB747WZ, OPB748WZ	-40° C to +80° C
Lead Soldering Temperature [1/16 inch (1.6mm) from the case for 5 sec. with soldering iron][1]	260°C
Input Diode (See OP165 (935 nm), OP265 (890 nm) or OVLAS6C88 (645 nm) for additional information)	
Forward DC Current	40 mA
Reverse DC Voltage	2 V
Power Dissipation[2]	100 mW
Sensor Output (See OP505 (Transistor), OP705 (R_{BE} Transistor) or OP535 (Darlington) for additional information)	
Collector-Emitter Voltage OPB708 OPB709 OPB740, OPB741, OPB742, OPB743, OPB744 OPB740WZ, OPB741WZ, OPB742WZ, OPB743WZ, OPB744WZ OPB748WZ OPB745 OPB745WZ OPB746WZ, OPB747WZ	 30 V 15 V 30 V 30 V 15 V 15 V 24 V
Emitter-Collector Voltage OPB708 through OPB745, OPB748 OPB746 through OPB747	 5.0 V 0.4 V
Power Dissipation[2]	100 mW

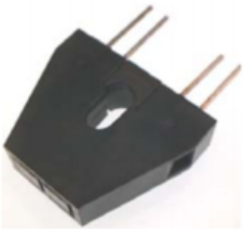


Figure 38: Selected speed sensor data [53]

6.6 Vibration sensors

As per the specification outlined in chapter 5, the requirements for the vibration sensor were as follows:

- Minimum measurement of 10rads/second

6.6.1 Gyroscope

Gyroscope sensors which are placed within MEMS are between 1 and 100 micrometre in size. If the gyroscope sensors is rotated, it uses the angular velocity to measure movement of a chosen axis. If a gyroscope is rotated or moved *'a small resonating mass is shifted'.* The sensor generates a low current signal when moved/rotated, this can be read by a microcontroller [57].

Strengths	Weakness
-Highly accurate - Can be used with a microcontroller - Not effected by different material	- Expensive - Could be effected by external moving parts
Opportunities	**Threats**
- Relatively straight forward to detect information from	- Can be complex - Small sensor – difficulty applying to the prototype design

Table 24: SWOT analysis of Gyroscopes

6.6.2 Strain gauge

Strain gauges are sensors that fan be used to measure force, pressure, tension or weight and convert any of these forces into resistance. The resistance can then be measured in relation to the force being applied [58].

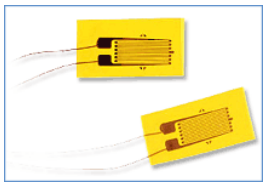


Figure 39: Strain Gauge [58]

Strengths	Weakness
- Inexpensive - Accurate	- Once installed, the gauge cannot be used again - Requires calibration - Easily damaged
Opportunities	**Threats**
- Available in variety of shapes and sizes - No moving parts – Gauge is fixed	- Technical application to apply gauge to equipment - Performance is effected by the environment - Non-linear

Table 25: SWOT analysis of Strain gauges

6.6.3 Proximity Probes

Proximity probes, also known as displacement transducers is a non-contact sensor transducer. The probe is fixed on a solid and fixed object and will

measure the distance between the known fixed point and a shaft/surface required to be measured. These types of probes measure low frequency with a signal response around 1.5kHz [59].

Strengths	Weakness
- Long life span - Easy to install	- Distance limitations
Opportunities	**Threats**
- High switching rate - Can be applied in any environment	- Only accurate when used on metal - Operating range is limited

Table 26: SWOT analysis of Proximity Probes

6.6.4 Market Research of Selected Gyroscopes

After reviewing the SWOT analysis of the different methods that could have been used to measure the vibration of the prototype motor, it was concluded that the Gyroscope was the strongest to be taken forward for market research. The reasoning for this was the sensor works with a microcontroller and it could applied to a bench type prototype.

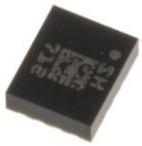
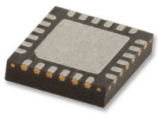
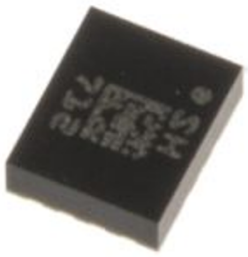
Selection				
Sensor	**Price**	**Measurement range**	**Voltage**	**Time response/Accuracy**
LSM6DS3TR, 3-Axis Accelerometer & Gyroscope  [60]	£2.14	3 axis	1.71V to 3.6V	+/-2 / +/-4 / +/-6g
410-326 Gyroscope  [61]	£22.13	9 axis	3.3V to 5V	+/-2 / +/-4 / +/-8g / 16g
MPU-3300 - MEMS Gyroscope  [62]	£75.61	3 axis	2.375V to 3.465V	±225 and ±450°/sec
L3GD20HTR - MEMS Gyroscope  [63]	£2.31	3 axis	2.2V to 3.6V	± 500°/s, ± 2000°/s

Table 27: Market Research of Selected Vibration Sensor

6.6.5 Selected Vibration Sensor

The chosen vibration sensor is the LSM6DS3TR Gyroscope. The reasoning behind this decision is that this gyroscope is marketed at £2.14 which is within the budget of the project. The gyroscope also provides the ability to measure the 3 axis required for the prototype motor with an adequate accuracy and within the 3-5V voltage range.



Symbol	Parameter	Test conditions	Min.	Typ.(1)	Max.	Unit
Vdd	Supply voltage		1.71	1.8	3.6	V
Vdd_IO	Power supply for I/O		1.62		Vdd + 0.1	V
IddHP	Gyroscope and accelerometer in high-performance mode	up to ODR = 1.6 kHz		1.25		mA
IddNM	Gyroscope and accelerometer in normal mode	ODR = 208 Hz		0.9		mA
IddLP	Gyroscope and accelerometer in low-power mode	ODR = 12.5 Hz		0.42		mA
LA_IddHP	Accelerometer current consumption in high-performance mode	up to ODR = 1.6 kHz		240		µA
LA_IddNM	Accelerometer current consumption in normal mode	ODR = 104 Hz		70		µA
LA_IddLM	Accelerometer current consumption in low-power mode	ODR = 12.5 Hz		24		µA
IddPD	Gyroscope and accelerometer in power down			6		µA
V_{IH}	Digital high-level input voltage		0.8 * VDD_IO			V
V_{IL}	Digital low-level input voltage				0.2 * VDD_IO	V
V_{OH}	High-level output voltage	I_{OH} = 4 mA (2)	VDD_IO - 0.2			V
V_{OL}	Low-level output voltage	I_{OL} = 4 mA (2)			0.2	V
Top	Operating temperature range		-40		+85	°C

Figure 40: Selected Gyroscope [64]

6.7 Battery

To identifying the requirements for the prototype battery, it was necessary to calculate the required Amp hour rate needed to power all of the outgoing applications. It was already identified within the specification that the motor was 24V. So the battery was required to be 24V and below specifies the overall amperage calculated.

Amp/hour Requirement	
Equipment	**Current**
Motor	16.5A
Speed sensor	40mA (0.04A)
Vibration sensor	1.25mA (0.0125A)
Temperature sensor	10mA (0.01A)
Total: 17.125A x 2 hours = 34.25A	

Table 28: Battery amperage rating requirements

6.7.1 Lead Acid

Lead acid batteries are rechargeable type batteries produced for high current applications. Due to the high current capacity, these are normally large batteries. The composition of this type of battery when charged is '*Pb (negative) and PbO_2 (positive) as electrodes with H_2SO_4 as electrolyte in charged form'* and *'A combination of and $PbSO_4$ and water in discharged form'* [65].

Strengths	**Weakness**
- Used on high current applications - Not toxic - Rechargeable	- Slow recharging - Danger of overheating during charging
Opportunities	**Threats**
- Rechargeable - High starting applications - Used for back-up power supplies	- Physical size – big and heavy

Table 29: SWOT analysis of lead acid batteries

6.7.2 Lithium

Lithium batteries use lithium in its pure ion compound. These batteries are rechargeable with mainly voltage output of 1.5V to 3.7V. Lithium cell batteries voltage production is twice as much as zinc-carbon or alkaline batteries [65].

Strengths	**Weakness**
- Better run time compared to alkaline batteries [65]	- Expensive
Opportunities	**Threats**
- Long life batteries	- Usually used for low current applications [65]

Table 30: SWOT analysis of Lithium batteries

6.7.3 Mercury

Mercury batteries are non-rechargeable batteries made up with mercuric oxide/manganese dioxide. The voltage level of these batteries does not drop below 1.35V but are used in low output voltage applications [65].

Strengths	Weakness
- Flat discharge curve	- Low voltage output [65]
Opportunities	**Threats**
- Useful for photographic light meters and electronic devices [65]	- Mercury is toxic - Hazardous to humans and animals

Table 31: SWOT analysis of Mercury batteries

6.7.4 Market Research of Selected Battery

From the SWOT analysis of different type of batteries, lead acid batteries were the selected batteries to be taken forward for market research. The reasoning for this is these batteries are applicable for larger loads, with the motor itself running at 16.5 amps this is a major requirement from the battery.

Battery Selection				
Sensor	**Price**	**Amperage**	**Voltage**	**Power**
Powerizer LiFeP04 Battery  [66]	$299	20Ahour	24V DC	240Whour
Siemens 6EP19356MF01  [67]	£152	12Ah	24V DC	Information not given
Injusa Repsol Pocket Racer  [68]	£18.69	7Ah	24V DC	Information not given

Table 32: Market Research of Selected Battery

6.7.5 Selected battery

Fortunately, a second hand 24V lead acid battery was acquired free of charge. The battery was slightly large and heavy, but suitable and cheap for the budget and operation of the prototype being produced.



Figure 41: Selected 2x12V Batteries

6.8 Microcontroller Selection

With all the key components selected for the Data Acquisition System, it was now possible to select an appropriate microcontroller. For the microcontroller to be appropriate and correct, the pin connection requirements would need to be identified from the selected sensors along with microcontroller size. The following tables will identify the pin count requirement of the microcontroller, bit size and clock cycle.

6.8.1 Microcontroller requirements

PIN requirement		
Input/ouput	**Equipment**	**PINS Required**
Analogue	Temperature Sensor	3
	Speed Sensor	4
Digital	Vibration Sensor	3
UART	RS232	2
	LCD	7
Power	3	3
Total number of pins: **22**		

Table 33: Microcontroller pin requirements

Bit Requirement for Each Sensor		
Sensor	**Calculation**	**Bit requirement**
Speed Sensor	Motor = 2650RPM $\frac{2650}{60} = 42.6$ The Shaft of the motor will turn 42.6 times per second.	8 bit = 256 8 bit is more than adequate
Temperature Sensor	Sensor measurement range = 205°C Minimum = -55°C Maximum = 150°C 10mV output per degree = 150°C = 150mV 25°C = 250mV -55°C = -550mV	8 bit = 256 More than adequate with a temperature range of 205°C

Table 34: Bit requirement

Clock cycle			
Sensor	**Read time intervals (Seconds)**	**Cycles per read**	**Cycles per second**
Speed sensor	0.5	250	0.002
Temperature Sensor	0.5	250	0.002
Vibration sensor	0.5	250	0.002
Total	**0.006 cycles per second**		

Table 35: Clock Cycle

6.8.2 Microcontroller Market research

When the requirements for the microcontroller were identified, the criteria was entered within microchip.com to identify a microcontroller that would fit some of the selected criteria. This can be seen within the below table.

Microcontroller Selection					
Microcontroller	**Cost**	**Number of pins**	**Total A/D Channels**	**SPI**	**URART**
PIC16F18325	$0.71	14	15	2	2
PIC18F2458	$1.65	28	25	1	1
PIC18F15354	$0.73	28	24	2	2

Table 36: Microcontroller Selection

6.8.3 Selected Microcontroller

As seen below the PIC18F2458 was brought forward for the prototype design. The justification for this microcontroller compared with the others was the fact it covered all the criteria needed for the prototype, as well as being within the projects original budget specified within chapter 5.

Selected Microcontroller	
Microcontroller	**Size**
PIC18F2458  [69]	28pin

Table 37: Selected microcontroller

6.9 Conclusion - Component Selection

Within this section, all of the identified key components were selected and purchased. The key components covered the motor, PWM controller, battery,

microcontroller and speed, vibration and temperature sensors. These can all be seen within the below tables.

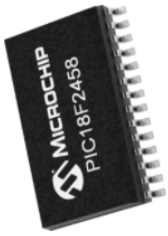
Motor	Speed control	Battery	Microcontroller
24V/300W Electric E-Scooter Motor  [23]	PWM 9V-60V 20A Variable speed controller  [33]	Sneider Electric 2X 12V Lead acid 	PIC18F2458  [69]

Table 38: Conclusion - Component Selection 1

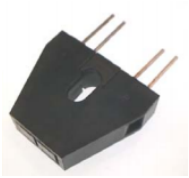
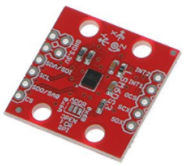
Speed sensor	Vibration Sensor	Temperature sensor
OPB 740 - Reflective  [53]	LSM6DS3 3 Axis Gyroscope Sensor 3 Axis  [70]	LM35 IC Temperarture sensor  [44]

Table 39: Conclusion - Component Selection 2

The next stage of the process to building the Electric motor acquisition system is to test the selected key components, ensuring they operated the way that was expected and required for the prototype. The tests carried out along with analysis of results are discussed within the next chapter.

Chapter 7 – Component Testing

7.1 Testing introduction

Once the key components were selected within chapter 6, it was necessary to test the selected sensors/components to ensure two things. One being that the sensors operate as per specification and two, ensuring the Data Acquisition System is built in such a way in which these components can be applied.

Within this chapter, testing procedures will be outlined for each key components, along with the testing itself and analysis of each test carried out. Tests were carried out on the LM35 temperature sensor, PWM Controller, battery, brushless motor, OPB740 speed sensor.

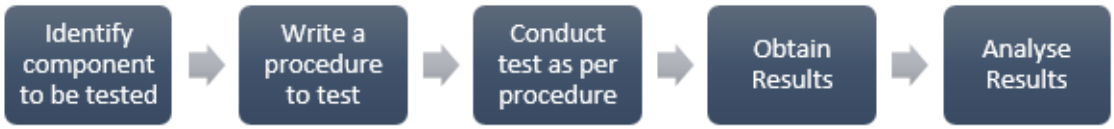


Figure 42: Process of testing components

7.2 Temperature Sensor

The measurement span of the LM35 temperature sensor was 205°C, ranging from -55°C to 150°C with a 10mV linear output proportional to the temperature. The purpose of testing the sensor prior to applying it to the prototype was to analyse these parameters with a 5V input supply. This allowed the operation of the sensor to be proven.

A test procedure was produced documenting the exact process in which the sensor was tested. The test was performed as per the procedure, critically analysing the results.

7.2.1 Test procedure

Apparatus required:
- Multi-meter - Power Supply - LM35 temperature sensor - RC-4 mini Temperature data logger - Excel spreadsheet
Expected outcome of test – mV output per °C. (Example: 10°C – 100mV output)

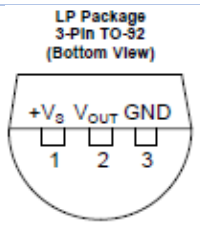
Step	Action	Comments
1	Connect LM35 sensor up to a 5V power supply	 [71]
2	Connect 'Vout' to a multi- meter or oscilloscope and read output mV	10mV output per 1°C
3	Add head in a close proximity to the sensor and confirm temperature/mV output changes	Confirm temperature with the RC-4 Temperature logger

Table 40: Temperature Sensor Test Procedure

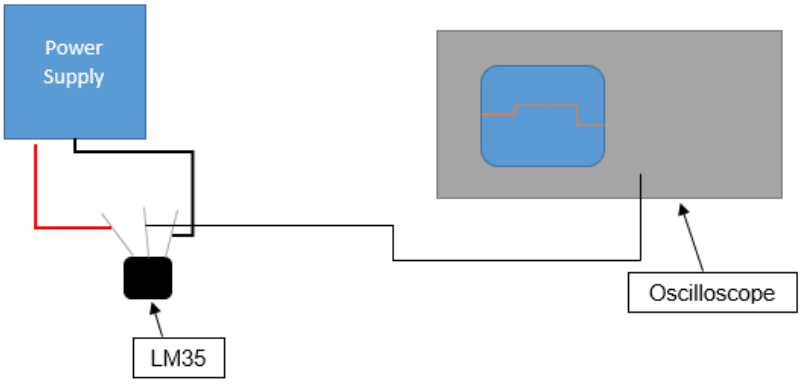


Figure 43: LM35 testing layout

7.2.2 Test analysis

The testing of the LM35 did not go as expected, the reason for this is still unknown. When the sensor was connected up to the power supply and oscilloscope, the output mV was not correct. As seen in the below figure, the ‘Value’ was at 27.2mV which indicated the LM35 was measuring a temperature of around 2.5°C. This was not the case as the sensor was based within of around 20°C.

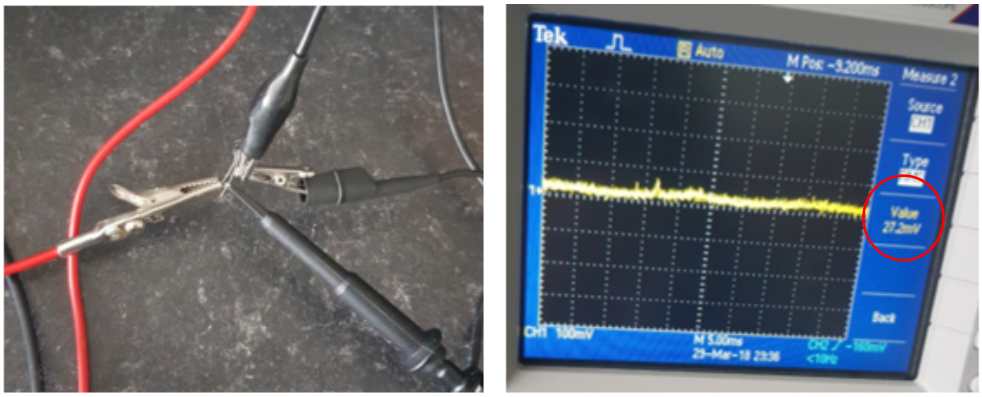


Figure 44: LM35 Test 1

It is also noted that the waveform within the above figure was not clear and suggested that the output of the LM35 was picking up noise, which was ultimately affecting the output waveform.

The data sheet was revisited to ensure nothing was missed within the initial procedure – nothing was apparent, with the polarity connected correctly. A different power supply was used, a new LM35 was connected, new test leads and a different oscilloscope was also used, but the output did not rectify.

With the output still indicating there was noise present which was effecting the output, a 9V battery was connected instead of the power supply to try and rectify the output mV. As seen in the below figure, the result of connecting the battery instead of the power supply seemed to be a success. The output value was now reading at around 200mV, indicating the room was at 20°C. It is noted that the waveform still indicated some noise on the output.

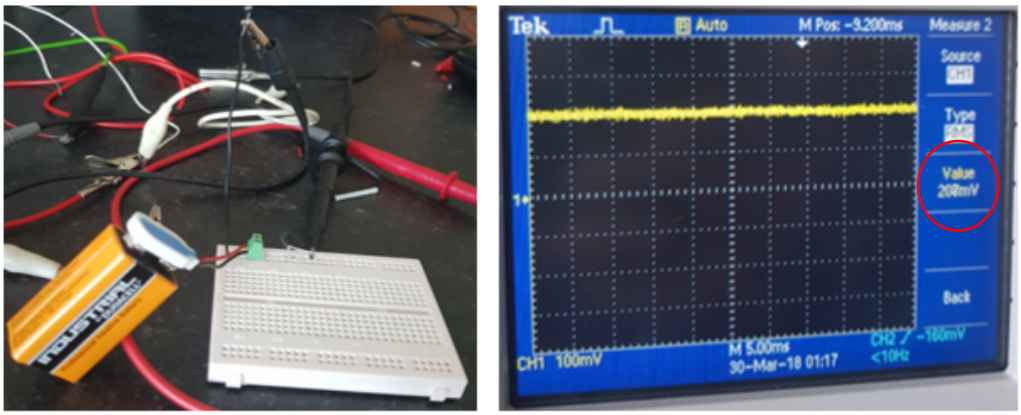


Figure 45: LM35 Test 2

The RC-4 Temperature logger indicated that the 200mV was a valid reading as



Figure 46: Temperature logger read out

the logger also read out a room temperature of 20.6°C at the time of testing.

Although the output was accurate at the initial temperature, the output mV did not increase when there was a heat source present within the proximity of the LM35. So this test could not be taken as a valid temperature indication. Inline resistors were connected to the output of the LM35 to see if this had any effect on the output, it did not.

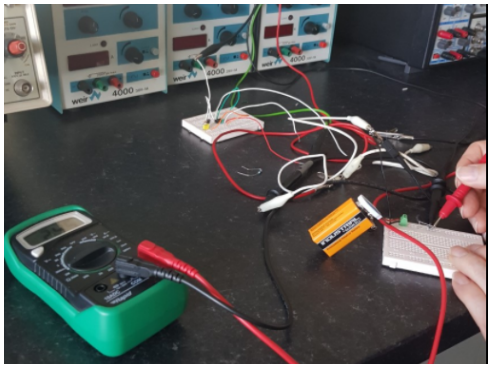


Figure 47: LM35 Testing using a multi-meter

7.3 Speed Sensor

The OPB 740 – Reflective sensor was tested to prove functionally of the sensor prior to connecting to the prototype. The justification for testing the sensor was to ensure the output of the sensor would be adequate to produce a signal to be read by the microcontroller.

A test procedure was also conducted for the OPB740 prior to being carried out, once the test was carried out the results were reflected upon.

7.3.1 Test procedure

Apparatus required: • 5V power supply & Breadboard • 2x10kohm resistors • OPB740 sensor		
Expected outcome of test – 5V output from OPB740 when object is detected		
Step	**Action**	**Comments**
1	Connect OPB740 sensor as required on bread board – connect a 10kOhm resister in series with the cathode and emitter to 0V.	Circuit ready for power supply
2	Set power supply to 5V DC and connect to the live and negative rail indicated on the bread board	5V present on breadboard
3	Confirm voltage on breadboard at the correct pins	
4	Confirm OPB740 is powered on using smart phone camera	Will net detect LED by eyesight
5	Using a varies material – Test sensitivity of sensor	Voltage out should indicate when the object is detected – 5v = most sensitive.
6	Using metal rule, record results on an excel spreadsheet	
7	Compare results	Plotted on a graph

Table 41: Speed Sensor Test Procedure

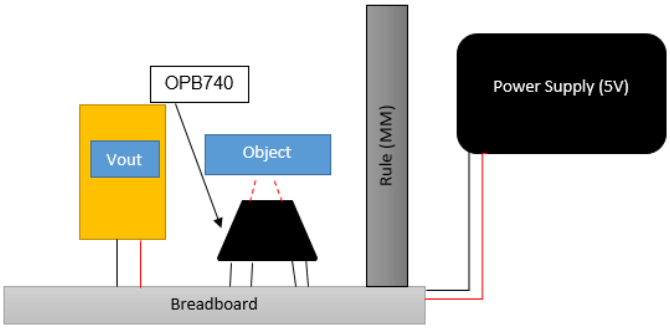


Figure 48: OPB740 Testing Layout

7.3.2 Test analysis

The initial set up of the testing can be seen within the below figure.

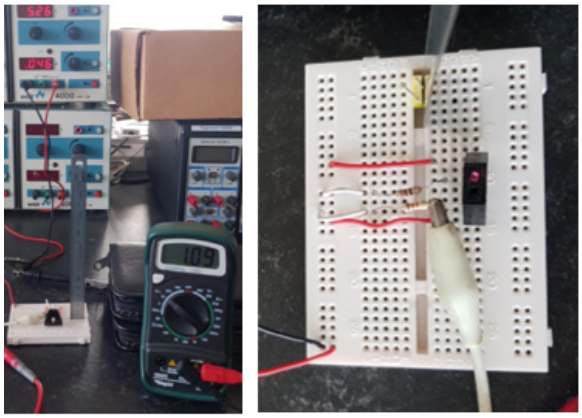


Figure 49: OPB740 Testing Setup

Test with wood – The first test carried out with the OPB740 sensor was to test its sensitivity with wood. As seen within the below figures it illutrated when the sensor has detected (4.45V) the piece of wood and when it hasn't (0.98V).



Figure 50: OPB740 Testing With Wood

The below graph shows the measurements gathered between the voltage out of the OPB740 and the distance in which the piece of wood is located. Analysing

the graph, it is seen the OPB740 strongest voltage output was around the distance of 10mm at just over 4.5V. the voltage rises in a linear motion from 2mm to 5mm, when it steadys off, this suggests that the sensor is at its stongest between the distances of 5mm to 12mm before the voltage begins to decrease. It is also noted that the the OPB740 output was at its weekest when the wood was at a distance of 30mm.

Weekest detection point – 2mm, 22mm to 30mm

Strongest detection point – 6mm to 10mm

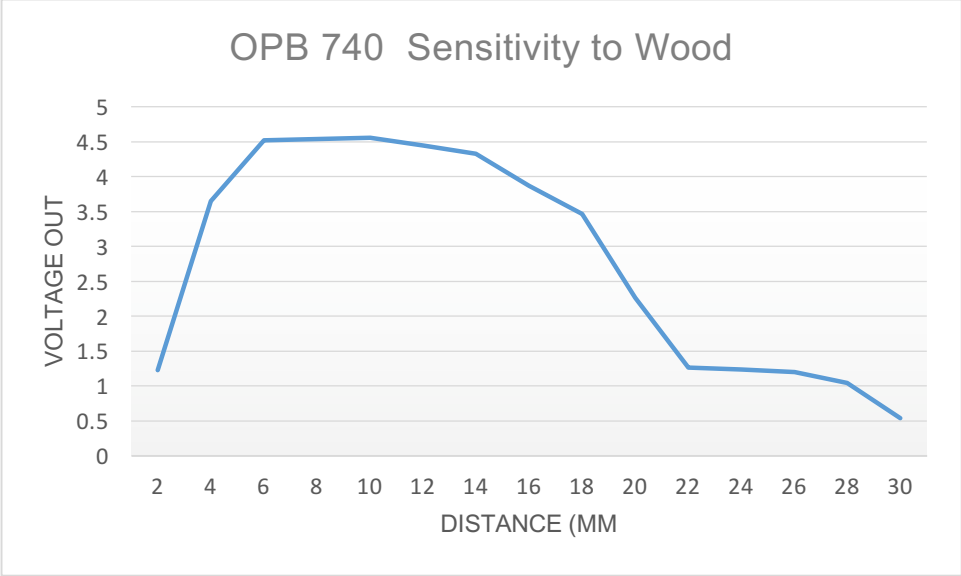


Figure 51: Wood Testing Results

Cardboard Test - The second test conducted with the OPB740 sensor was to test its sensitivity with cardboard. As seen within the below figures it illutrated when the sensor has detected (4.42V) the cardboard and when it hasn't (0.87V).

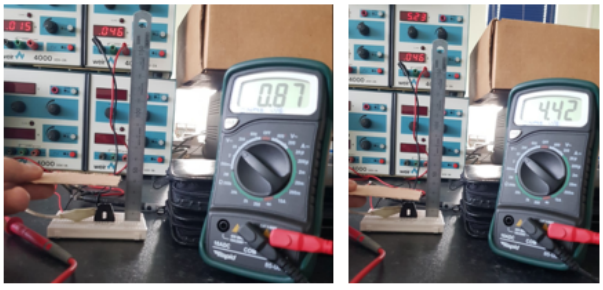


Figure 52: OPB740 Testing With Cardboard

The below graph highlights the results obtained from the test carried out with cardboard. As seen within the graph, the cardboard is detected at 2mm but only

at 2.5 volts which indicates it is not at its strongest sensitivity. The voltage then drops to 2V at 6mm before picking back up to 4.5 V at 8mm. between 8mm to 12mm it is shown when the detection of cardboard is at its strongest, ranging between 4-4.5V. After 12mm the graph rapidly decreases to 1.5V at 18mm. From 18mm to 30mm is when the sensors detection of cardboard is at its lowest, gradually decreasing to below 1V at this stage.

Weekest detection point – 18mm to 30mm

Strongest detection point – 8mm to 12mm

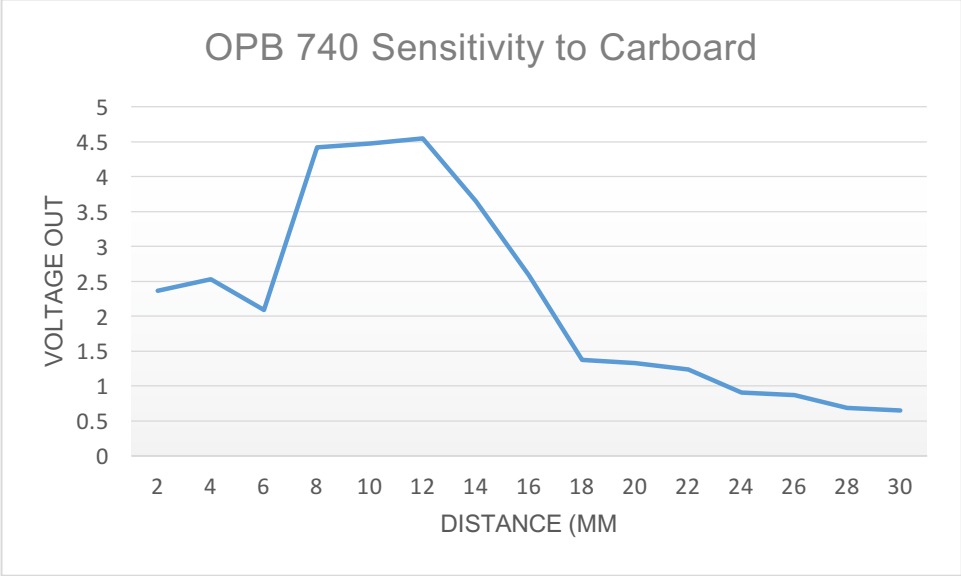


Figure 53: Cardboard Testing Results

Reflective Plastic Test - The third test conducted with the OPB740 sensor was to test its sensitivity with reflective plastic. As seen within the below figures it illutrated when the sensor has detected (4.52V) the plastic and when it hasn't (0.70V).

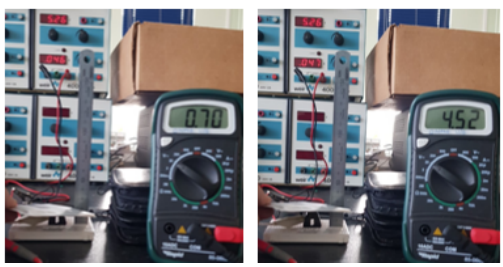


Figure 54: OPB740 Testing With Reflective Plastic

The reflective plastic testing indicated that at 2mm the OPB740 detected the material, with an output voltage of 4.5V at this stage. The Voltage is steady at

this voltage until the distance of 10mm, before it gradually depletes from 10mm to 16mm to 1.75V. The detection reduces from 16mm to 30mm ranging from 1.5V to 0.7V at this stage. These results are highlighted within the graph below.

Weekest detection point –18mm to 30mm

Strongest detection point – 2mm to 11mm

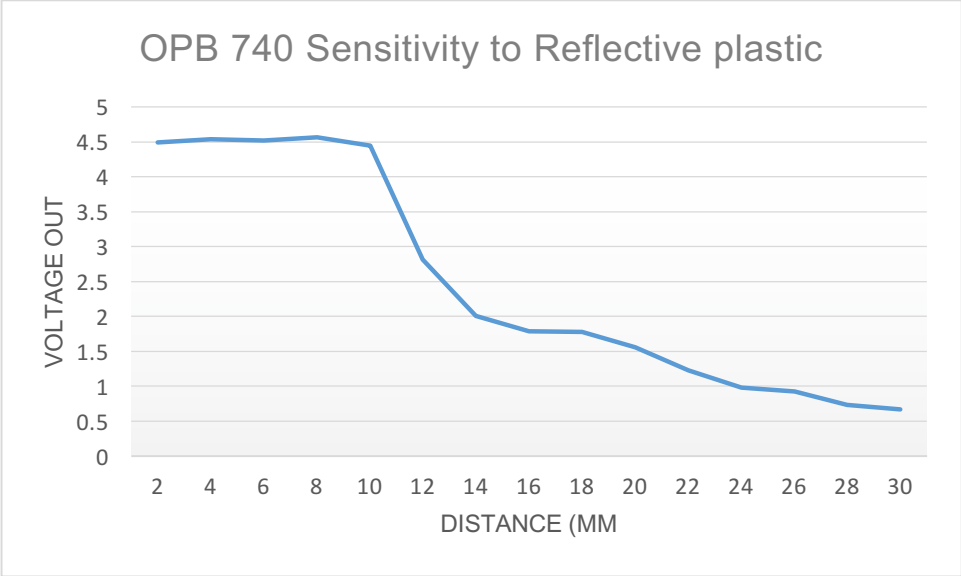


Figure 55: Reflective plastic Testing Results

Paper Test- The fourth test conducted with the OPB740 sensor was to test its sensitivity with reflective paper. As seen within the below figures it illutrated when the sensor has detected (4.37V) the paper and when it hasn't (1.33V).

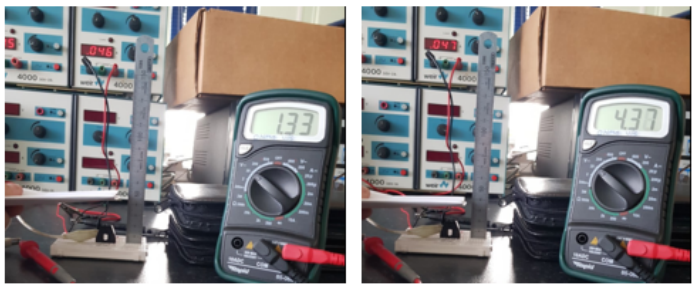


Figure 56: OPB740 Testing With Paper

As highlighted within the below graph, paper was fully detected by the OPB740 at 5mm showing 4.5V. To get to this point, the sensor increased its detection from 2mm to 5mm, ranging from 1.2V to 4.5V. From 7mm at 4.6V, the sensor detection slowly decreases until 17mm with the voltage remaining at just under

4V. After the 17mm stage, the voltage depletes and reduces from there on until 30mm at just below 1V.

Weekest detection point – 2mm, 28mm to 30mm

Strongest detection point – 5mm to 10mm

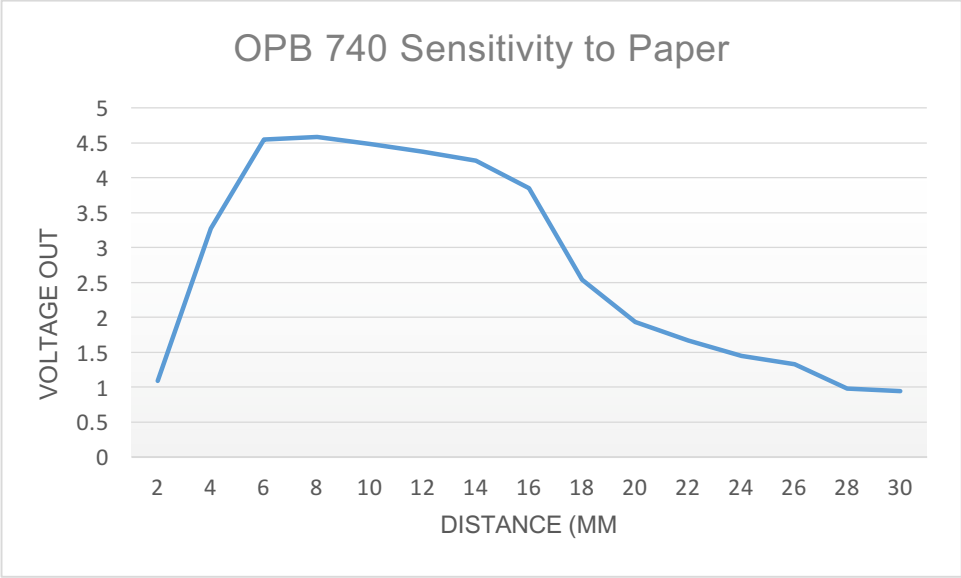


Figure 57: Paper Testing Results

Clear Plastic test - The fifth test conducted with the OPB740 sensor was to test its sensitivity with clear plastic. As seen within the below figures it illutrated when the sensor has detected (4.50V) the plastic and when its on the detection limit of the sensor (2.07V).



Figure 58: OPB740 Testing With Clear Plastic

The below graph is a reflection of the output produced by the OPB740. As seen, the strongest output from the sensor is between 8-10mm at 4.5 V. After 10mm, the voltage out from the sensor decrease dramatically until 14mm, dropping

2.5V. from 14mm to 30mm the voltage gradually drops off with just over 1V different between these two points

Weekest detection point – 14mm to 30mm

Strongest detection point – 8mm to 10mm

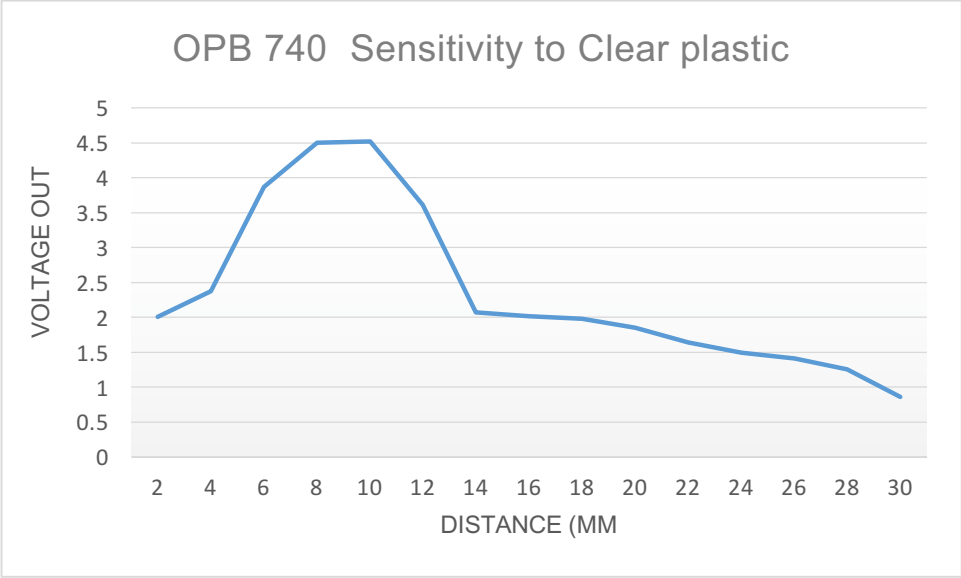


Figure 59: Clear Plastic Testing Results

White Plastic Test - The sixth test conducted with the OPB740 sensor was to test its sensitivity with whiter plastic. As seen within the below figures it illutrated when the sensor has detected (4.54V) the plastic and when its on the detection limit of the sensor (1.47V).



Figure 60: OPB740 Testing with White plastic

The below graph illistrated the reaction the OPB740 has to solid white plastic. The sensor is at its strongest from 6mm to 10mm at 4.5V, the sensor then drops 3V from 10mm to 12mm. From 12mm to 30mm, the voltage gradually drops from 1.5V to 0.75V.

Weekest detection point – 12mm to 30mm

Strongest detection point – 6mm to 10mm

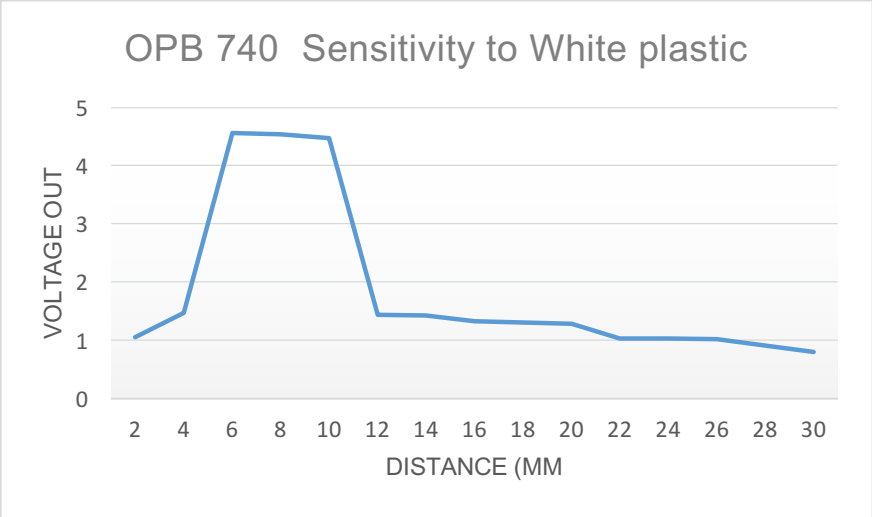


Figure 61: White Plastic Testing Results

Overall Comparison - As it can be seen in the below table, all of the results obtained from all six different materials tested. It can be seen from the highlighted numbers, 4V or more was chosen to be used as to when the detection is at its strongest. Cardboard is at its strongest from 8-12mm, paper from 6-14mm, clear plastic only from a small range of 8-10mm, white plastic also from a small range of 6-10mm, reflective plastic is seen to be at its strongest from a short distance ranging from 2-10mm and wood being within 6-14mm strong detection range.

The results show that the OPB740 sensor works, and operates as per its design. It also indicates that all materials tested will give an adequate read out to be logged as long as they are within their strongest measurement range. Paper, reflective plastic and wood are highlighted as the best materials to be used for the sensor due to all three having a range of 10mm where they are at the strongest. Reflective plastic must be used at a closer range to what paper and wood could be used.

OPB740 Testing						
Distance MM	Cardboard	Paper	Clear plastic	White plastic	Reflective plastic	Wood
2	2.36	1.09	2.01	1.05	4.49	1.23
4	2.53	3.27	2.37	1.47	4.54	3.65
6	2.09	4.55	3.87	4.56	4.52	4.52
8	4.42	4.58	4.5	4.54	4.57	4.54
10	4.47	4.48	4.52	4.47	4.45	4.56
12	4.55	4.37	3.61	1.44	2.82	4.45
14	3.65	4.24	2.07	1.43	2.01	4.33
16	2.58	3.85	2.02	1.33	1.79	3.87
18	1.37	2.54	1.98	1.3	1.78	3.46
20	1.33	1.93	1.85	1.28	1.56	2.26
22	1.24	1.67	1.64	1.03	1.23	1.26
24	0.91	1.45	1.49	1.03	0.98	1.24
26	0.87	1.33	1.41	1.02	0.93	1.2
28	0.69	0.98	1.25	0.91	0.73	1.04
30	0.65	0.94	0.86	0.8	0.67	0.54

Table 42: OPB740 Test Result Comparison

The below graph shows all of the results consulted together. As it can be seen, the dark blue, green and orange line within the plotted line graph are at the 4V region for the longer period.

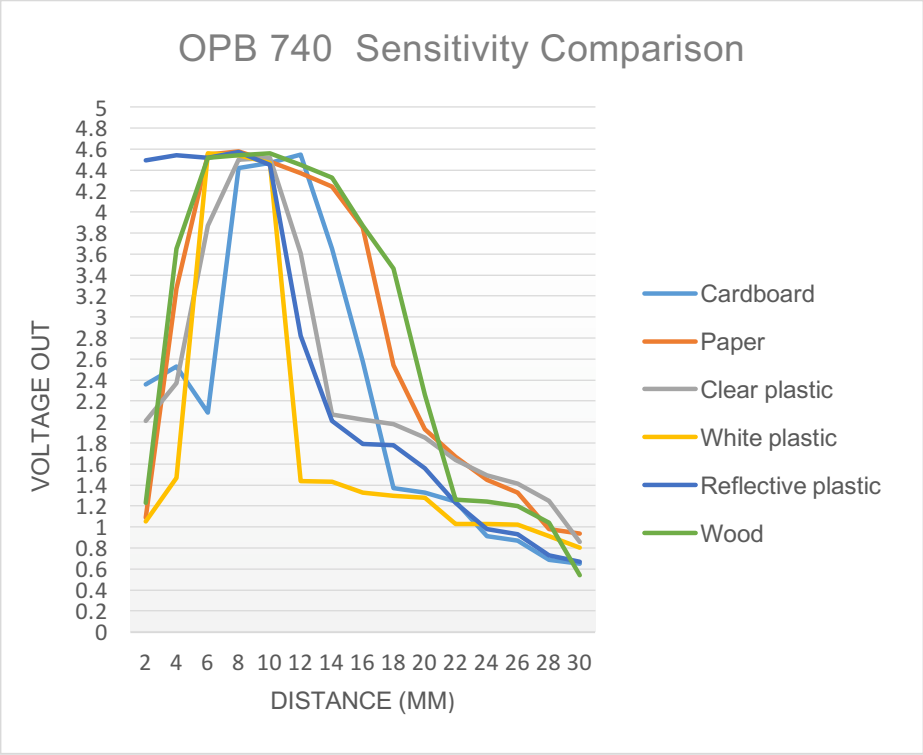


Figure 62: OPB740 Test Result Comparison

7.4 PWM Controller

Testing of the PWM controller ensured that the controller worked correctly with a pulsed output. This could be verified and analysed to ensure the system/motor would run at the required speed when the pot of the PWM controller was operated.

A test procedure was produced identifying the steps taken to test the PWM controller. The test/test procedure was also fully analysed.

7.4.1 Test procedure

Apparatus required:		
- PWM controller - Power supply - Oscilloscope - Camera - 24V motor		
Expected outcome of test – Control motor speed from 0 RPM – 2600 RPM		
Step	**Action**	**Comments**
1	Connect motor and PWM module to power 24V power supply	
2	Confirm motor operates and controls via the PWM module	Motor operation
3	Connect oscilloscope to PWM output and display the duty cycle of the modulation via channel 1	
4	Confirm the duty cycle controls at minimum setting, as close to 0%- 50%-100% in accordance with the PWM POT controller	
5	Analyse waveform	

Table 43: PWM Module test procedure

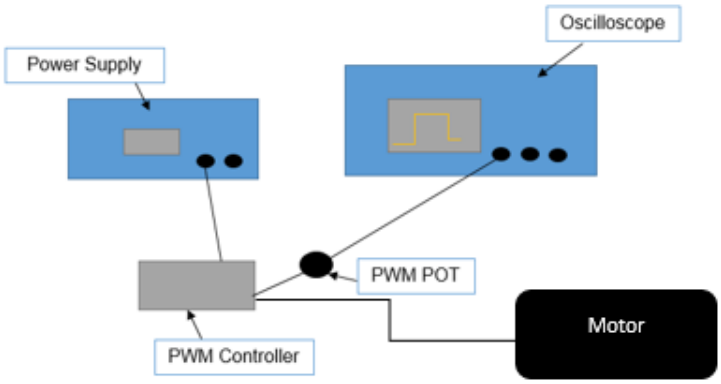


Figure 63: PWM Testing Layout

7.4.2 Test analysis

The below figure indicated the layout in which the test was conducted, this was the first time in which the motor had been connected to a power supply. A toggle switch was used to power on/off the PWM controller, a 15Amp fuse was also connected to aid protection.

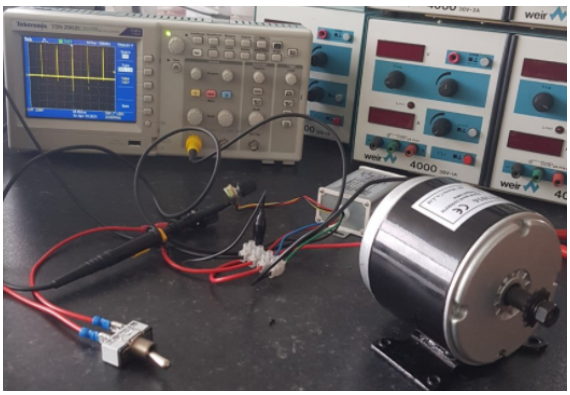


Figure 64: PWM controller, Motor and Oscilloscope Connected Together

Minimum Speed test - With the PWM pot set to the minimum range, the motor was still slightly turning at a very low speed. This can be seen in regards the oscilloscope output waveform within the figure below. It also refers to the duty cycle being at 1.48%, which explained why the motor was still turning slowly.

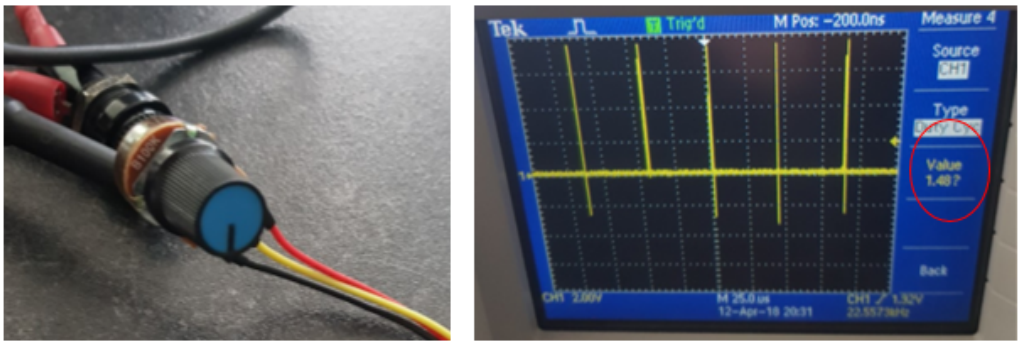


Figure 65: PWM Controlling at Minimum Setting

Half Speed - As seen in the figure below the PWM controller was tuned to around 50% (1300RPM) of the speed via the pot controller. This is also reflected on the oscilloscope output waveform, with the duty cycle also indicating 49.7%.

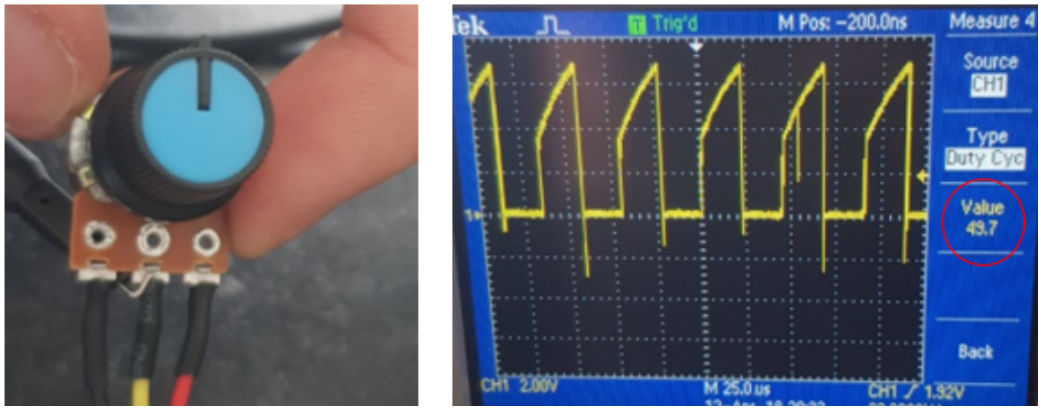


Figure 66: PWM Controlling at 50% Speed

Full Speed - The below output from the PWM controller set to 100% (2600RPM), shows the duty cycle only at 85.2%. The output speed will be at 100% but the torque produced will be at 85% – If a load was added the speed would slowly drop off.

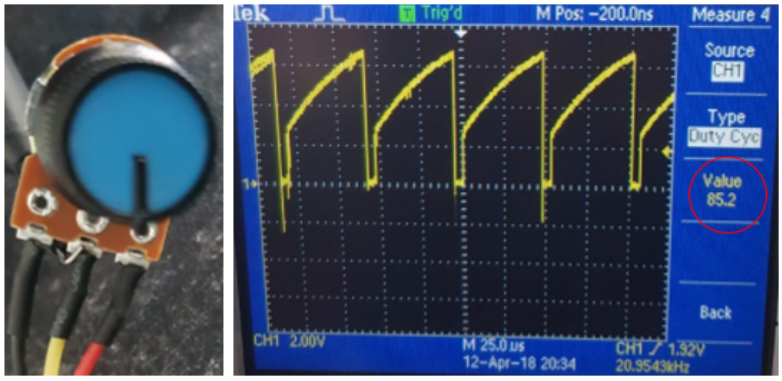


Figure 67: PWM Controlling at 100% Speed

As seen in the waveforms produced from the oscilloscope for all 0%, 50% and 100%, there is a slight curve before reaching its peak instead of a square ‘on’ ‘off’ waveform. This is due to the fact the PWM is charging the coil (inductor) at this point and cannot produce maximum ‘on’ output straight away. Once the waveform has its peak, the waveform discharges to the ‘off’ state. It can also be analysed that in some instances, there are signs of overshoot before the waveform steadies itself. This is produced from the discharging of the charged inductor.

7.5 Battery Testing

Testing the battery was required as the battery used was recycled so ensuring correct function after being charged was a must. The test also ensures that when the two 12V batteries are connected together it will provide 24V, as needed for the 24V prototype motor.

7.5.1 Test procedure

Apparatus required: - **2x12V batteries** - **Multi-meter** - **Link cable**		
Expected outcome of test – Ensure batteries give out full range of 12V & 24V		
Step	**Action**	**Comments**
1	Charge both 12v Batteries	Batteries 100% charges
2	Using multi-meter – measure across the negative and positive of both batteries, confirming 12V on both batteries	Both batteries are at 12V
3	Using linking cable – Connect negative on one of the 12v batteries to the positive of the 2nd battery	Connecting the batteries together
4	Using multi-meter – measure voltage across the open ended positive and negative of both batteries	
5	Confirm 24V present	Confirming the power supply is valid at 24V

Table 44: Battery Test procedure

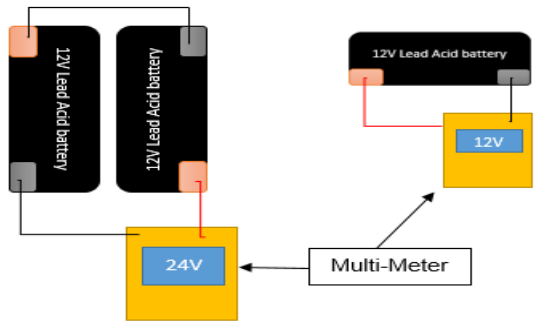


Figure 68: Battery Testing Layout

7.5.2 Test analysis

The tests carried out on the batteries gained the results that were expected. When the two batteries were fully charged, a multi-meter was placed across the positive and negative terminals to ensure a reading of 12V. This can be seen within the below figure.

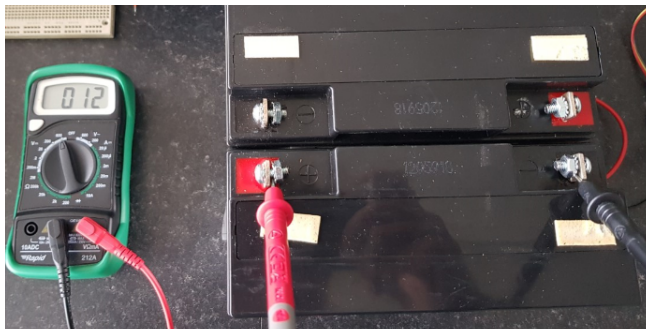


Figure 69: Testing 12V Battery

The below figure highlights how the two batteries connected together were tested. With the two batteries connected, a multi-meter was places across the positive and negative terminals of the two batteries, which provided a reading of 24V.

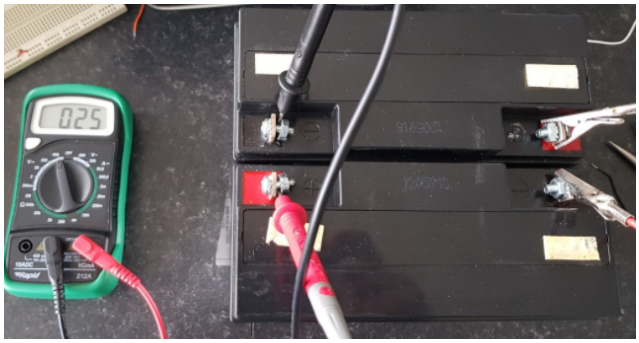


Figure 70: Testing 24V Battery

7.6 Motor Testing

The DC brushless motor was tested to analyse the motor temperature over a 35 minute period.

A test procedure below was used to test and document the testing of the DC motor. This test was then analysed and assessed.

7.6.1 Test procedure

Apparatus required: - 24V batteries, 24V motor, PWM module connected - RC-4 mini Temperature data logger - Stopwatch - Excel spreadsheet		
Expected outcome of test – Temperature increase of motor at different positions over a 35 minute period		
Step	**Action**	**Comments**
1	Strap RC-4 logger to the 24V Motor – Position 1	
2	Record standing temperature	
3	Start motor to 100% power and stop watch	Motor at full power/working load
4	Take a temperature reading every 1 minute for 35minutes	Log temperature readings on a spreadsheet
5	Power down motor and allow to cool down	Motor back to standing temperature
6	Repeat steps 1 through to 5 with the RC-4 logger measuring at a different reference points – Position 2	
7	Compare both results and analyse	

Table 45: DC Motor Test Procedure

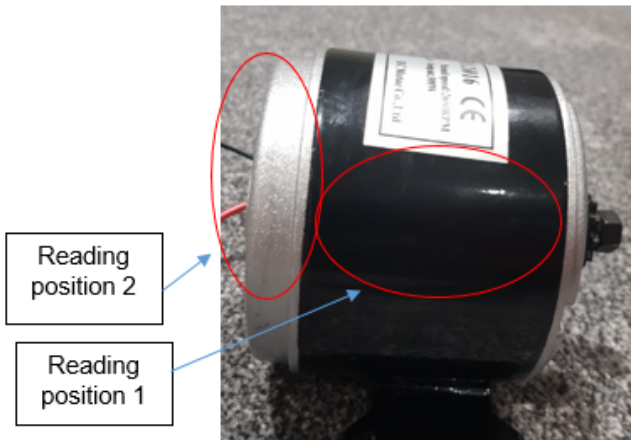


Figure 71: Motor Testing Positions

7.6.2 Test analysis

The below figure indicates how the motor testing was carried out. The two tests carried out were conducted on two different days due to allowing the motor to cool down to room temperature. The room temperature on the two different testing dates was only 0.1ºC of a difference, meaning the results were not overly affected.

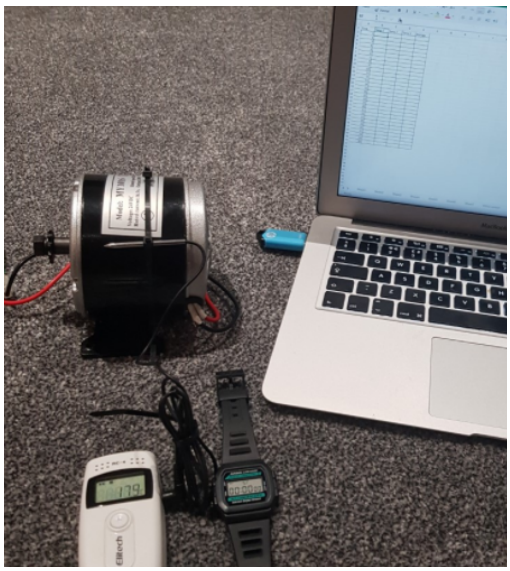


Figure 72: Motor Testing

Position 1 - As seen within the below figure, a graph was plotted reflecting the temperature range of the motor when measured at full speed over a test period of thirty-five minutes. With the temperature probe at position one which was the outside wall of the motor. The graph shows a gradual linear increase in temperature from 17.9°C to 39°C.

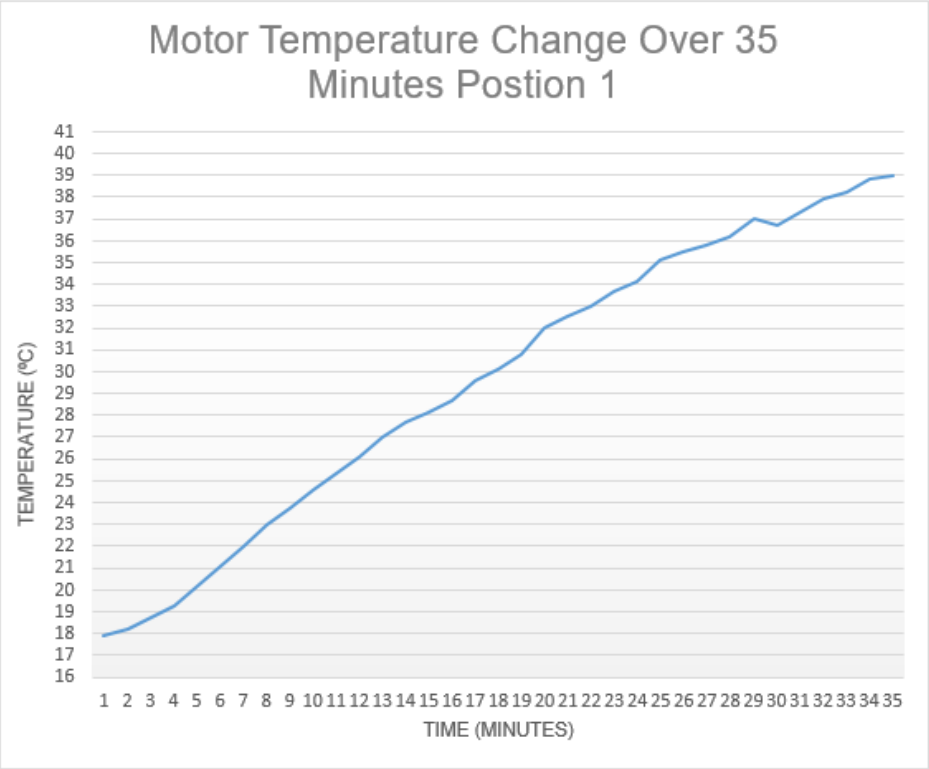


Figure 73: Motor Temperature Results 1

Position 2 - The same graph was plotted to reflect the temperatures recorded from position two shown on the rear of the motor. As seen within the below graph also showed the temperature increase gradually from 18°C to 39.6°C over a thirty-five-minute test.

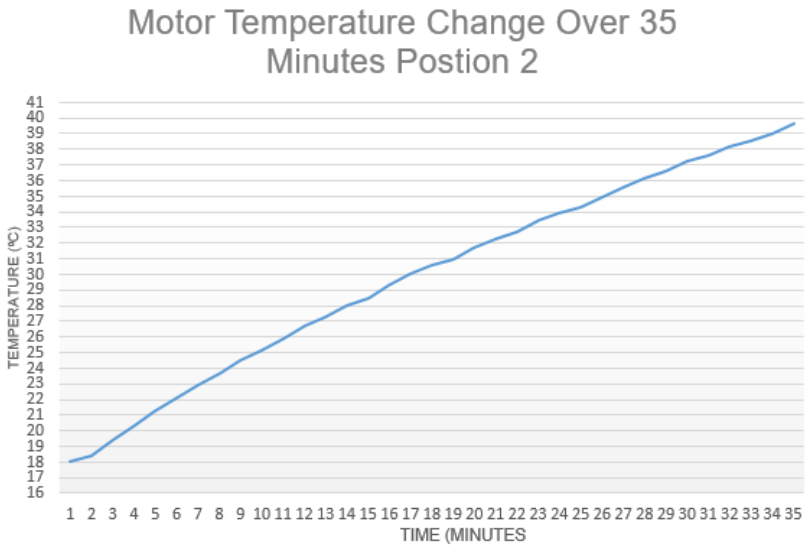


Figure 74: Motor Temperature Results 2

Overall Comparison - The table and comparison graph on the following page were a reflection of the two graphs produced for the separate tests. Position one and position two results can be seen within the graph and the difference in measurements are minimal. The results obtained from position two on the motor are reflected as a more gradual, smooth increase comparing with position ones results. The temperature shall be placed within position two of the final prototype design for this reason.

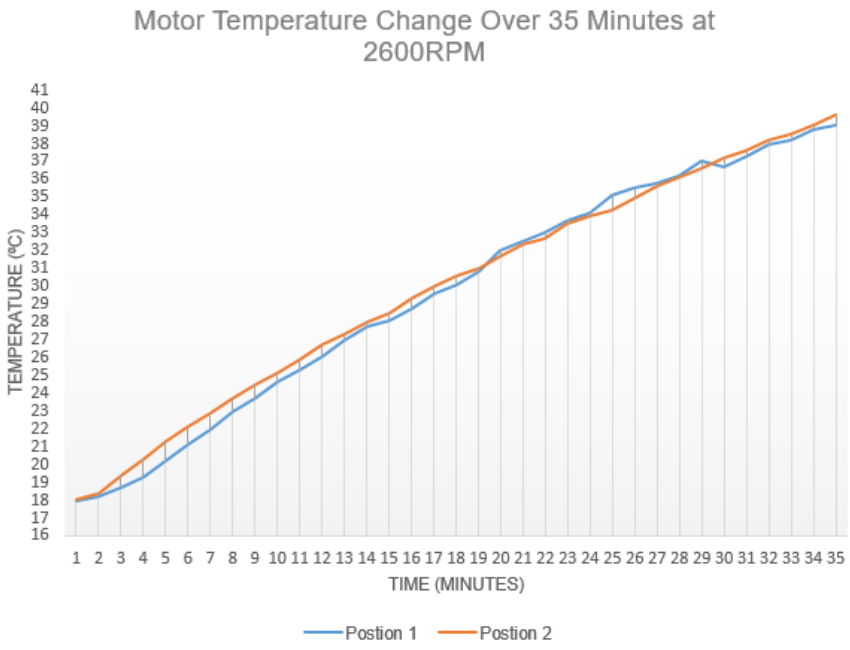


Figure 75: Motor Temperature Results

Motor Temperature Testing		
Time (mins)	Position 1	Position 2
1	17.9	18
2	18.2	18.4
3	18.7	19.4
4	19.3	20.3
5	20.2	21.3
6	21.1	22.1
7	22	22.9
8	23	23.7
9	23.7	24.5
10	24.6	25.1
11	25.3	25.9
12	26.1	26.7
13	27	27.3
14	27.7	28
15	28.1	28.5
16	28.7	29.3
17	29.6	30
18	30.1	30.6
19	30.8	31
20	32	31.7
21	32.5	32.3
22	33	32.7
23	33.7	33.5
24	34.1	33.9
25	35.1	34.3
26	35.5	34.9
27	35.8	35.6
28	36.2	36.1
29	37	36.6
30	36.7	37.2
31	37.3	37.6
32	37.9	38.2
33	38.2	38.5
34	38.8	39
35	39	39.6

Table 46: Motor Temperature Results

7.7 Conclusion – Component Testing

As discussed within the introduction of this chapter, only the key components were tested prior to any design work was taken place. The key components were identified as critical components to enable to outcome result of the Data Acquisition System successful and accurate. All other components are discussed within the implementation stage within chapter 9 of this report.

The tested conducted aided with the authors understanding on how the system would operate prior to the design works. It also ensured that any complications such as the LM35 sensor could be identified prior to the design and implementation stage.

Within the next chapter, the design and the design testing will be discussed. This covers both proteus, CCS, Easy PC, and physical designing and coding testing simulation carried out on proteus.

Chapter 8 – Design & Design Testing

8.1 Introduction - Design

Within this chapter the key aspects of the prototype was design as per the design specification and selected components. It was key to expand firstly on the systems flow diagram from the specification. This enabled the slow diagram to be more detailed and up to date to enable an accurate system layout in which the system design can be implemented.

The proteus design, easy-PC schematic and PCB design was also produced within this chapter along with the CCS coding for the final prototype. The CCS coding was tested in stages throughout the process of producing the final code, this was also discussed within this chapter.

As well as the software/hardware, a physical design was also produced to aid the prototype implementation section within chapter 9.

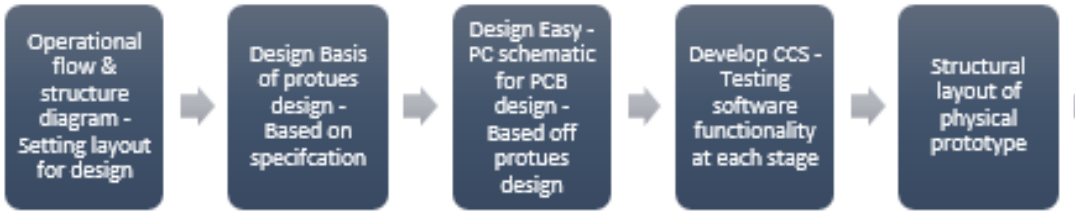


Figure 76: Designing process

8.2 Operational Flow Chart

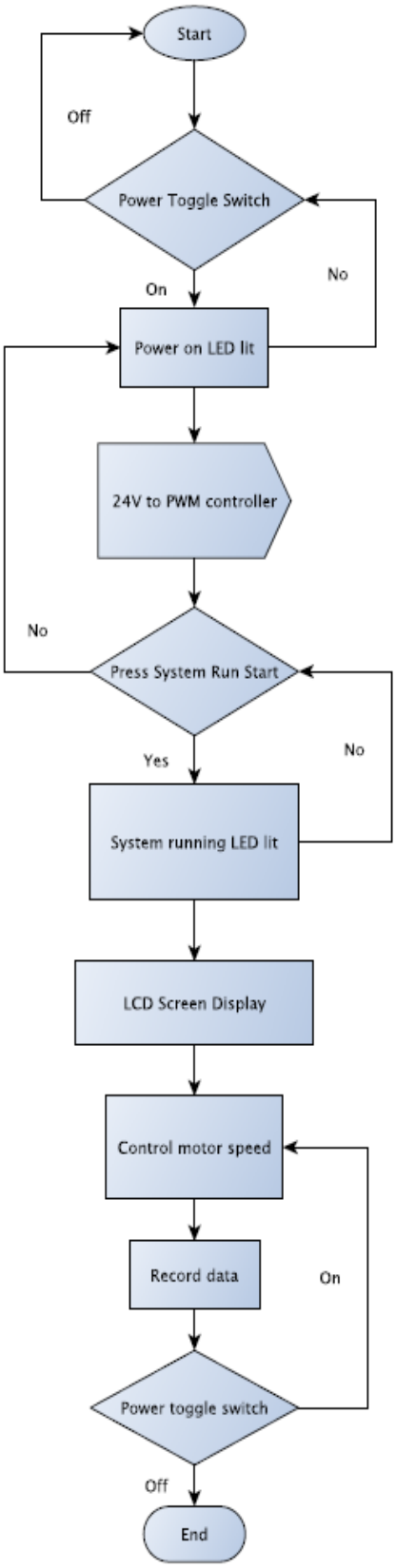


Figure 77: Operational Flow Chart

8.3 Structure Diagram

The structure diagram as shown below is how the software was produced within the prototype. As shown, all the inputs digital or analogue read back to the microcontroller, with the output from the microcontroller being the LCD screen and the RS232 connection – both displaying the read values.

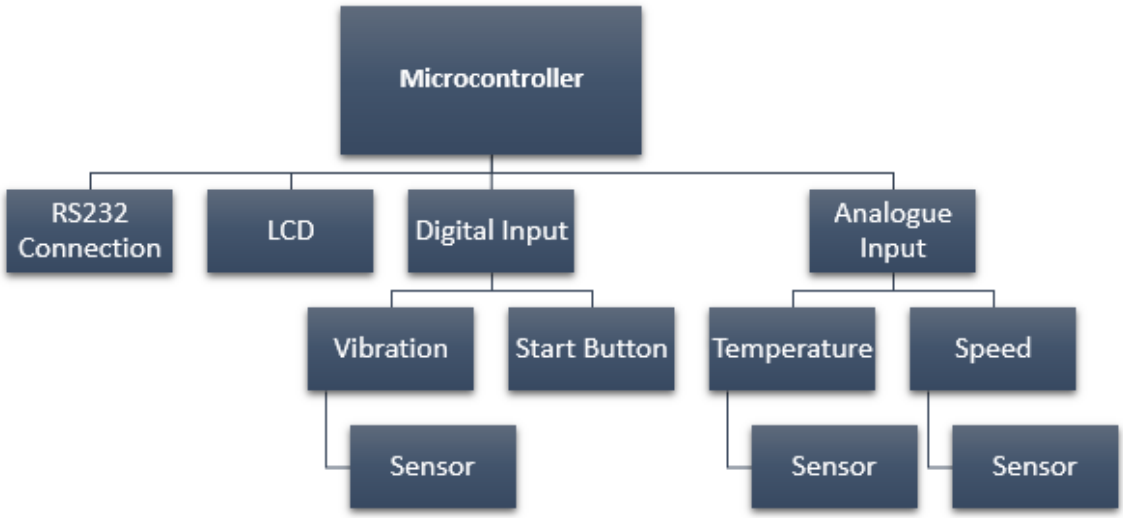


Figure 78: Structure Diagram

8.4 Proteus Design

The proteus design was the first to be produced, this was a schematic design of the Electric motor Data Acquisition System. Proteus was the most appropriate tool to produce the prototype acquisition system as well as being able to produce a schematic design of the system, it also has the capability to apply coding to the schematic.

8.4.1 Overall Design

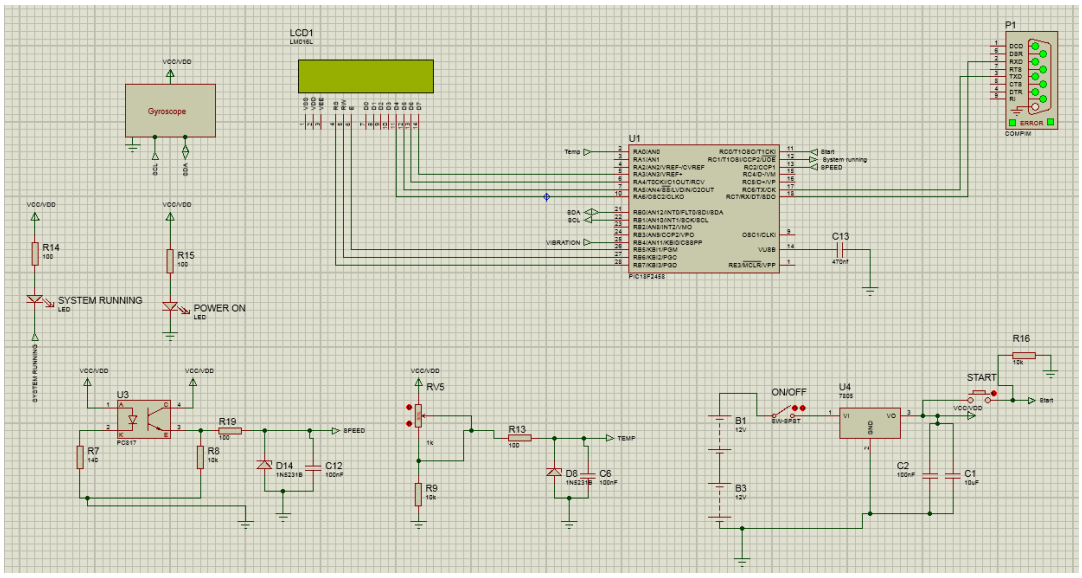


Figure 79: Overall Proteus Design

8.4.2 Speed Sensor

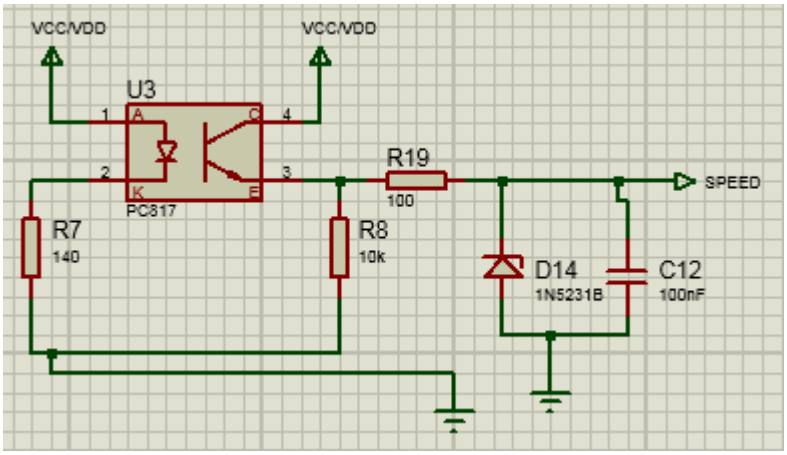


Figure 80: Proteus speed sensor design

8.4.3 Vibration Sensor

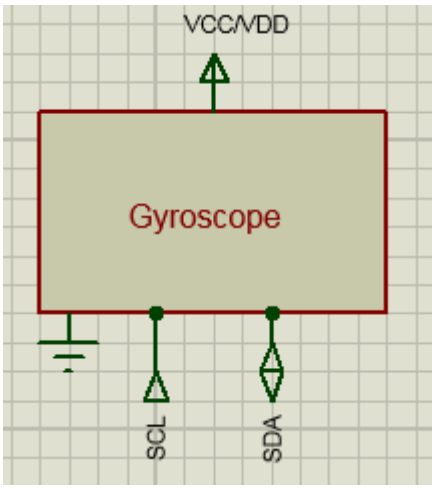


Figure 81: Proteus vibration sensor design

8.4.4 Temperature Sensor

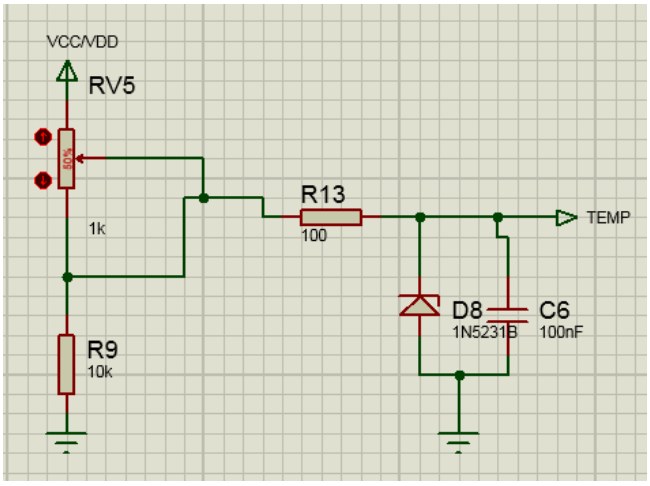


Figure 82: Proteus temperature sensor design

8.4.5 Power Supply

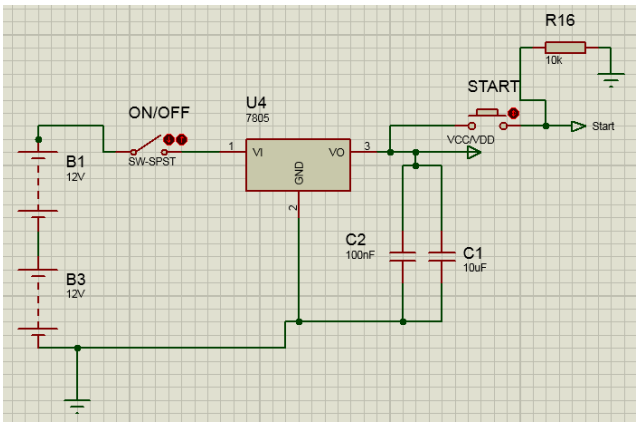


Figure 83: Proteus power supply design

8.4.6 Microcontroller

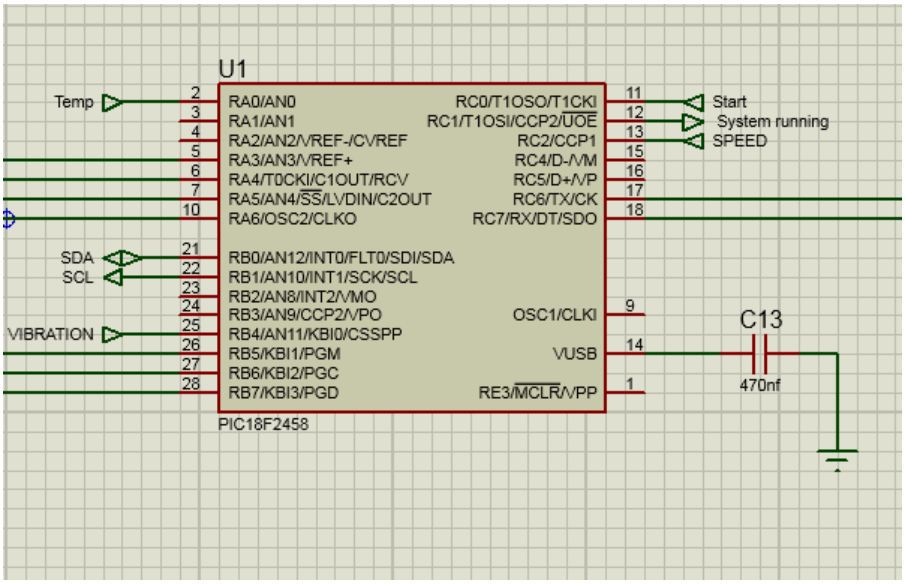


Figure 84: Proteus microcontroller design

8.4.7 Running Indication

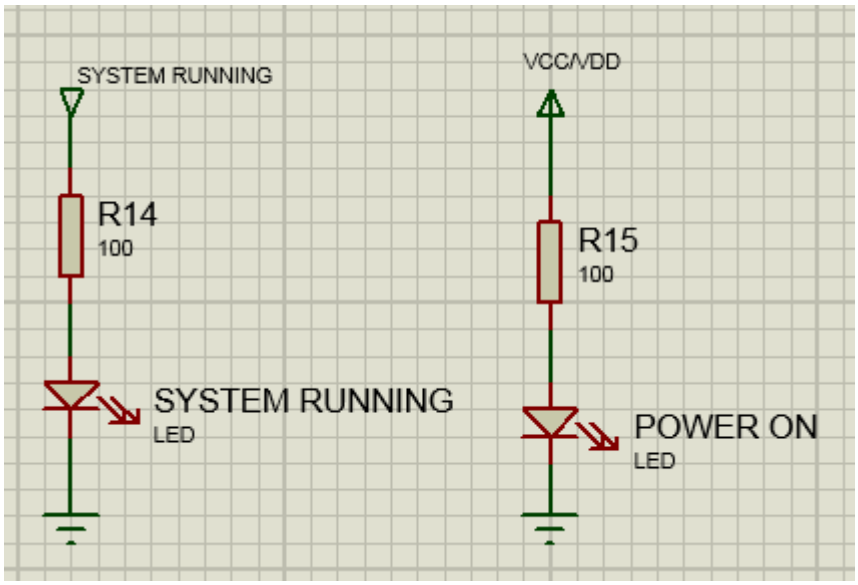


Figure 85: Proteus indication

8.4.8 RS232

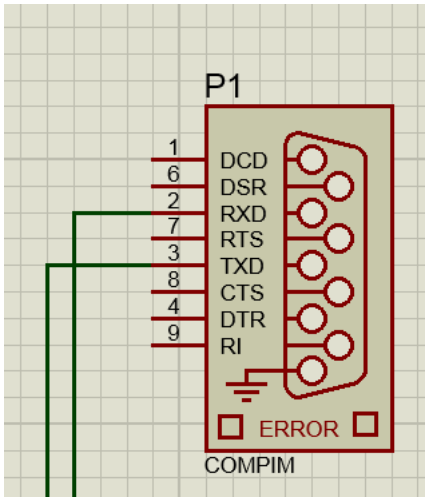


Figure 86: Proteus RS232

8.5 Easy-PC design

A Software called easy-PC was used to design the schematic of the original proteus design. This process was used to apply the design to the PCB structure. Within this schematic, all of the connectors and ‘nets’ such as 0V and 5V were specified to enable printing on the PCB.

8.5.1 Overall Design

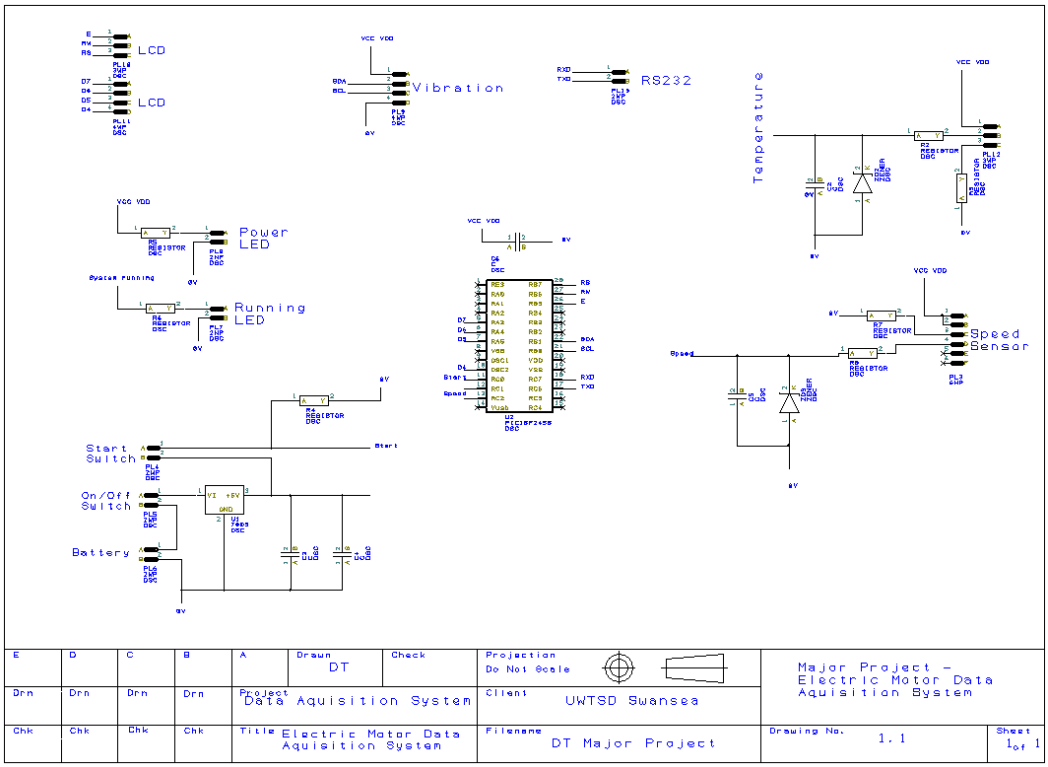


Figure 87: Overall Easy-PC design

8.5.2 Speed Sensor

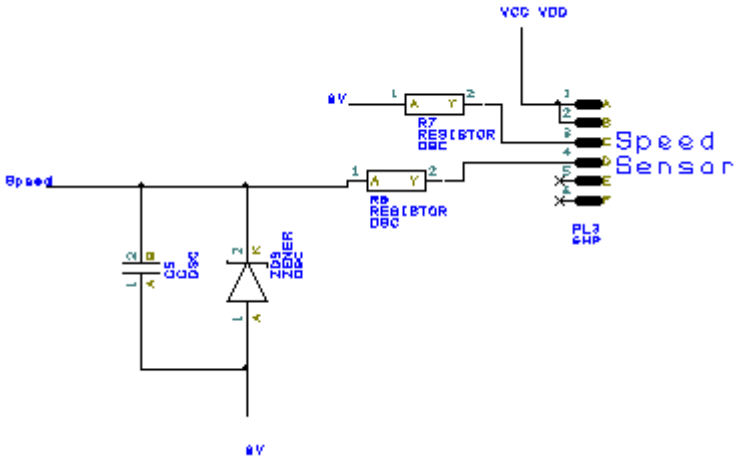


Figure 88: Easy-PC speed sensor

8.5.3 Vibration Sensor

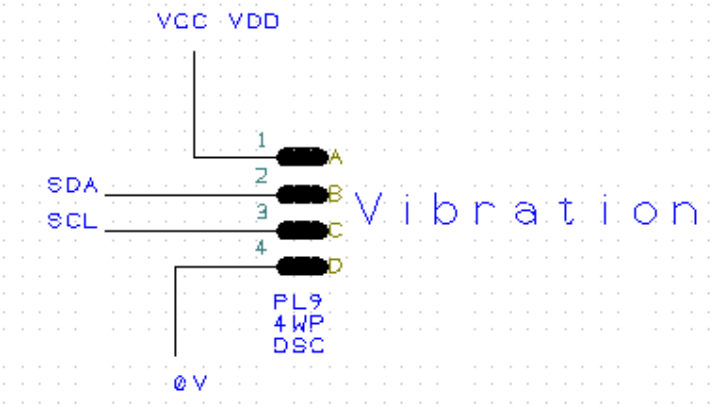


Figure 89: Easy-PC vibration sensor

8.5.4 Temperature Sensor

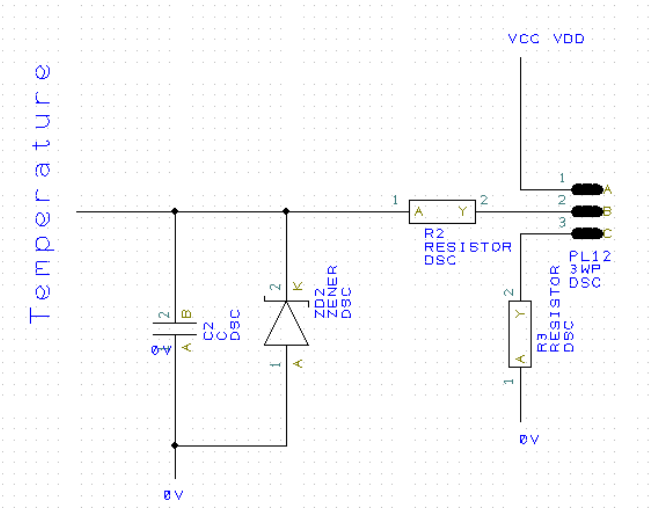


Figure 90: Easy-PC temperature sensor

8.5.5 Power Supply

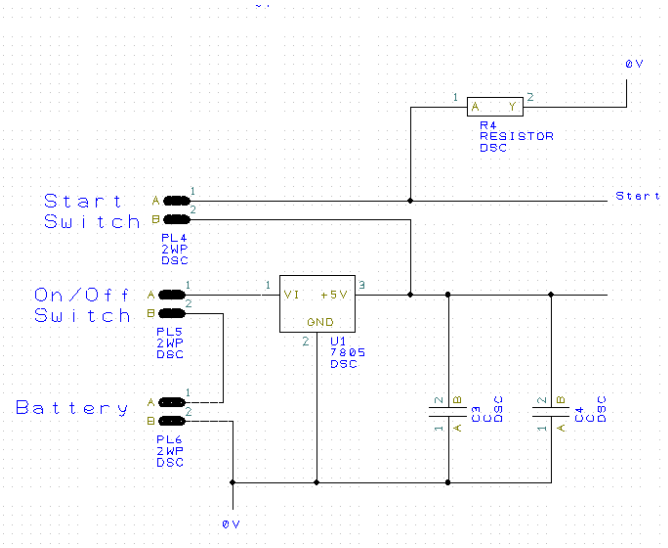


Figure 91: Easy- PC power supply

8.5.6 Microcontroller

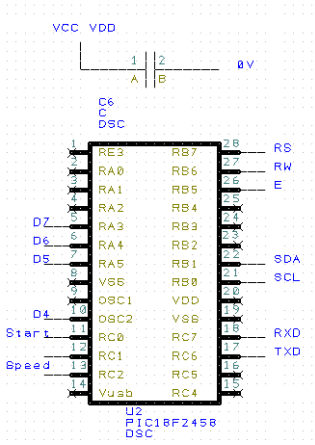


Figure 92: Easy-PC microcontroller

8.5.7 Running Indication

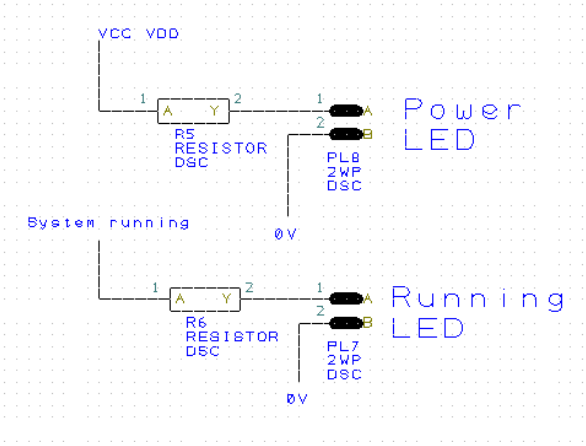


Figure 93: Easy-PC indication

8.5.8 RS232

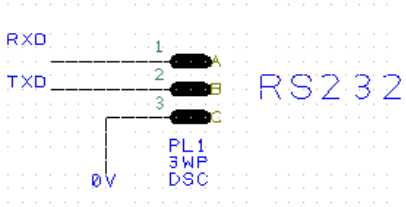


Figure 94: Easy-PC RS232

8.5.9 LCD

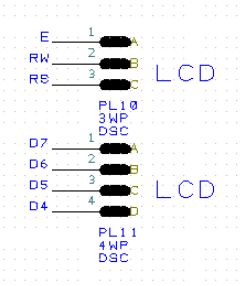


Figure 95: Easy-PC LCD connections

8.6 PCB Design

After the easy-PC schematic was produced and finalised, the design could then be translated to the PCB. The components were then organised in a sufficient enough way in which the layout minimised the size of the PCB but also being well presented and laid out. The copper layers of 0V and 5V were also applied. The below figures show the copper pour areas along with a final 3D design of the proposed PCB.

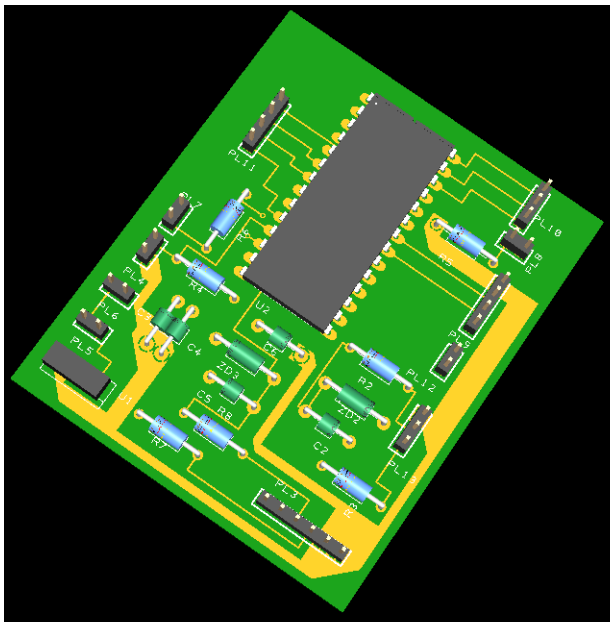


Figure 96: PCB 3D design

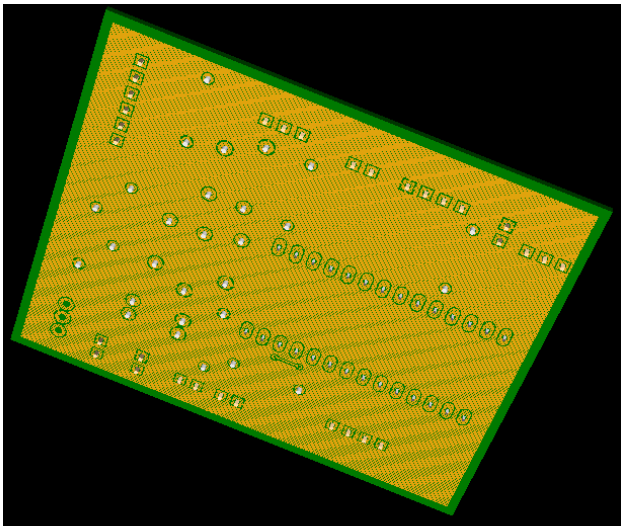


Figure 97: PCB 3D design - 0v copper pour

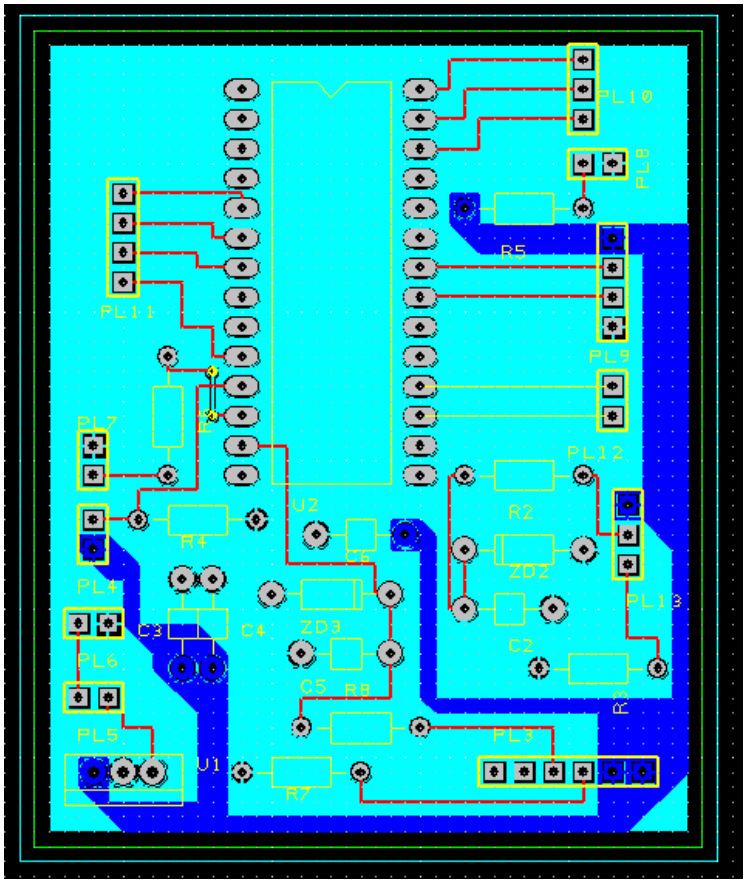


Figure 98: PCB 0v and 5v copper pour

8.7 CCS Design and Testing

As discussed within the design of the proteus schematic design, CCS was used to code the schematic design running the system as specified. Within this section of this design chapter, coding was produced to reflect the design requirements and specification. This coding was tested throughout each stage of the build on the proteus schematic design already produced enabling a simulation of correct operation.

8.7.1 CCS Development

Within this section, areas of interest and initial set up of the CCS has been demonstrated and discussed. All other coding can be found within the memory stick provided with this report.

Initial set-up

The below figure was the first step of CCS development, the figure illustrates how the CCS software was configured set up to read to the PIC18F2458, the LCD, RS232 communication, system on/start button and sensor reading. The line highlighted in yellow (line 2) shows how CCS was Programmed to read at 8 MHZ also.

```
1  #include <18F2458.h>
2  #device ADC=8
3
4  #FUSES FCMEN              //Fail-safe clock monitor enabled
5  #FUSES IESO               //Internal External Switch Over mode enabled
6  #FUSES NOPUT              //No Power Up Timer
7  #FUSES BROWNOUT_SW        //Brownout controlled by configuration bit in special file register
8  #FUSES BORV27             //Brownout reset at 2.7V
9  #FUSES VREGEN             //USB voltage regulator enabled
10 #FUSES NOPBADEN           //PORTB pins are configured as digital I/O on RESET
11 #FUSES LPT1OSC            //Timer1 configured for low-power operation
12 #FUSES NOMCLR             //Master Clear pin used for I/O
13 #FUSES STVREN             //Stack full/underflow will cause reset
14 #FUSES NOLVP              //No low voltage prgming, B3(PIC16) or B5(PIC18) used for I/O
15 #FUSES NOXINST            //Extended set extension and Indexed Addressing mode disabled (Legacy mode)
16 #FUSES NOPROTECT          //Code not protected from reading
17 #FUSES NOCPB              //No Boot Block code protection
18 #FUSES NOCPD              //No EE protection
19 #FUSES NOWRT              //Program memory not write protected
20 #FUSES NOWRTC             //Configuration registers not write protected
21 #FUSES NOWRTB             //Boot block not write protected
22 #FUSES NOWRTD             //Data EEPROM not write protected
23 #FUSES NOEBTR             //Memory not protected from table reads
24 #FUSES NOEBTRB            //Boot block not protected from table reads
25
26 #use delay(internal=8MHz)
27 #use rs232(baud=9600,parity=N,xmit=PIN_C6,rcv=PIN_C7,bits=8,stream=PORT1,errors)
28 #use i2c(Master,Fast,sda=PIN_B0,scl=PIN_B1,force_hw)
29
30 #define LED PIN_E3
31 #define DELAY 500
```

Figure 99: Initial CCS set-up

Then next two figures are used to test the operation and function of the communication between CCS and the proteus design. The first snippet of code demonstrates how the LCD connections were connected with the coding, along with flashing PIN A1, displaying ‘hello’ on the LCD to ensure correct function/operation.

```
#include <main.h>
#define LCD_ENABLE_PIN PIN_B5
#define LCD_RS_PIN PIN_B7
#define LCD_RW_PIN PIN_B6
#define LCD_DATA4 PIN_A6
#define LCD_DATA5 PIN_A5
#define LCD_DATA6 PIN_A4
#define LCD_DATA7 PIN_A3

#include <lcd.c>

void main()
{
    setup_adc_ports(AN0);
    setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUL_0);

  lcd_init();

    while(TRUE)
    {

        //Example blinking LED program
        output_low(PIN_A1);
        delay_ms(DELAY);
        output_high(PIN_A1);
        delay_ms(DELAY);

        //TODO: User Code

      printf(lcd_putc,"\ahello");
    }

}
```

Figure 100: CCS to LCD connections and 'hello' display

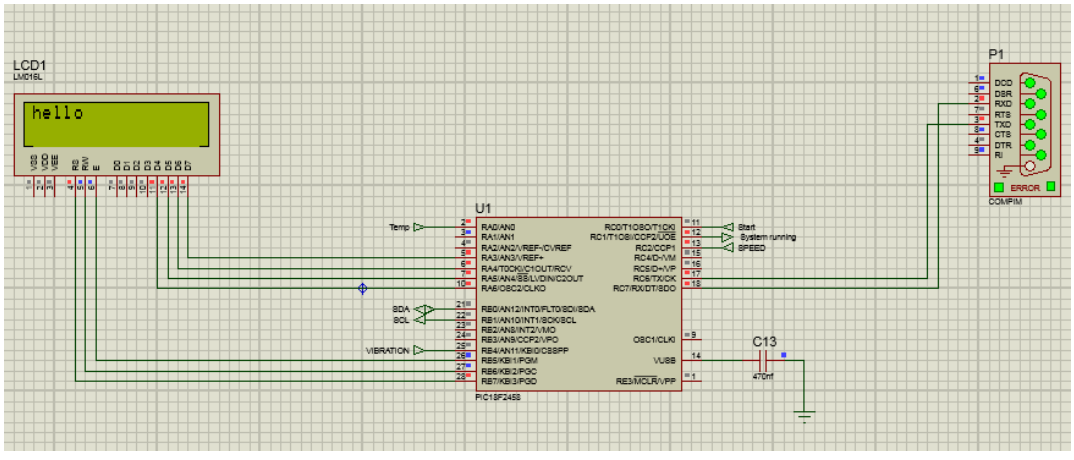


Figure 101: Proteus LCD communication

Once the CCS and proteus communication was confirmed, the initial ‘hello’ was set up as a default on every start-up of the system, allowing the user to know the system was being turned on. The below snippet of coding was produced to delay ‘hello’ for a period of 1 second before any other readings.

```
50      enable_interrupts(GLOBAL);
51
52    lcd_init();
53        printf(lcd_putc,"\ahello");
54        delay_ms(1000);
55        printf(lcd_putc,"\f");
56      while(TRUE)
57      {
```

Figure 102: Printing 'hello' for 1 second

Temperature reading

Once the setup of the initial start-up display and communications were confirmed. It was then necessary to start developing the sensors to also be displayed and communicated. Below it can be seen, ‘temp’ was defined at the start of the code.

```
10  #include <lcd.c>
11
12  void read_temp(void);
13  void read_rpm(void);
14
```

Figure 103: 'temp' defined

```
40
41  void main()
42  {
43      setup_adc_ports(AN0);
44      setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUL_0);
45      setup_timer_2(T2_DIV_BY_16,195,16);      //1.5 ms overflow, 25.0 ms interrupt
46
47
48      enable_interrupts(INT_TIMER2);
49      enable_interrupts(INT_EXT2);
50      enable_interrupts(GLOBAL);
51
52    lcd_init();
53        printf(lcd_putc,"\ahello");
54        delay_ms(1000);
55        printf(lcd_putc,"\f");
56      while(TRUE)
57      {
58
59
60          read_temp();                    // call temp subroutine
61          read_rpm();
62      }
63
64  }
65
66  void read_temp(void)
67  {
68    unsigned int value=0;
69
70    set_adc_channel(0);
71    delay_us(10);
72    value = read_adc();
73    lcd_gotoxy(1,1);
74    printf(lcd_putc,"Temp-%2U",(value/2));
75
```

Figure 104: Temperature sensor CCS set up

It can be seen above, ‘gotoxy(1.1)’ is the position the ‘temp’ reading will be displayed on the LCD, (1.1) indicating the top left of the screen. It can also be demonstrated that, a 127ºC temperature swing was produced due to the Microcontroller being 8 bit = 256 so (value/2) divides this by 2 and giving a 127ºC swing.

RPM readings

Like ‘temp’, ‘rpm’ had to be defined at the start of the code, as seen below.

```
10  #include <lcd.c>
11
12  void read_temp(void);
13  void read_rpm(void);
14
```

Figure 105: 'rpm' defined

```
void main()
{
    setup_adc_ports(AN0);
    setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUL_0);
    setup_timer_2(T2_DIV_BY_16,195,16);      //1.5 ms overflow, 25.0 ms interrupt


    enable_interrupts(INT_TIMER2);
    enable_interrupts(INT_EXT2);
    enable_interrupts(GLOBAL);

  lcd_init();
      printf(lcd_putc,"\ahello");
      delay_ms(1000);
      printf(lcd_putc,"\f");
    while(TRUE)
    {

      read_temp();                    // call temp subroutine
      read_rpm();
    }

}

void read_temp(void)
 {
   unsigned int value=0;

   set_adc_channel(0);
   delay_us(10);
   value = read_adc();
   lcd_gotoxy(1,1);
   printf(lcd_putc,"Temp-%2U",(value/2));

 }


 void read_rpm(void)
   {
      unsigned int value=0;
      if(flag)
         {
            value=counter;
            counter=0;
            flag=0;
             lcd_gotoxy(9,1);
             printf(lcd_putc,"RPM-%4Ld",((long) value*30));
         }
   }
```

Figure 106: RPM set up on CCS

The below bullet points outline how the RPM sensor was set up within CCS:

- ‘void read_rpm(void)’ was defined as the function for reading the RPM sensor, type void was started as an output was not expected.
- Unsigned in value = 0; setting a variable called value – only a whole number – set to 0
- Delay_us(10); - waiting 10 micro seconds for a reading
- Value=read_adc(); - looking at the value coming in on the defined pin of the microcontroller which set to value
- ‘gotoxy(9,1)’ positions the reading on the top right of the LCD screen
- Value’30 is the greatest value obtainable but still adequate for the 2600RPM motor used on the prototype

Vibration reading

The Gyroscope was also set up within CCS, but this sensor was and I2C sensor, unlike RPM and temperature being analogue. It was noticed at this stage, how complex the data sheet was for the gyroscope picked and purchased. At this stage, a conscious decision was made to produce the set up and test the setup of the gyroscope within proteus but not produce the actual coding required for the sensor as the data could not be understood, even with guidance from project supervision.

```
// write data for gyro simulation to i2c mem
    i2c_start();                    // send i2c start
    i2c_write(0xa0);                // write to the i2c memory
    i2c_write(0x3e);                // write to low order byte
    i2c_write(4);                   // low order fifo output
    i2c_write(0x01);                // high order fifo output
    i2c_stop();
```

Figure 107: Gyroscope set-up on CCS

```
void init_gyro(void)
]    {
       // initiate the gyro
     }


void read_gyro(void)
]    {
      char low,high;
       unsigned long gyro_out;
       //read from gyro (this is a simulation using 24lc08
       i2c_start();              // set start condition;
       i2c_write(0xa0);          //write i2c memory address
                                          // change to gyro adress
       i2c_write(0x3e);          //write i2c data address
       i2c_start();
       i2c_write(0xa1);          //write i2c memory address
                                          // change to gyro adres
       low=i2c_read(1);
       high=i2c_read(0);
       i2c_stop();
       gyro_out=high;
       gyro_out*=256;
       gyro_out+=low;
       gyro_out/=65;

       lcd_gotoxy(1,2);
       printf(lcd_putc,"vib %Lu   ",gyro_out);

     }
```

Figure 108: Set up of the gyroscope on CCS, communication with the LCD

The coding produced above was the outline of what was required for the LCD to print the vibration sensor, as well as the high and low values obtained from the sensor. The sections *'//Change to gyro address'* has been added to illustrate where the actual sensors coding would need to be added if the time arose.

8.7.2 Temperature Sensor Testing

To test the operation of the software side of the temperature sensor set up, a voltage point was taken from the output of the simulated temperature variable resister that was used on the original design. As the LM35 temperature sensor set to be used gave 10mV for ever degree, a 4k resister was also added in series with the variable resister. This was to enable to variable resister to range from 0°C -100°C = 0V to 1V. This could then be read by the voltage point added to the proteus design, this can be seen in the figure below.

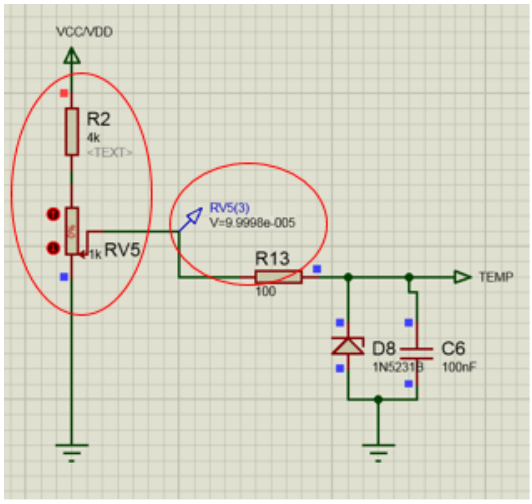


Figure 109: Proteus Measuring Testing Points

As seen in the below figure, when the variable resister is at 0%, the voltage is at 0V and the ‘temp’ read out on the LCD is 0°C. The below figure also highlights that when the variable resister is at 100%, the voltage out is at 0.99V which is close enough to 1V, and the ‘temp’ display on the LCD also shows 100°C. This indicates that the coding and connections within the proteus design works correctly.

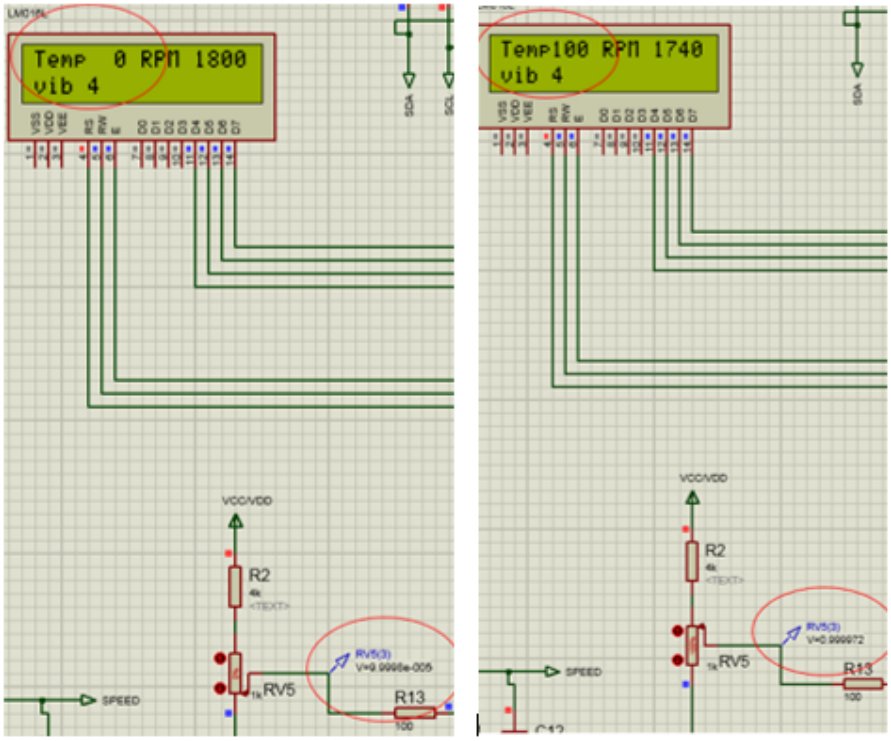


Figure 110: Proteus Temperature Testing

The test carried out within the above figures was carried out through 0% of the variable resister to 100%, conferring with the voltage out and what was displayed on the LCD. The results from this can be seen below.

Variable resistor position	Voltage out	LCD display
0%	1.00E-04	0
5%	0.05	4
10%	0.0999999	10
15%	0.15	14
20%	0.2	20
25%	0.249999	24
30%	0.299999	30
35%	0.349999	34
40%	0.399999	40
45%	0.44998	46
50%	0.499998	49
55%	0.549997	55
60%	0.599997	59
65%	0.649996	65
70%	0.99996	69
75%	0.749995	71
80%	0.799995	79
85%	0.84994	85
90%	0.899993	91
95%	0.949993	95
100%	0.999972	100

Table 47: Proteus Temperature Sensor Results

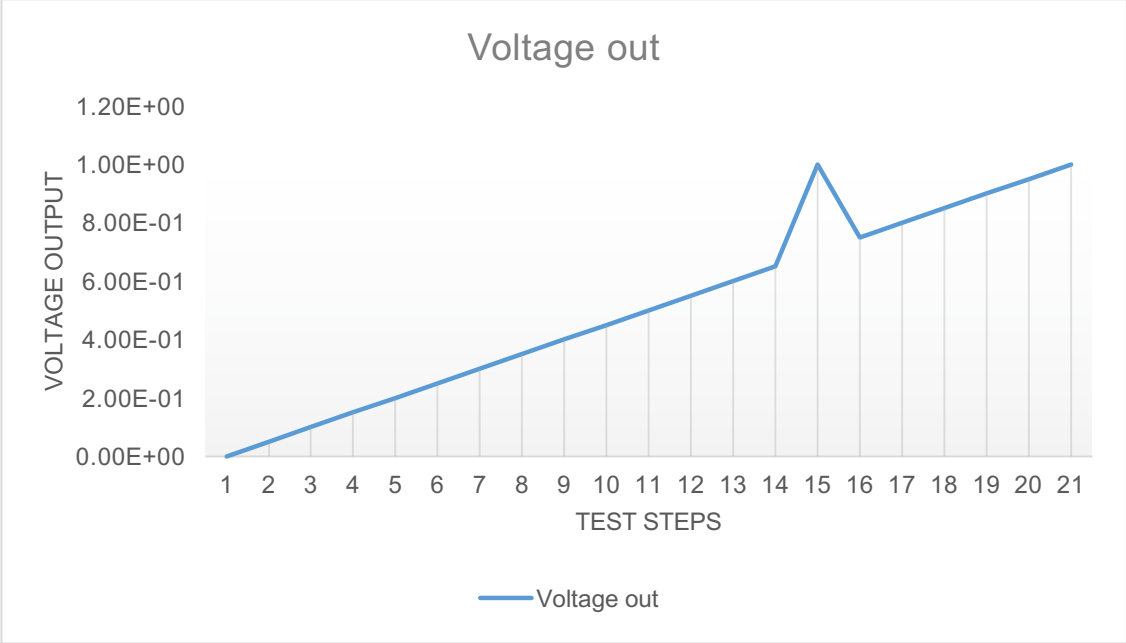


Figure 111: Proteus Temperature Sensor Testing 1

As seen in the above graph of 'voltage out', this reflected the voltage out against each test step conducted. The output in linear, ranging from below 0V to near 1V output which will be inputted into the microcontroller. It is noted the spoke in results at step 15 of the test. This is an ambiguous reading. The test was carried out again, and this ambiguous spike was not present.

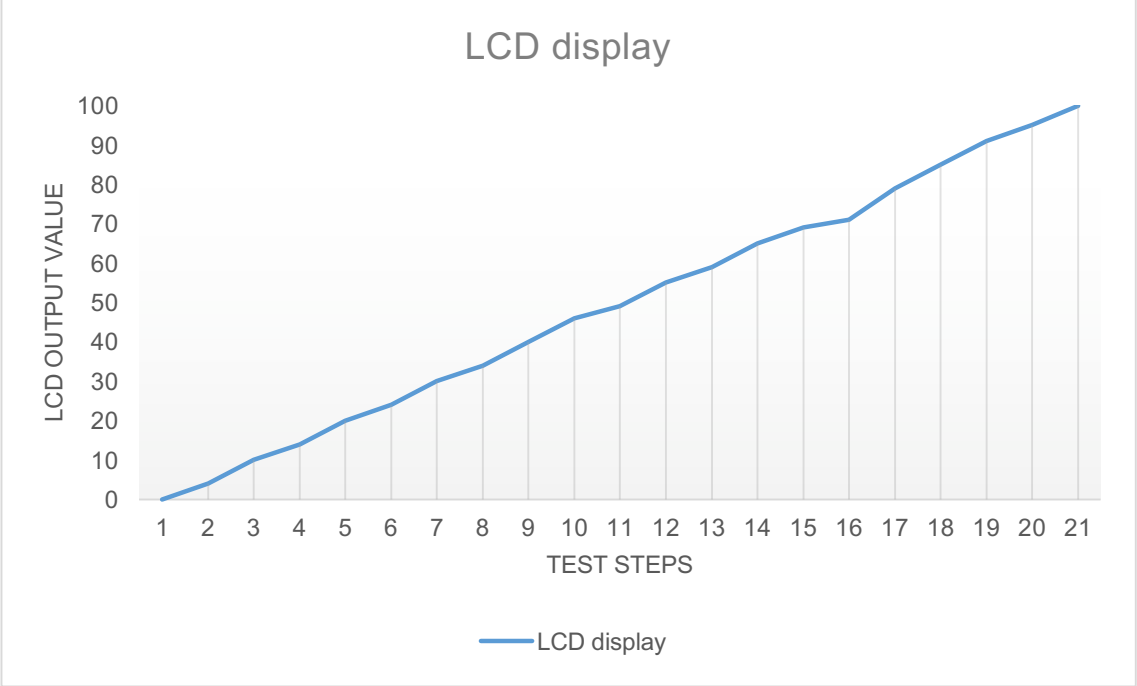


Figure 112: Proteus Temperature Sensor Testing 2

The above figure of ‘LCD display’ reflects the output displayed on the LCD against the 21 steps of the test that was conducted. It can be seen that this graph gradually rises from 0 to 100 from steps 1-21, as expected.

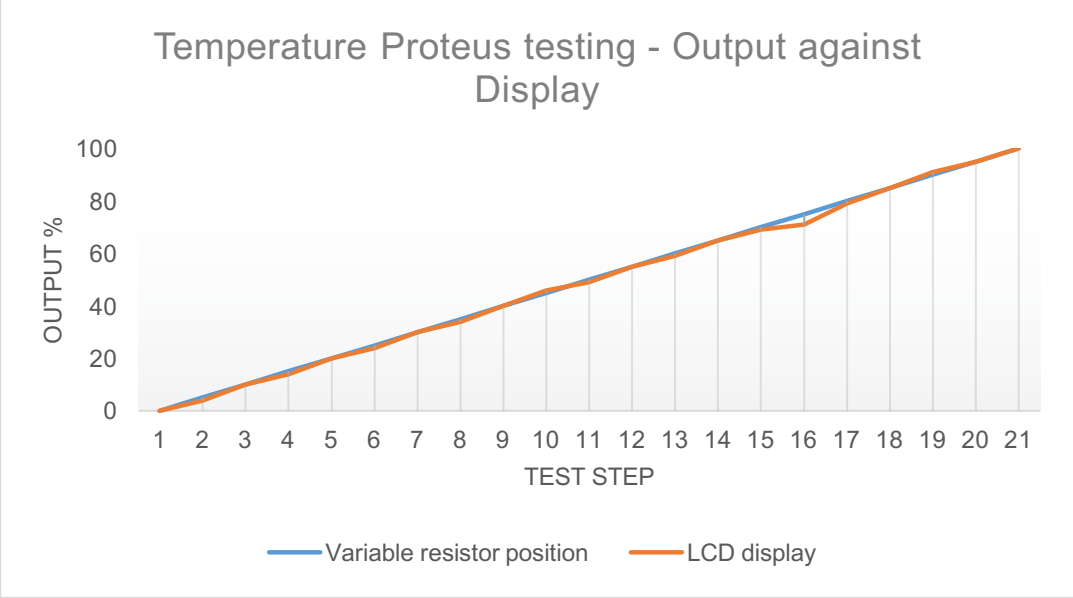


Figure 113: Proteus Temperature Sensor Testing Comparison

The above graph reflects and compares the output from the LCD and the position on the variable resister. It can be seen that both outcomes are similar, rising together from sets 1 to 21 from 0% to 100%. This is a clear indication that the system is working correctly.

8.7.3 Vibration Sensor Testing

The vibration sensor was also tested within proteus to ensure correct and accurate operation. As discussed previously within this chapter, the actual coding of the gyroscope intended to be used was not inputted into CCS. For this testing, manual inputted figures will be inputted into the CCS coding to be displayed.

The below snippet gathered from the proteus software illustrated the function test carried out confirming the communication between the I2C sensor and the RS232 output.

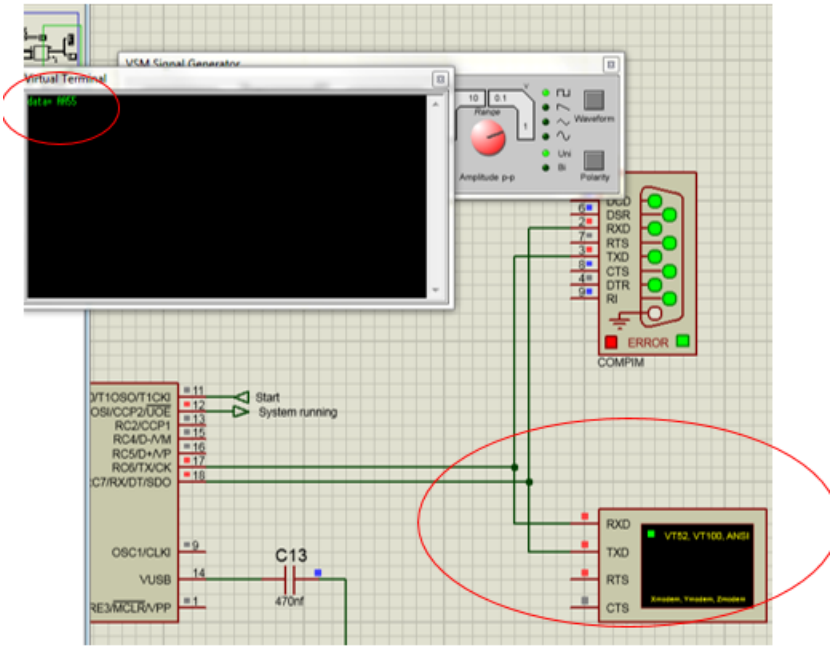


Figure 114: I2C sensor testing to RS232 communication

The below snippet of coding reflects the manual input of figures to ensure the vibration section of the LCD functions correctly. As seen, 4 is displayed within the LCD and this is what was intended to be written from the coding. This confirms the function of this setup.

```
void main()
{

    // write data for gyro simulation to i2c mem
        i2c_start();                    // send i2c start
        i2c_write(0xa0);                // write to the i2c memory
        i2c_write(0x3e);                // write to low order byte
        i2c_write(4);                   // low order fifo output
        i2c_write(0x01);                // high order fifo output
        i2c_stop();
```

Figure 115: Vibration sensor testing on CCS

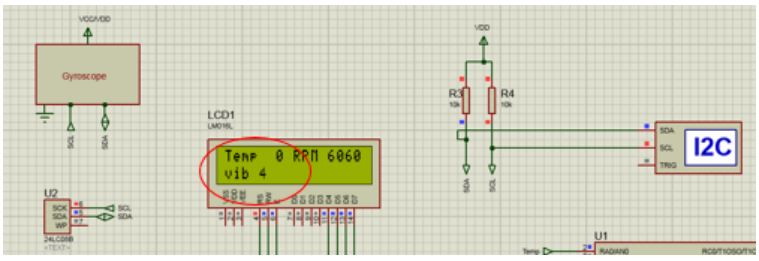


Figure 116: Vibration sensor testing on Proteus

8.7.4 Speed Sensor Testing

To test the Speed senor on proteus, a signal generator was connected to the sensor to generate a signal intended to reflect the information being gathered. This can be seen on the below snippets.

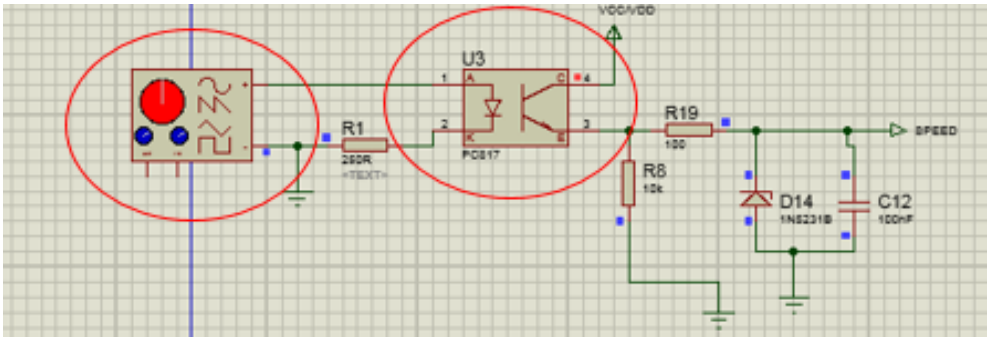


Figure 117: Speed Sensor Proteus Test

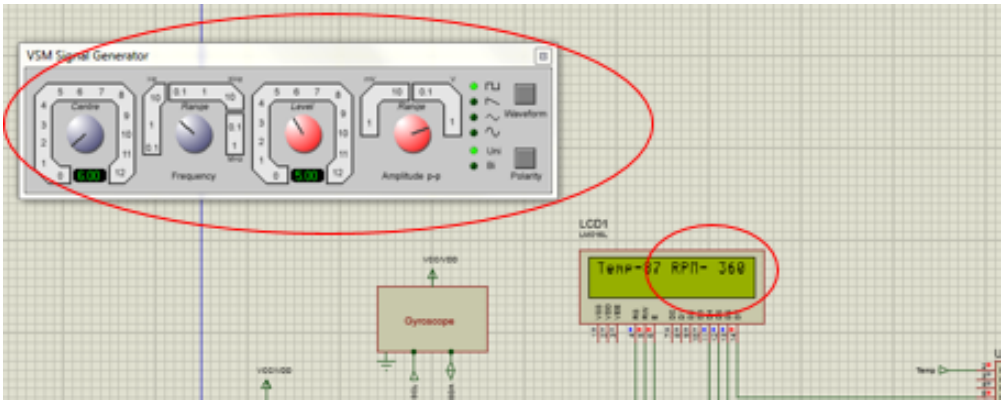


Figure 118: Speed Sensor Proteus Signal Generator

The output from the signal generator, and comparing this with the LCD display output was produced in the below table and reflected within graphs also seen. The test was produced from 0-1200HZ, this is where the signal generator maxed out.

Signal Generator Output (Hz)	LCD Display
0	0
50	300
100	600
150	900
200	1200
250	1500
300	1800
350	2100
400	2400
450	2700
500	3000
550	3300
600	3600
650	3900
700	4200
750	4500
800	4800
850	5100
900	5400
950	5700
1000	6000
1050	6300
1100	6600
1150	6900
1200	7200

Table 48: Proteus Speed Sensor Test Results

The below graph reflects the signal generator frequency output. This was tested over 25 steps, ranging from 0 to 1200Hz.

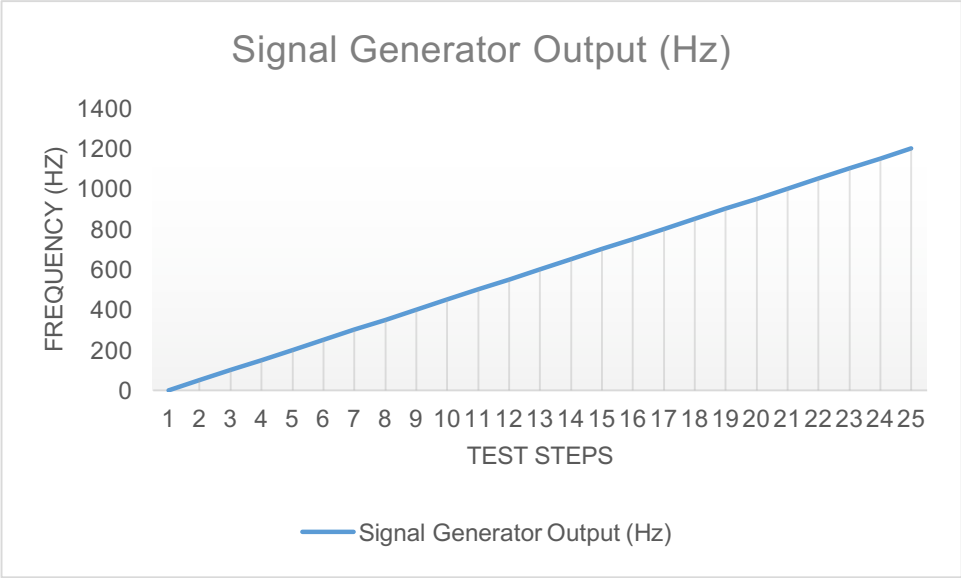


Figure 119: Speed Sensor Proteus Signal Generator Output

The below graph also reflects results obtained but now being the output from the LCD display, this is a gradual increase, ranging from 0 to 7200 being displayed over a 25 step test.

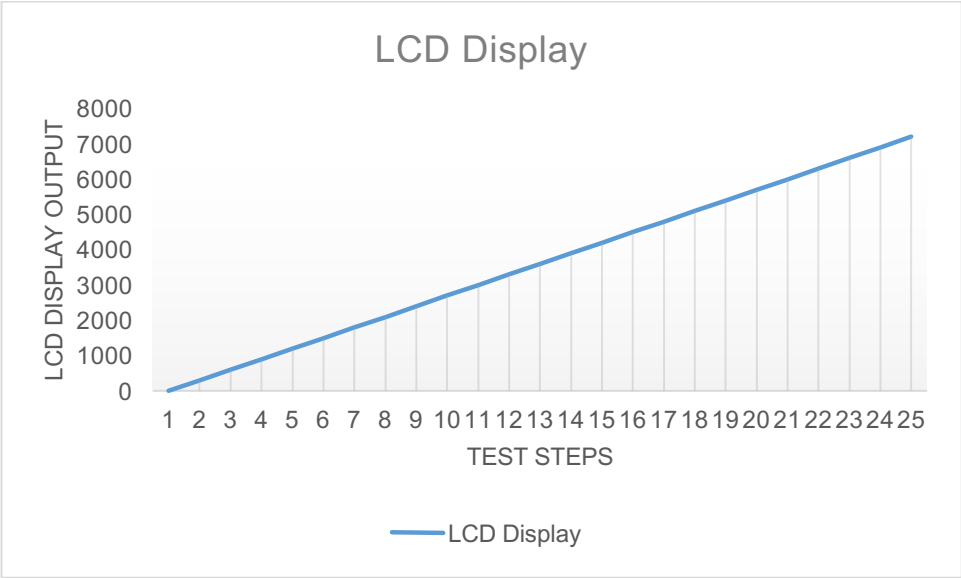


Figure 120: Speed Sensor Proteus LCD Output

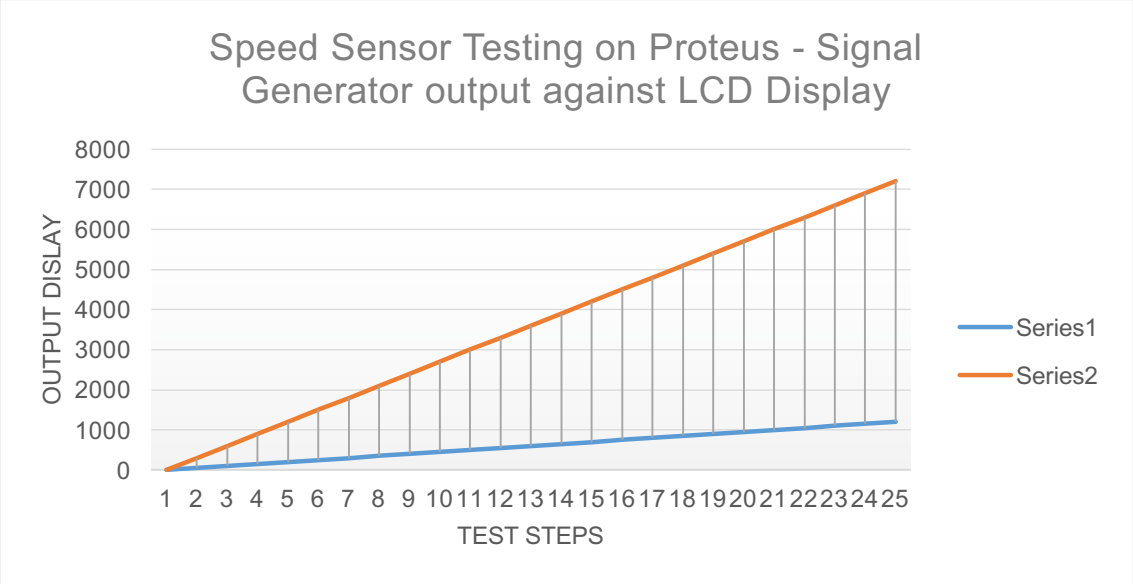


Figure 121: Speed sensor Test on Proteus Comparison

The above graph reflects the output and comparison of the two previous graphs. Series1, being the signal generator and series2 showing the output from the LCD display. As seen, both gradually increase over the 25 steps, at the same gradient. Although the output on the display is a much steeper increase. The motor being measured maximum speed is 2600RPM, indicating this is capable of producing this value of output.

8.7.5 On/Off button & Start button plus LED Testing

The two below snippets of the proteus design demonstrates the testing carried out on the on/off button and start button with LED's to reflect this sequence. This operation worked correctly with no errors identified.

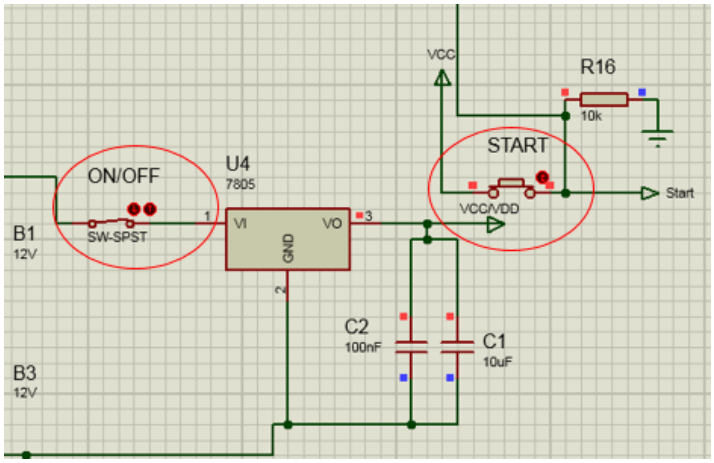


Figure 122: ON/Off & Start Proteus Test 1

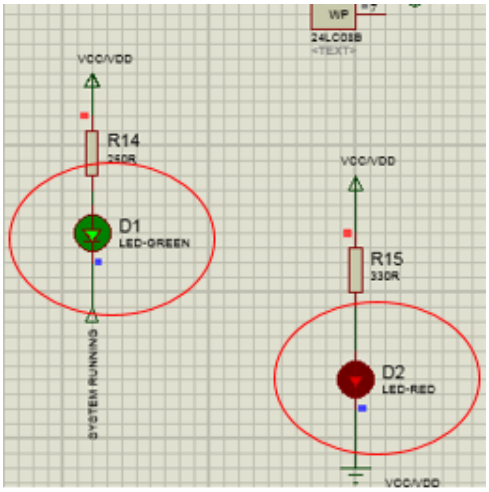


Figure 123: ON/Off & Start Proteus Test LED's

8.8 Structural Design of Prototype

Below indicates how the final design was going to be produced, components based on a wooden base. This will allow good access for the prototype to be shown via a presentation or an exemplary basis to persons who may show interest.

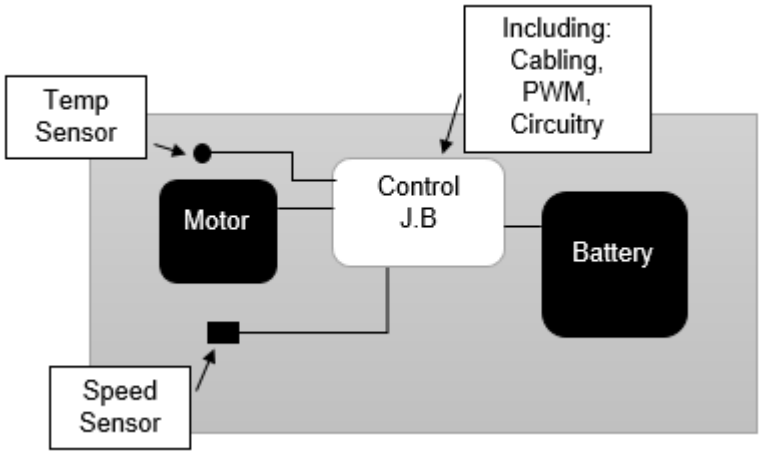


Figure 124: Prototype layout

8.9 Design - Conclusion

The design process was completed with all aspects being covered. The proteus design was built in line with the requirements of a LCD display, RS232 communication, temperature, and speed and vibration sensors with a power on button being supplied via a 24/12V supply. Once this was produced and the design was completed, this schematic was reflected within Easy-PC and PCB design was produced. This was not going to be used for a prototype design but could be used for further development in future.

Coding via CCS was used to reflect the working principle of the system, again in line with the specification laid out within this report. The tests were conducted after the CCS was produced and completed along with ongoing testing as the coding was being produced. The tests conducted were all successful with the function of the system working exactly as required. This was a good stepping stone to setting this project up for success of meeting its aims and objectives.

Within the next chapter of this report, the implementation of this design will be conducted, along with testing procedures and tests being discussed.

Chapter 9 – Implementation

9.1 Implementation – Introduction

Within the implementation chapter, it is shown how the design itself is implemented into a physical design. It also covers any miscellaneous components that were selected that have not already been stated within this report. After all of the components were selected, an overall components list was produced to indicate the prototype total costings.

This chapter also covers how the CCS and proteus design was implemented into a physical.

9.2 Miscellaneous Components

The miscellaneous components as stated within the below table are all of the components and devices used within the prototype build that needed to be purchased as well as the key components already covered within the component selection process.

Component		Quantity
Winstar WH1602B-TMI-JT 16x2 LCD Display	 [72]	1
Red Running LED	 [73]	1
Green Power on LED	 [74]	1
Zener Diode	[75]	10
10k resistor	 [76]	10
100 ohm resistor	 [77]	25
140 ohm resistor	 [78]	25
Enclosure	 [79]	1
Power on/off & system on/off toggle switch	 [80]	2
LM2940CT-5.0/NOPB Voltage Regulator	 [81]	1

Table 49: Miscellaneous Components

9.3 Overall Costing's

A costings list of the project can be seen below, the final cost shall be reflected upon within the evaluation section of this report. The costings list covered both key components and miscellaneous components.

Equipment	Quantity	Type	Manufacturer	Part Number	Cost
Speed sensor	1	OPB740	Farnell	OPB742	£1.59
Temperature sensor	1	LM35	Farnell	1469236	£1.68
Vibration sensor	1	LSM6DS3	Magideal	N/a	£3.99
Speed controller	1	PWM 9V-60V 20A	Bang good.com	1118024	£5.46
Motor	1	24V/300W	Red circle	ESC05	£26.99
Microcontroller	1	PIC18F2458	RS components	666-8933	£2.96
Red LED	5	Kingbright	RS components	228-5988	£0.24
Green LED	5	Kingbright	RS components	228-6004	£0.206
Zener Diode	250	1N5231B	RS components	811-5967	£0.046
10k resistors	10	RS Pro series	RS components	707-7745	£0.10
100ohm resistors	10	TE connectivity LR1	RS components	148-269	£0.048
100nf capacitors	100	RS pro Aluminium Electrolytic	RS components	711-1396	£0.02
140ohm resistors	5	Arcol MRA0207	RS components	497-5189	£0.596
Enclosure	1	Tempo ABS	RS components	104-199	£12.23
LCD	1	Winstar 16x2 LCD	Rapid electronics	57-2228	£5.33
On/Off toggle switch	2	Toggle Switch SP	RS components	251-9253	£8.68
Reflective tape	10	RS PRO reflective tape	RS components	845-9731	£6.27
Voltage Regulator	1	LM7805CT -	Farnell	1102157	£0.85
Total Costings: £76.70					

Table 50: Overall costing

9.4 Prototype Build

The build of the major project covers the physical structural build of the prototype, uploading the CCS file to the microcontroller and implementing all electronics with the power supply, some for the first time. Continued testing was applied througout the process. Pictures are provided were available, interesting testing/results will also be discussed.

9.4.1 Stuctural Build

The below figure shows the first fix of the base and controlling junction box of the structural build.

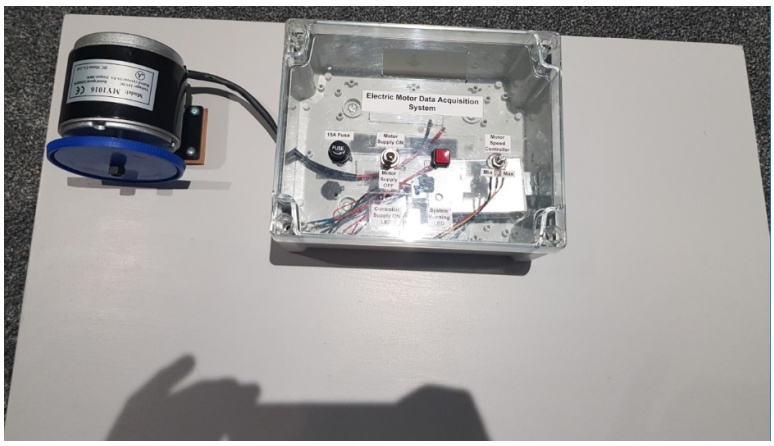


Figure 125: Prototype base layout

A plastic disc was connected to the shaft of the motor to allow the speed sensor to measure the speed of the shaft, the disc would be its reference point.



Figure 126: Motor and speed measurement point

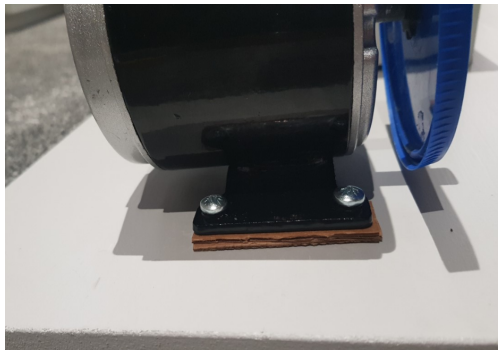


Figure 127: Motor base vibration softener

All connections requiring soldering were sleeved with heat shrink to ensure no shorting of connections or poor connections could be reduced.

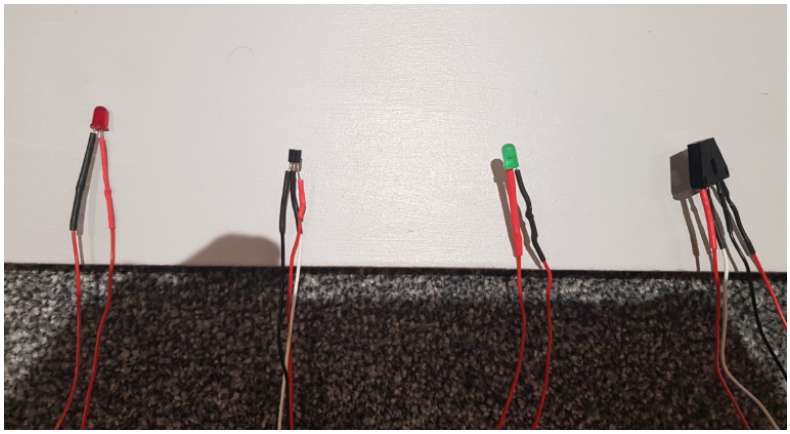


Figure 128: Components soldered and sleeved

9.4.2 Software Build

The CCS file was downloaded to the PIC18F2458 via a software called MPLABXDE. The coding needed to be produced into a hex file to do this. The data sheet for the microcontroller and the PICKIT 3 device layout drawing was required, this was easily obtainable online.

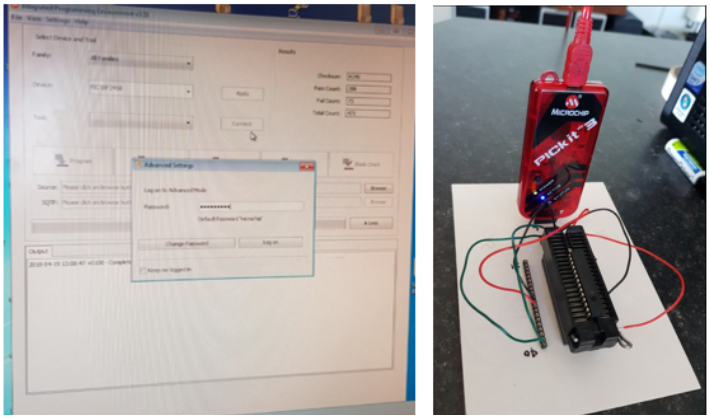


Figure 129: Uploading CCS file to the Microcontroller

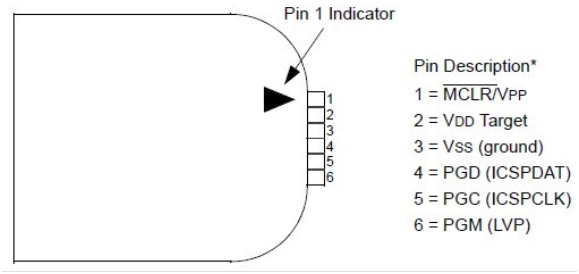


Figure 130: Pickit 3 device [82]

9.4.3 Electronic Build & Testing

The following steps within this section of the chapter will cover the electronic side of the implemetation. Tests conducted and successes and failures also featured along the way.

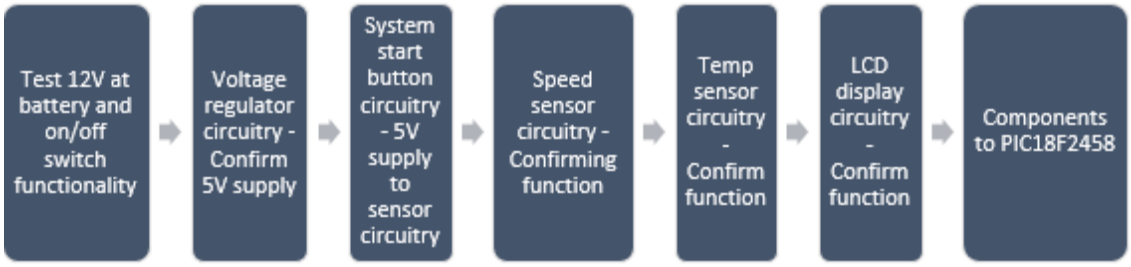


Figure 131: Process to implementing Electronics

Voltage regulator

Firstly, a basic outline of a testing procedure was produced to conduct the implementation and testing of the voltage regulator.

Voltage Regulator Implementation Testing Procedure	
Expected outcome of test – 12V measured at pin 1 of the voltage regulator and 5V measured on pin 3.	
Step	**Action**
1	Connect voltage regulator circuitry is connected on breadboard
2	Confirm 12V at battery terminals
3	Connect battery 12V supply to breadboard
4	Confirm operation of voltage regulator with the use of a multi- meter

Table 51: Voltage Regulator implementation procedure

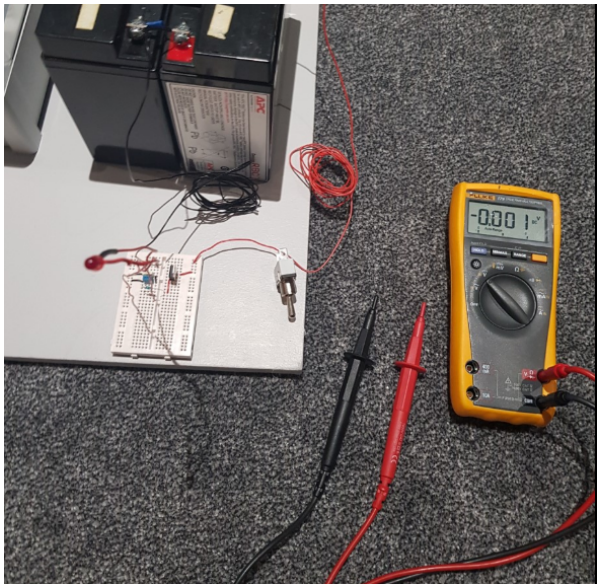


Figure 132: Voltage regulator implementation

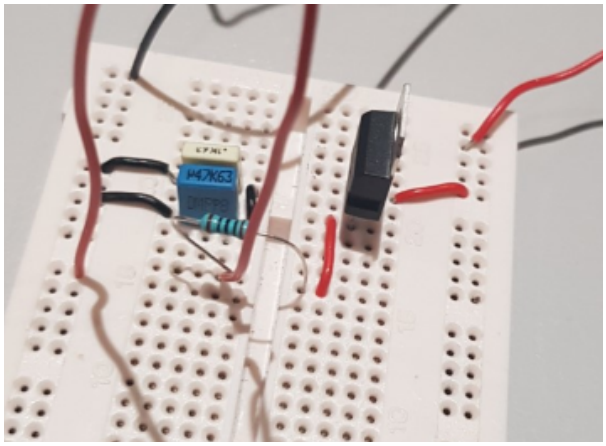


Figure 133: voltage regular layout on breadboard

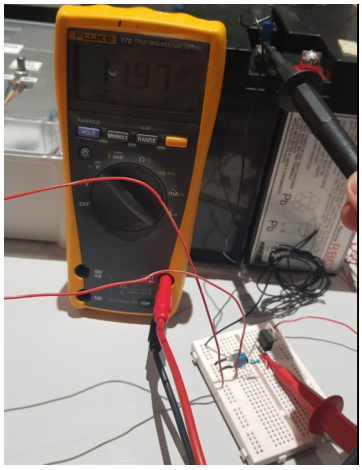


Figure 134: Voltage regulator error

Errors found - When initial powering up of the voltage regulator, 12V was picked up on each pin of the voltage regulator meaning the output would be 12V instead of 5V. If this was connected to the microcontroller or sensors this could cause significant damage due to over voltage. After further investigation it was identified that pin 2 was not connected to ground as required as per the data sheet, as seen below - This was rectified.

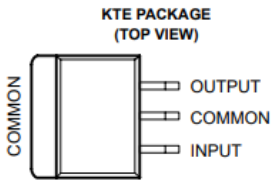


Figure 135: 7805 Voltage regulator pin layout [84]

Successes – After the initial miswiring the voltage regulator worked correctly and provided an adequate output of 5V.

System Start

System Start Button Implementation Testing Procedure	
Expected outcome of test – Button to make and break the 5V supply intended to supply the microcontroller	
Step	**Action**
1	Connect button in line with output from voltage regulator
2	Confirm output of start button is 0V when not pressed and 5V when pressed with the use of a multi-meter

Table 52: System Start implementation procedure

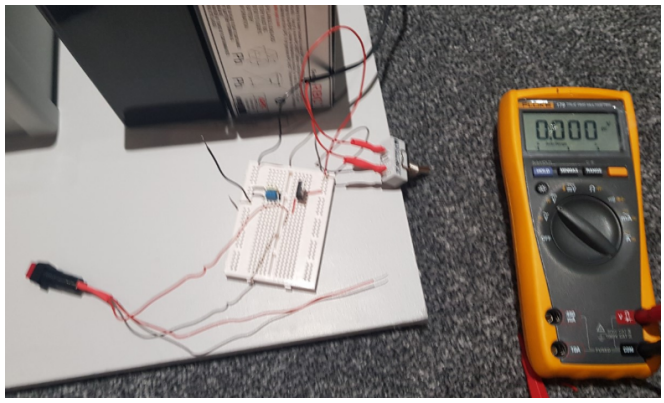


Figure 136: System start button implementation

This implementation had no errors and worked correctly first time.

Speed Sensor

Speed sensor Implementation Testing Procedure	
Expected outcome of test – Confirm power up of sensor and output changes from sensor as object passes sensor	
Step	**Action**
1	Connect speed sensor circuitry is connected on breadboard
2	Connect 5V supply from system on button to circuitry
3	Confirm sensor is energised via smart phone camera
4	Using hand, confirm output voltage changes once its passed across the face of the sensor

Table 53: Speed implementation testing procedure

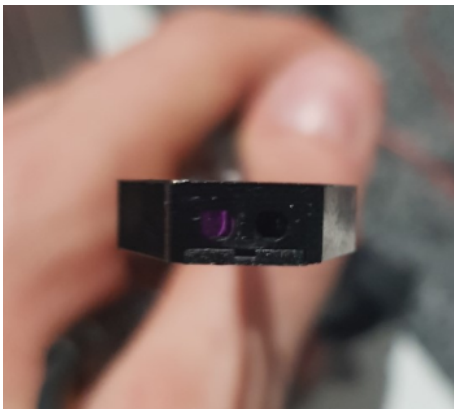


Figure 137: initial power up of Speed sensor

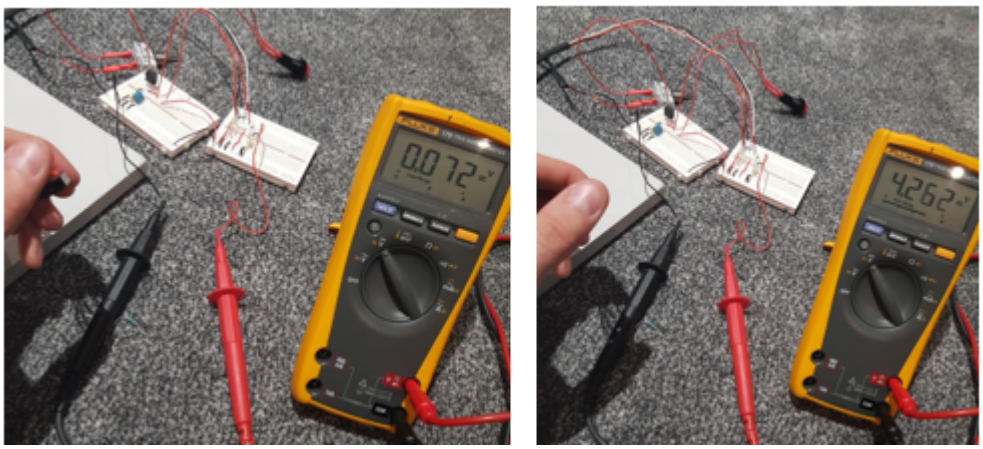


Figure 138: Speed sensor functionality check

This test had no errors and worked as expected and as stated within the procedure. The above figures illustrate the voltage output change when a finger passes the face of the sensor as required.

Temperature sensor

Temperature Sensor Implementation Testing Procedure	
Expected outcome of test – Power up of sensor and 10mv output from the sensor per 1ºC	
Step	**Action**
1	Build Temperature sensor circuitry on breadboard
2	Connect voltage regulator 5V output to circuitry
3	Confirm power up sensor via multi-meter
4	Take mV reading from sensor output and measure temperature confirming output is correct as per data sheet.

Table 54: Temperature implementation testing procedure

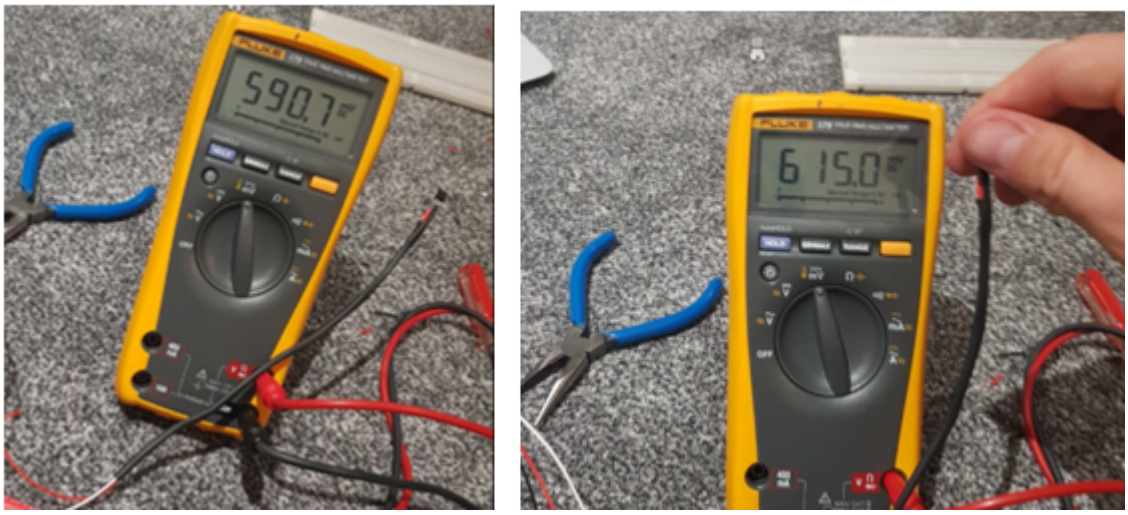


Figure 139: Temperature sensor functionality



Figure 140: Temperature sensor functionality 2

Errors Found – As seen within the above pictures, the output from the sensor was 487.5mV when the room temperature was recorded at just over 23ºC. The mV output would indicate the sensor is measuring a temperature of 48.8ºC which is highlighted as incorrect. This error was also found within the component testing section of the report and no solution was obtainable. In was decided to continue with the design and when connected, potentially add additional circuitry to rectify this error.

Successes – Although incorrect, the senor did power up and did display a mV output which could be identified by the microcontroller.

LCD Screen

LCD to microcontroller Implementation Testing Procedure	
Expected outcome of test – Confirm LCD powers up and displays initial 'hello' as required within the coding	
Step	**Action**
1	Connect micro controller to breadboard
2	Connect positive and negative connections as per data sheer for the PIC18F2458
3	Connect LCD circuitry as per data sheet to the microcontroller
4	Turn on 5V supply to microcontroller
5	Confirm LCD energises and displays output

Table 55: LCD to Microcontroller implementation procedure

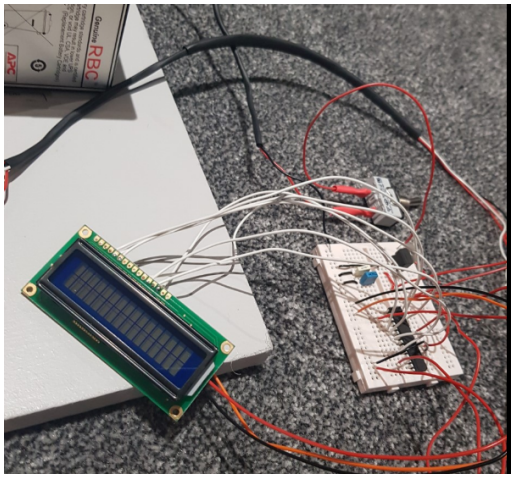


Figure 141: LCD Error

Errors Found – When powered, the LCD did not display any values, Black squares as shown within the above figure appeared, and this indicated it was powered.

Fault finding steps taken:

1. All connections were verified and confirmed against the proteus design, LCD datasheet and PIC18F2458 data sheet
2. Another PIC18F2458 was used that had the same hex file downloaded.
3. A pot was used on the contrast terminal of the LCD to vary the resistance. It was believed that this contract output was originally connected to the common ground on the breadboard

None of the above made any difference, with the LCD still showing back squares on power up.

Successes – The LCD did power up with the inevitable black squares being displayed.

9.5 Conclusion - Implementation

The implementation reflected all miscellaneous components that was included within the design but that was outside of the key components and component selection process of this report. This enabled the purchasing of all components to be conducted with an overall costings list being produced in line with the purchases. The overall costing came to £76.70 which shall be evaluated against

the specification set out, this will be conducted within the next few chapter of this report.

The structural build and initial testing of the speed sensor, controlling switches, LED indications, PWM system and voltage regulator was successful and worked as required. But unfortunately, the implementation did not go as successfully as the design process of this project. The fault which occurred through the LCD screen was still an ongoing fault finding methods at the time of this report being written, although it is hoped to be working by the project presentation process.

When conducting research into possible fixes to this fault, a previous project within the university was read to see if this had occurred in previous years, and it had. A student used the same microcontroller as used within this project, and also could not get the LCD to work, although the outcome fault and learnings were not identified.

The time spent on conducting the implementation section of this project could have been reduced dramatically due to the wrong microcontroller being ordered. It was not realised until the day of wanting to download the hex file that a PIC18F2458 SOIC was ordered instead of a PIC18f2458PDIP. The SOIC would not fit a breadboard or anything else within university. A new microcontroller was required to be ordered.

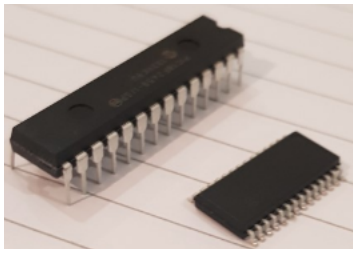


Table 56: Miss Order of PIC18F2458

The next chapter within this report will be the evaluation. This will evaluate the outcome of this project, comparing with the aims and objective reflected within chapter 1.

Chapter 10 - Evaluation

10.1 Introduction – Evaluation

In order to evaluate the project, it is relevant to revert back to chapter one of this report and highlight the aims and objectives set as a bench mark for this project. Aspects of the project that could be done differently will also be closely evaluated within this chapter. This chapter will also evaluate lessons learned by reflecting on what could have been done differently.

10.2 Project Aims

***'Aim:** Design and produce a Microcontroller based Electric Motor Data Acquisition System.'*

This statement was taken from chapter one of this report, indicating the initial aim of this project. As far as the design concept and testing performed on the design within proteus and CCS, it is evaluated that the project successfully achieved its aim set.

10.3 Project Objectives

The below objectives were also taken from chapter one of this report, the bullet point inserted under each italic objective was a reflection of whether they were successfully or unsuccessfully met.

Objectives:

- *Research into AC and DC motors and identify their main characteristics*
    - This was successfully completed with the background research section of this report (Chapter 4)
- *Research into the major failings for AC and DC motors*
    - This was successfully completed within the background research section also. (Chapter 4)
- *Identify a way in which the failings could be monitored via sensors*
    - This was successfully complete, within the component selection process (Chapter 6)
- *Design and build a prototype Data Acquisition System*

        - The design and build of a prototype system was successfully completed. Included within chapter 8 (Design and Design Testing) and also chapter 9 (Implementation)
- *Test the Data Acquisition System*
        - Testing the Data Acquisition design was also successfully conducted within chapter 8 ‘Design and Design testing’
- *Gather data from the bench motor*
        - This objective was unsuccessful at the date of the project report submission due to the ongoing issue with the LCD
        - Data was gathered from the bench motor through chapter 7 ‘Component testing’ although this was through an external sensor.
- *Evaluate and conclude the project*
        - This objective was also a success, reflected within this chapter and chapter 11 of this report.
- Look at further opportunities for the system to be improved and produced as a usable system on site.
        - The final objective can be reflected upon within chapter 11 &12 of this report, ‘Conclusion’ and ‘Recommendations’

10.4 Successful Aspects

There were many successful aspects of the project, including many outside of this report. The successful aspects are bullet pointed below:

- Identifying a need for a Data Acquisition System within the current authors place of work. If this project was to be produced for a full scale final product it could be seen as great benefit to the chemical plant.
- Although the implementation was not complete, the planning aspect of this project within chapter three of this report was done in such a way it set the project up to be successful. SMART goals were set, requiring milestones to be identified with a Gantt chart to reflect these dates. All aims and objectives were covered within the timescale identified.
- The research conducted, both the background research and component research was undertaken in a logical order, setting the project up to be

successful. A background understanding of motors, their failings, areas that should and could be measured for the Data Acquisition System were highlighted. The research also provided an area such as condition based monitoring where this system could be used. The survey conducted was completed by fifteen experienced personnel within chemical plant, providing expertise to reflect their thoughts. Components were also identified through SWOT analysis to conclude with the key components for this project.

- The specification was used to aid the objectives of the end product and act as a criterion for the component selection process to take place. A design specification is required for any project or build wanting to be successful and fit for purpose.
- The Speed, motor and PWM system selection were as required and when tested gave valuable information that could be interpreted and analysed to reflect their operation.
- The battery, although recycled was used and produced 24V and 12V with no defects or failures.
- The initial proteus design produced a successful schematic layout of the microcontroller used, along with all of the sensors required and communications
- The Easy-PC design schematic was produced and successfully translated into a PCD design ready for build when required.
- The CCS coding in correspondence with the proteus design was developed, implemented and tested successfully with output results being reflected within this report.
- The valuable lessons learnt from the background research, time management and the authors personal development within the electronic world from fault finding techniques to component understand were successfully developed throughout this project.
- Specification stated that the prototypes budget was £100. The actual cost came in under that at £76.70

10.5 Unsuccessful Aspects

When evaluating the unsuccessful aspects of the project, it is identified that they only became noticeable at the end of the project, where aspects may have been better established with more time. The Unsuccessful areas have been bullet pointed below:

- Although the planning aspect of this project was seen a success, it was also identified as an unsuccessful aspect. The reasoning for this was the plan produced did not allow enough time for fault finding on the implementation side of the project. Although this is unpredictable how long this could take, more time could have been allowed.
- One unsuccessful aspect of the project was also the LM35 testing, although connected as per the data sheet, neither the author nor the others supervisor could understand why the sensor would not output as expected. Multiple techniques and LM35 sensors were used, but the functionality was still not operable in a way stated on the data sheet.
- Implementing the selected gyroscopes code within CCS was also unsuccessful due to the complexity of the data sheet.
- Unfortunately, the implementation of the prototype build is an unsuccessful aspect of the project due to the ongoing issue with the LCD. This has ultimately halting the progression of the projects implementation

10.6 What would be done differently?

When evaluation any project or assignment there are always pointers for improvement or aspects that could have been conducted differently. The list below details areas that could have been done differently. These pointers are a reflection of the unsuccessful aspects also discussed.

- As already discussed within this chapter, if this project was to be replicated, time management could be improved. This could be done by the following:
    - Allowing more time for failures and fault finding at the latter stages of the academic year.

    - Allowing study time from work, being able to use the electronic labs throughout the week
- To improve with the implementation with the CCS coding side of the design, coding techniques and coding language would be included within the background research of the project. This would enable easier transition when attempting to design the interface coding between microcontroller, communications and sensor data gathered.
- Component purchasing would be carried out differently if this project was to be done again. Ensuring all correct products were purchased, this includes investigating all components once purchased, analysing how they will be applied to the prototype and that the right product has been delivered. For example, within this project the wrong microcontroller was purchased and it was not noticed until the latter stages before the correct microcontroller was purchased. When selecting components, the data sheet could also be examined in more detail, identifying exactly how it can be applied. For example, the Gyroscope purchased required its own coding with high complexity to be operated which could not be carried out with the knowledge of the author.

10.7 Conclusion - Evaluation

When concluding on the evaluations outcomes, the aims and objectives of this project were highlighted a success with only one of the objectives not being fully successful. This was to gain information and gather information from a bench motor. This was not obtained from the system intended to be produced, but other measuring devices. The results from this are reflected within the component testing chapter. All other objectives listed were fully obtained and successful, due to a successful design and simulation testing.

The back end of the implementation is the area in which the faults occurred, and unfortunately this is where time ran out for the purpose of this report. Fault finding and troubleshooting the operability of components and the design produced is a major gain in the technical knowledge from a learning point of view.

The next chapter will look at the projects overall conclusion, also looking at areas of future potential for this project.

Chapter 11 – Conclusion

There were several successes and unsuccessful areas throughout the project development. The main aim within chapter one of '*Design and produce a Microcontroller based Electric Motor Data Acquisition System*.' was successfully achieved, although the implementations of a structural prototype design was unsuccessful.

Within chapter one, many aspects of the report were outlined and a bench mark for what would be done throughout the report was stated. This was derived from the aim and objectives stated, reflected by the SMART goals set.

Once the bench mark for the project was stated within chapter one, it led into chapter two which indicated the Research methodology approach used throughout the reports research and discussions. The research onion was used to outline the methodology used. Each layer of the onion was covered by positivism, deductive, grounded theories and surveys, longitudinal, both primary and secondary sources used, as this was best suited to the project in hand.

The research methodology approach, along with the aims, objectives and SMART goals set within chapters one and two were used to reflect a project plan within chapter three. Within this chapter, key milestones were stated including a milestone objectives to identify areas which needed to be completed to reach the milestone date. From the milestones and milestone objectives, an overall Gantt chart was produced to reflect the milestones set within the academic year. The Gantt chart was updated and assessed throughout the project to reflect the project status. Some dates changed due to shortfalls within the project proposal stages, ordering of components and the final implementation. The plan for the project could have been improved by providing more time at the later stages of the project for implementation of the final design. Within the planning stages, resources that were required to aid completion of the milestone were also outlined, although it is felt, more recourse time from supervisors within the university should have been identified. This could have been beneficial when complex coding arose.

After the plan was produced, the first milestone to be complete was the background research. This was covered within chapter four of this report. The

background research areas were identified by reflecting the objectives of the report stated within chapter one. Within the background research motor failings were researched, finding that over 50% of motor failings were caused by bearing failure. Market research was also researched, finding a number of Data Acquisition Systems. It was felt, finer detail could have been applied to different systems that were more relevant to the prototype being produced. A survey was also conducted from fifth teen work colleagues with vast experience being surveyed. Two of the survey results obtained reflected the workers strong beliefs that a Data acquisition System would be beneficial to the Chemical plant in question, reflected within the pie charts below.

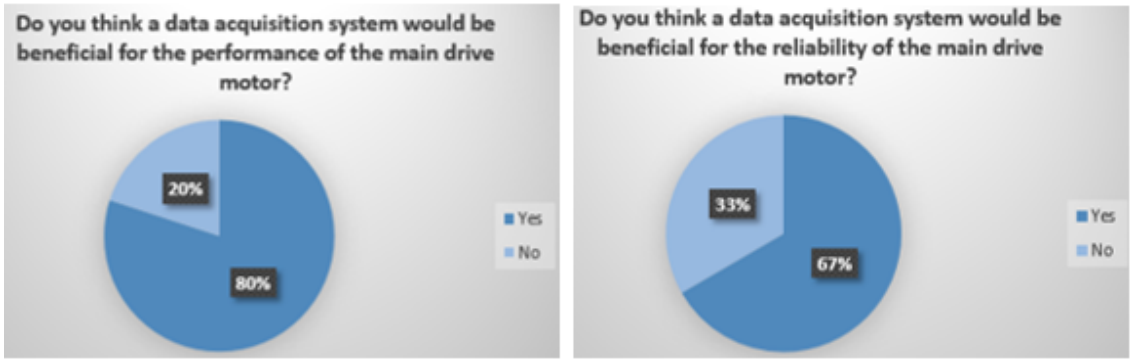


Figure 142: Survey Results

The findings from the background research plus the surveys conducted were used to outline a design specification within chapter five. This chapter specified what the system must measure. This covered speed, vibration and temperature as a reflection of the findings. It was stated that the speed, vibration and temperature sensors must read every half a second, with the temperature sensor also reading every degree. The specification also outlined the LCD and RS232 communications, motor voltage, and 24V power supplied via batteries, the target cost of £100, with all of the hardware/software uses being outlined. The final specification stated the testing used, which inevitably played a vital role within the design and implementation stages of this report.

Once the specification was outlined, key components were identified requiring further investigation to be selected, covered within chapter six. The key components were the battery, speed, temperature and vibration sensors along with the PWM system and the motor itself. These components were chosen by the selected method of SWOT analysis. The SWOT analysis did not identify the

threat of the gyroscope providing complex coding to be produced, this was a downfall within the completion of the structural build.

Chapter seven including all the testing and testing analysis of the components selected within chapter six. To ensure the correct methods of testing was used, a testing procedure was followed for each test conducted. The procedures were followed and the tests were conducted. If a problem/fault occurred when testing, the procedures could not be used, this was the only downfall of procedure based testing. Some tested were concluded to be more successful than others. The major outcomes of these tests were the Speed sensor OPB740 worked correctly as shown within the plotted graph below. The sensors sensitivity was measured to different materials specified, reflected in the graph below.

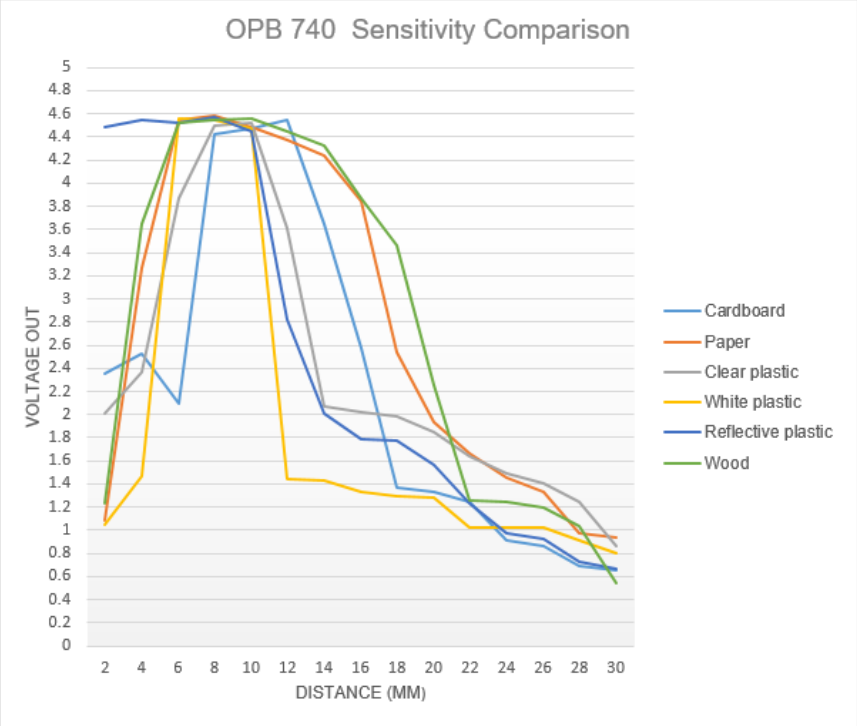


Figure 143: OPB740 Testing Conclusion

The PWM system was tested via an oscilloscope which reflected the functionality of the system at 0%, 50% and 100% of its outputs.

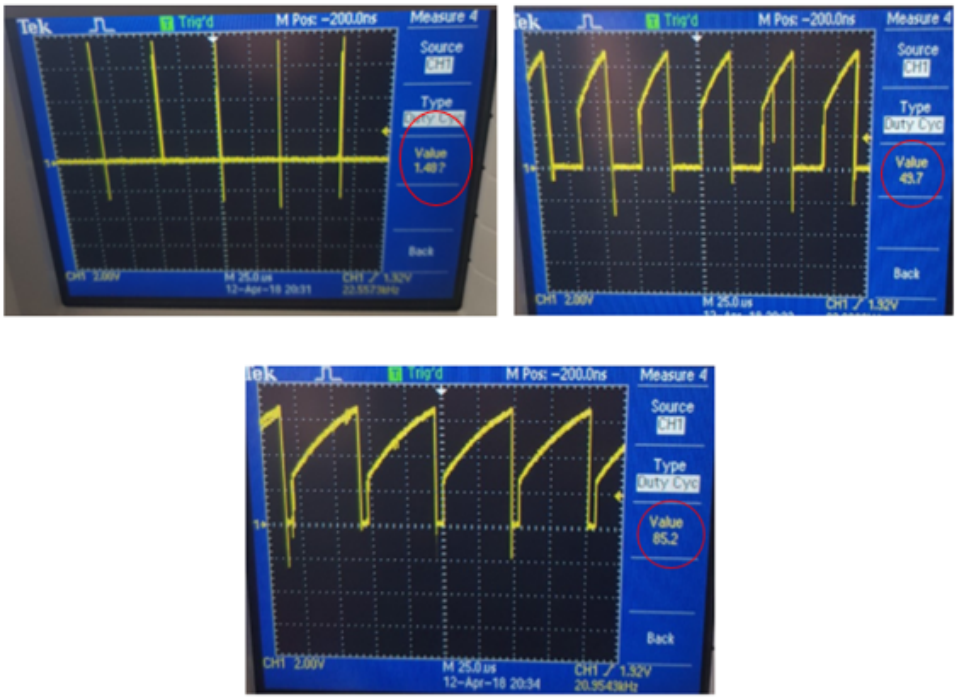


Figure 144: PWM Testing Conclusion

The LM35 however was not a successful test conducted, with the investigation still on going, it was unclear why the mV output of the sensor did not reflect the temperature present.

As all of the key components had been tested and their operation was known, the design was then implemented within chapter eight. Firstly producing an overall schematic of the system on Proteus, included the microcontroller, all sensors, LCD, power regulator and RS232 interface. This can be seen in the below figure.

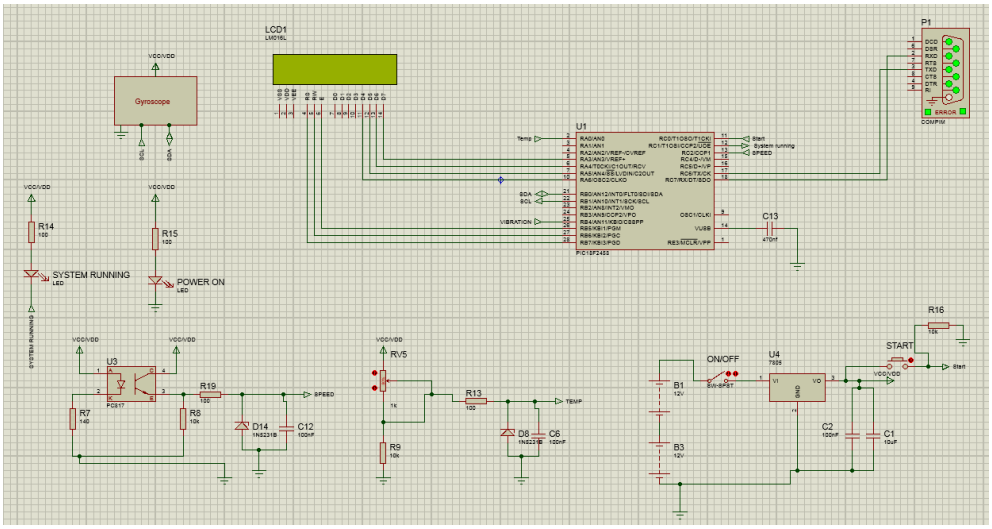


Figure 145: Overall Proteus Design Conclusion

Once the proteus design was produced the design was then transferred into an Easy-PC schematic that was later used to produce a PCB design. The PCB design produced would require re-structuring to reduce the size of the board if this project was to be mass produced.

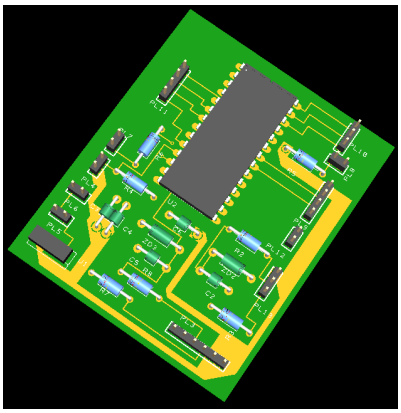


Figure 146: PCB Design Conclusion

After the schematic design was correct, a CCS file was compiled to produce coding reflecting the systems operation. This was developed in a systematic way, testing each aspect as the relevant coding was produced. This ensured correct functionality at each stage of the CCS development. Once the coding was completed, the design as a unit was tested, voltage points and signal generators were included in the design to test the inputs from the sensors. The test results can be seen within the below graphs.

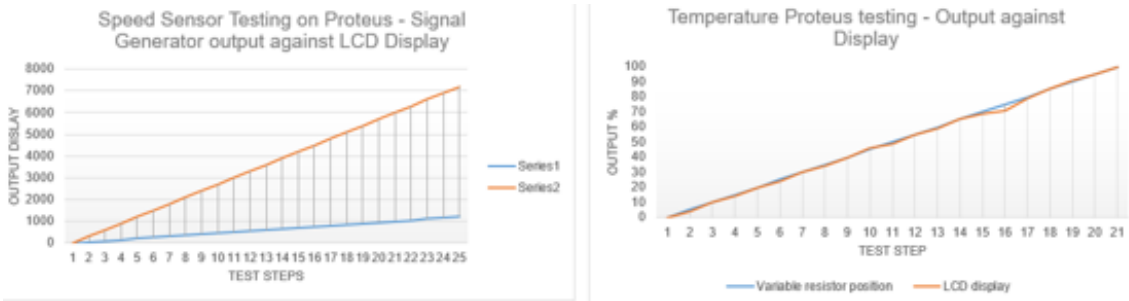


Figure 147: Proteus Testing Results

Within chapter nine, a base and junction box were fixed together to house the electronic circuitry, sensors, battery and DC motor. Once this was completed, the proteus schematic was produced on a breadboard with the required circuitry. As with the design testing, the implementation was tested as each circuit was built such as, sensor circuits and supply voltage circuitry. This was

completed and successful, although when the LCD was connected it did not work as expected. The ongoing fault investigation was being conducted as this report was submitted.

The successes and unsuccessful aspects along with the evaluation of the aims and objectives were included within chapter ten. Aspects of the project that could be carried out differently was also included within this chapter.

Chapter 12 – Recommendations

It is believed that there are many avenues in which this project design could be progressed further. This is discussed and recommended within the below points along with initial recommendations.

Initial Recommendations:

The initial recommendations would be required to produce a fully functional prototype design, this was not implemented at the time of this report being submitted.

- **LCD display** - Rectify the fault with the LCD not displaying the required readings. This could be investigated further, using a variable resister to adjust the contrast.
- **Coding** – Further research into the complex FIFO CCS coding for the gyroscope. This would enable the vibration sensor to work successfully on the prototype, reading data back to the LCD and RS232.
- **Functional Prototype** – Once the LCD fault had been rectified, build the physical prototype as specified within this report. Testing the output of the sensors with the required output data.
- **PCB** –The PCB design could be printed, tested and used within the final prototype enabling professional and final finishing within the circuitry.
- **Demonstration** – Use the system when fully functional on students covering Data Acquisition to aid with learning and understanding of how the system operates on a bench prototype.

Further Recommendations:

Further recommendations can be made to progress this project into different avenues. If more time was allowed, the following steps could be implemented and researched further.

- **Sensors** - Sensors for the device could be investigated further for contactless measurement.
    - Why it was not implemented - This was not done within the prototype design due to the budget, size and time frame of the project.

    - Benefit of doing this - Contactless sensors would allow the System to be diverse enabling it to measure different motors and applications.
- **Handheld** – Prototype circuitry and sensors built into a handheld devise
    - Why it was not implemented – Handheld device was not part of the main aim and objectives stated within chapter one of this report.
    - Benefit of doing this – Aid with use on a live working plant application. A hand held device could also aid when wanting to use as part of on shift operator round.
- **SD Card** – The system currently uses RS232 and a local LCD to read the data gathered from the motors. With the use of an SD card, the information could be gathered and stored within an SD card for analysis.
    - Why it was not implemented – SD storage was not stated within the specification listed for the system. It did not also fit into the budget and timeframe of this project.
    - Benefit of doing this – Removable storage of data gathered that can be produced on a PC remote from the system. Installing SD capability could also aid with the development of a hand held device.
- **Specific measurement** – Specific measurement such as, pull-in analogue/digital sensors could be used to aid the user applying this system to multiple motors.
    - Why it was not implemented - The sensors used within this prototype was a reflection on the survey conducted and also the background research.
    - Benefit of doing this – The Acquisition system would become more diverse for different industries and applications gathering for specific devices.
- **DCS monitoring** – Data gathered from the Acquisition System could be imbedded into the DCS, operators control panel.
    - Why it was not implemented – DCS monitoring was not part of the aims and objectives of this project

- Benefit of doing this – Online operational monitoring display of data being gathered from the devices being measured.

Chapter 13 – Reflection

To fully reflect upon the BEng Major Project produced within this report, this chapter has been split into two sections. Firstly, reflecting upon my learnings and secondly how the project has changed me as person.

13.1 Learnings

Predominately being an electrical technician with an electrical background, not having a great deal of experience with electronics prior to starting the BEng in Electronic and Electrical engineering. I feel it has provided me with a greater understanding of electronic applications and software designing. Using proteus to produce an electronic schematic of the Data Acquisition System, CCS to produce the coding required to run the system and designing a PCB of the system using Easy-PC was something I had not done prior to starting this course. All of these applications and skills were both challenging and enjoyable to learn and progress into a final, simulated design.

The Major project has also aided me with time management, pursuing a part time degree has been overly time consuming with the demands of work, both shift and day work, including family and friend time has been a challenge. The project has taught me the need to schedule deliverables in a timely manner, to reach an end milestone. Being S.M.A.R.T from the outset was key to this. Although some of the milestones were not met within this project, it was a valid lesson learnt on why it was and is important to have milestones scheduled to be met.

I thoroughly enjoyed testing and fault finding components, sections of the design and the final design. Although quite daunting at times, analysing the data feedback given from the tests and faults provided me with a greater understanding and appreciation to how to analyse and interoperate data.

Writing the major project report has provided me with an appreciation for structuring technical reports and how critical it is. Enabling the reader to gather, interoperate and judge results or discussions stated within the report.

13.2 Personal Development

The learnings stated above of an academic and hands on experience with electronic applications and components have definitely encouraged me to broaden my understanding of not just electrical applications but a wide range of electrical and electronic applications.

With the Major Project being a double award in regards the BEng Degree, and being predominately being a self-driven study outside of university, more so than the other modules, it has been a tough challenge. Having to manage work commitments, family commitments along with study has taken my work ethic and self-belief to a level that will benefit me throughout my working life.

I now feel more comfortable and confident to improve and hopefully take my career to the next stage of progression.

Chapter 14 - References

[1] Y. Coach, “Your Coach,” [Online]. Available: http://www.yourcoach.be/en/coaching-tools/smart-goal-setting.php. [Accessed 14 03 2017].

[2] John, “Write pass,” 14 09 2017. [Online]. Available: https://writepass.com/journal/2017/09/understanding-research-methodology/].. [Accessed 17 11 2017].

[3] “UK Essays,” 18 05 2017. [Online]. Available: https://www.ukessays.com/essays/psychology/explanation-of-the-concept-of-research-onion-psychology-essay.php. [Accessed 23 11 2017].

[4] “Gantt.com,” [Online]. Available: http://www.gantt.com. [Accessed 26 11 2017].

[5] K. Sleight, “Bright Hub Engineering,” 30 08 2011. [Online]. Available: https://www.brighthubengineering.com/diy-electronics-devices/41740-classification-of-electrical-motors/. [Accessed 19 03 2018].

[6] “Galco,” [Online]. Available: https://www.galco.com/comp/prod/moto-ac.htm. [Accessed 19 03 2018].

[7] “PC Control,” [Online]. Available: https://www.pc-control.co.uk/dc-motors.htm. [Accessed 21 03 2018].

[8] P. Electric. [Online]. Available: https://www.precision-elec.com/difference-between-ac-and-dc-motors/. [Accessed 25 03 2018].

[9] C. Young, “EC&M,” 01 10 2004. [Online]. Available: http://www.ecmweb.com/content/explaining-motor-failure. [Accessed 17 01 2018].

[10] “Processing Magazine,” 03 05 2017. [Online]. Available: https://www.processingmagazine.com/2017/05/03/early-warning-signs-motor-failure/. [Accessed 12 03 2018].

[11] “National Instruments,” [Online]. Available: http://www.ni.com/data-acquisition/what-is/. [Accessed 02 03 2018].

[12] “Fiix,” [Online]. Available: https://www.fiixsoftware.com/condition-based-maintenance/. [Accessed 01 02 2018].

[13] D. Manning-Ohren, “10 Rules for condition monitoring,” *Plant & Works,* 08 07 2015.

[14] “Vbox Automotive,” [Online]. Available: https://www.vboxautomotive.co.uk/index.php/en/products/data-loggers#features. [Accessed 1 12 2017].

[15] “Race Technology,” [Online]. Available: https://www.race-

technology.com/za/racing/products/data-loggers/dl1-sport. [Accessed 13 11 2017].

[16] "Tempcon," [Online]. Available: https://www.tempcon.co.uk/shop/media/pdf/D262_HOBO_UX90_004M.pdf. [Accessed 10 11 2017].

[17] "Omega," [Online]. Available: https://www.omega.co.uk/pptst/OM-VIB-101.html. [Accessed 11 11 2017].

[18] "Mind Tools," [Online]. Available: https://www.mindtools.com/pages/article/newTMC_05.htm. [Accessed 30 11 2017].

[19] A. Gregory, "The Balance," 16 02 2018. [Online]. Available: https://www.thebalance.com/swot-analysis-for-small-business-2951706. [Accessed 9 03 2018].

[20] C. McGrady, "Arrow," 18 01 2016. [Online]. Available: https://www.arrow.com/en/research-and-events/articles/which-dc-motor-is-best-for-your-application.

[21] C. McGrady, "Arrow," 18 01 2016. [Online]. Available: https://www.arrow.com/en/research-and-events/articles/which-dc-motor-is-best-for-your-application. [Accessed 12 11 2017].

[22] M. Dirjish, "Electronic Design," 16 02 2012. [Online]. Available: http://www.electronicdesign.com/electromechanical/what-s-difference-between-brush-dc-and-brushless-dc-motors. [Accessed 21 11 2017].

[23] "Red Circles," [Online]. Available: http://redcircles.co.uk/24v-300-watt-electric-e-scooter-motor/ . [Accessed 18 01 2018].

[24] "Gems Motor," [Online]. Available: http://gemsmotor.com/nema-17-square-brushless-dc-motor. [Accessed 22 01 2018].

[25] "RS Components," [Online]. Available: https://uk.rs-online.com/web/p/dc-geared-motors/5324250/. [Accessed 05 01 2017].

[26] "Electronics Tutorials," [Online]. Available: https://www.electronics-tutorials.ws/blog/pulse-width-modulation.html. [Accessed 17 03 2017].

[27] 12 02 2018. [Online]. Available: https://knowledge.ni.com/KnowledgeArticleDetails?id=kA00Z0000019OkFSAU. [Accessed 13 03 2018].

[28] "ETRICAL," 05 05 2016. [Online]. Available: https://etrical.blogspot.co.uk/2016/05/speed-control-of-dc-motor_5.html. [Accessed 23 11 2017].

[29] "EDGEFX," [Online]. Available: https://www.edgefx.in/speed-control-methods-of-dc-motor/]. [Accessed 23 11 2017].

[30] “Circuit Globe,” [Online]. Available: https://circuitglobe.com/speed-control-of-dc-motor-armature-resistance-control-and-field-flux-control.html. [Accessed 26 11 2017].

[31] “Your Electrical Home,” 31 10 2011. [Online]. Available: http://www.yourelectrichome.com/2011/10/speed-control-of-dc-shunt-motor-flux.html. [Accessed 02 12 2017].

[32] A. Farahat, “Electrical Equipment,” 25 05 2015. [Online]. Available: http://machineryequipmentonline.com/electric-equipment/speed-control-of-d-c-motorsmerits-and-demerits-of-rheostatic-control-method/]. [Accessed 15 12 2017].

[33] “Banggood,” [Online]. Available: https://www.banggood.com/PWM-DC-9V-12V-24V-48V-60V-20A-Stepless-Variable-Speed-Pulse-Width-Motor-Speed-Regulation-Switch-p-1118024.html?gmcCountry=GB&currency=GBP&createTmp=1&utm_source=googleshopping&utm_medium=cpc_elc&utm_content=zouzou&utm_campaign=pla-uk-elc2-brand-pc&gclid=EAIaIQobChMIjt7-2aXB2QIVLrHtCh1scQoXEAQYASABEgK8-vD_BwE&cur_warehouse=CN. [Accessed 01 02 2018].

[34] “Robot shop,” [Online]. Available: https://www.robotshop.com/uk/cytron-30a-5-30v-single-brushed-dc-motor-driver.html. [Accessed 01 02 2018].

[35] “Robot shop,” [Online]. Available: https://www.robotshop.com/uk/pololu-20a-single-motor-controller.html . [Accessed 01 02 2018].

[36] “Omega,” [Online]. Available: https://www.omega.co.uk/technical-learning/infrared-temperature-measurement-theory-application.html. [Accessed 20 02 19].

[37] “JMS,” [Online]. Available: http://www.jms-se.com/rtd.php. [Accessed 20 03 2018].

[38] “ThermoKinetics,” [Online]. Available: http://www.thermo-kinetics.com/resistance-temperature-detectors. [Accessed 2018 01 2018].

[39] “ElectricsTutorials,” [Online]. Available: http://www.electronics-tutorials.ws/io/io_3.html. [Accessed 23 02 2018].

[40] [Online]. Available: https://www.elprocus.com/temperature-sensors-types-working-operation/.. [Accessed 23 02 2018].

[41] “Automation Forum,” [Online]. Available: https://automationforum.in/t/what-are-the-advantages-and-disadvantages-of-thermocouple/1297. [Accessed 13 03 2018].

[42] T. Agarwal, “Elprocus,” [Online]. Available: https://www.elprocus.com/optical-sensors-types-basics-and-applications/. [Accessed 04 02 2018].

[43] “Omega,” [Online]. Available: https://www.omega.co.uk/prodinfo/Integrated-Circuit-Sensors.html. [Accessed 12 01 2018].

[44] “Farnell,” [Online]. Available: http://uk.farnell.com/texas-instruments/lm35dz-nopb/temp-sensor-0-4-c/dp/1469236?mckv=73kNSYYh_dc|pcrid|78108290469|&gross_price=true&CATCI=pla-77217964501&CAAGID=14983481469&CMP=KNC-GUK-GEN-SHOPPING-

TEXAS_INSTRUMENTS&CAGPSPN=pla&gclid=EAIaIQobChMIusOo6aXB2QIVz7_tCh2wqQXTEAQYASABEgK-cPD_BwE&CAWELAID=120173390001319545. [Accessed 02 02 2018].

[45] "Omega," [Online]. Available: https://www.omega.co.uk/pptst/AD590.html. [Accessed 03 02 2018].

[46] "Omega," [Online]. Available: https://www.omega.co.uk/pptst/OM-2628.html . [Accessed 03 02 2018].

[47] "Farnell," [Online]. Available: http://uk.farnell.com/analog-devices/tmp36gt9z/ic-sensor-temp-to-92-3/dp/1438760. [Accessed 03 02 2018].

[48] OMRON. [Online]. Available: https://www.ia.omron.com/support/guide/43/introduction.html. [Accessed 04 02 2018].

[49] G. e. a. Frigyes, "Automation.com," [Online]. Available: https://www.automation.com/library/articles-white-papers/sensors-sensing-technologies/fundamentals-of-photoelectric-sensors. [Accessed 04 02 2018].

[50] S. Ball, "Embedded," 17 06 2003. [Online]. Available: https://www.embedded.com/design/prototyping-and-development/4024586/Exploring-optical-and-magnetic-sensors. [Accessed 19 02 2018].

[51] E. Ramsden, Hall -Effect Sensors Theory and Application, Oxford, Newnes, 2016, p. 1.

[52] "Electronic Tutorials," [Online]. Available: http://www.electronics-tutorials.ws/electromagnetism /hall-effect.html. [Accessed 05 02 2018].

[53] [Online]. Available: https://www.voti.nl/docs/OPB740.pdf. [Accessed 05 03 2018].

[54] 03 03 2018. [Online]. Available: https://www.checkline.com/photoreflectivespeedsensors/ls-s50mlr#buynow.

[55] [Online]. Available: https://www.checkline.com/product/MCS-655. [Accessed 03 03 2018].

[56] [Online]. Available: https://www.mouser.com/ProductDetail/Omron-Automation-and-Safety/E3ZLT81D2M?qs=sGAEpiMZZMu7wllPd7wRkdb6vv7GWtkMhsU8sbSJqc%252bZGU1mpRUVtw%3d%3d. [Accessed 03 03 2018].

[57] "Sparkfun," [Online]. Available: https://learn.sparkfun.com/tutorials/gyroscope/how-a-gyro-works. [Accessed 10 11 17].

[58] "Omega," [Online]. Available: https://www.omega.co.uk/prodinfo/straingauges.html. [Accessed 10 11 17].

[59] "National Instruments," [Online]. Available: http://zone.ni.com/reference/en-XX/help/372416A-01/svtconcepts/vbr_sig/. [Accessed 10 09 17].

[60] "RS Components," [Online]. Available: https://uk.rs-online.com/web/p/accelerometer-

ics/1106552/?searchTerm=Gyroscope+LGA14&autocorrected=y&relevancy-data=636F3D3126696E3D4931384E53656172636847656E65726963266C753D656E266D6D3D6D61746368616C6C7061727469616C26706D3D5E2E2A2426706F3D31333326736E3D5. [Accessed 11 01 18].

[61] "Mouser," [Online]. Available: https://www.mouser.com/ProductDetail/Digilent/410-326?qs=sGAEpiMZZMt6ebhnBMWiDBEdWRB6n8muQjGgYBU4WXw7VnL5iN7sCA==. [Accessed 11 01 18].

[62] "Farnell," [Online]. Available: http://uk.farnell.com/invensense/mpu-3300/gyroscope-3axis-450dps-24qfn/dp/2147217?st=gyroscopes%20sensor. [Accessed 13 01 18].

[63] "Farnell," [Online]. Available: http://uk.farnell.com/stmicroelectronics/l3gd20htr/mems-gyroscope-245-500-2000dps/dp/2762758?st=gyroscopes%20sensor. [Accessed 13 01 17].

[64] "RS-Online," [Online]. Available: https://docs-emea.rs-online.com/webdocs/14d7/0900766b814d7c4f.pdf. [Accessed 15 01 2018].

[65] "Bright Hub Engineering," [Online]. Available: http://www.brighthubengineering.com/power-generation-distribution/123909-types-of-batteries-and-their-applications/. [Accessed 21 10 17].

[66] "Battery Space," [Online]. Available: http://www.batteryspace.com/powerizer-lifepo4-battery-24v-10ah-240wh-40a-rate-----replace-sla-24v-10ah-with-4-times-cycle-life-lighter-weight----un-38-3-passed-dgr.aspx. [Accessed 13 12 2017].

[67] "RS Components," [Online]. Available: https://uk.rs-online.com/web/p/lead-acid-rechargeable-batteries/3730366. [Accessed 13 12 2018].

[68] "Amazon," [Online]. Available: https://www.amazon.co.uk/Injusa-Repsol-Pocket-Racer-Replacement/dp/B00A82F5TQ/ref=sr_1_3?ie=UTF8&qid=1521901533&sr=8-3&keywords=24v+battery. [Accessed 13 12 2017].

[69] [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/39887c.pdf. [Accessed 03 01 2018].

[70] "Amazon," [Online]. Available: https://www.amazon.co.uk/dp/B07453CPBT/ref=pe_3187911_189395841_TE_3p_dp_1. [Accessed 12 11 17].

[71] "Ti," [Online]. Available: http://www.ti.com/lit/ds/symlink/lm35.pdf. [Accessed 2018 02 15].

[72] "Rapid Electronics," [Online]. Available: https://www.rapidonline.com/winstar-wh1602b-tmi-jt-16x2-lcd-display-blue-negative-mode-white-led-backlight-57-2228. [Accessed 23 03 2018].

[73] "Rs Components," [Online]. Available: https://uk.rs-online.com/web/p/products/2285988/. [Accessed 15 03 2018].

[74] “RS components,” [Online]. Available: https://uk.rs-online.com/web/p/products/2286004/. [Accessed 15 03 2018].

[75] “RS Components,” [Online]. Available: https://uk.rs-online.com/web/p/products/8115967/. [Accessed 15 03 2018].

[76] “RS Components,” [Online]. Available: https://uk.rs-online.com/web/p/products/7077745/. [Accessed 15 03 2018].

[77] “RS Components,” [Online]. Available: https://uk.rs-online.com/web/p/products/0148269/. [Accessed 17 03 2018].

[78] “RS components,” [Online]. Available: https://uk.rs-online.com/web/p/products/4875189/. [Accessed 17 03 2018].

[79] “Rs Components,” [Online]. Available: https://uk.rs-online.com/web/p/products/0104199/. [Accessed 18 03 2017].

[80] “RS Components,” [Online]. Available: https://uk.rs-online.com/web/p/toggle-switches/2519253/. [Accessed 18 03 2018].

[81] “RS Components,” [Online]. Available: http://uk.farnell.com/texas-instruments/lm2940ct-5-0-nopb/ic-v-reg-linear-5v/dp/1469074?MER=bn_search_2TP_LastViewed_2. [Accessed 18 03 2018].

[82] “Google,” [Online]. Available: https://www.google.co.uk/search?q=pickit+3+pin+out&source=lnms&tbm=isch&sa=X&ved=0ahUKEwio0unyqMbaAhWBAMAKHZbQD0UQ_AUICigB&biw=1600&bih=834#imgrc=MPjOYu96p0i3qM:. [Accessed 18 04 2018].

[83] “Spark fun,” [Online]. Available: https://www.sparkfun.com/datasheets/Components/LM7805.pdf. [Accessed 19 04 2018].

[84] [Online]. Available: http://www.ti.com/lit/ds/symlink/lm35.pdf . [Accessed 03 02 2018].

[85] “Farnell,” 0e 03 2018. [Online]. Available: http://www.farnell.com/datasheets/2331923.pdf?_ga=2.90772058.1159459020.1519569592-1851185780.1519569592&_gac=1.7653894.1519572964.EAIaIQobChMIjOmCtqvB2QIVRbobCh1pTgx8EAAYASAAEgKBKPD_BwE .

[86] “Electrical4u.com,” [Online]. Available: https://www.electrical4u.com/permanent-magnet-dc-motor-or-pmdc-motor/. [Accessed 16 09 2017].

[87] “RS Components,” [Online]. Available: https://uk.rs-online.com/web/p/products/7570054/. [Accessed 18 03 2018].

[88] “Rs Online,” Design Spark, [Online]. Available: https://www.rs-online.com/designspark/different-types-of-motors-and-their-use.

[89] “RS-online,” Design Spark, 25 11 2014. [Online]. Available: https://www.rs-online.com/designspark/different-types-of-motors-and-their-use. [Accessed 15 11 2017].

[90] “National Instruments,” [Online]. Available: http://www.ni.com/data-acquisition/what-is/. [Accessed 01 03 2018].

[91] “Google,” 18 04 2018. [Online]. Available: https://www.google.co.uk/search?q=pickit+3+pin+out&source=lnms&tbm=isch&sa=X&ved=0ahUKEwio0unyqMbaAhWBAMAKHZbQD0UQ_AUICigB&biw=1600&bih=834#imgrc=MPjOYu96p0i3qM:.

Chapter 15 – Bibliography

[1] [Online]. Available: https://www.edugeeksclub.com/blog/How_to_Write_Your_Best_Dissertation/. [Accessed 19 01 2017].

[2] "Mind tools," [Online]. Available: https://www.mindtools.com/pages/article/smart-goals.htm. [Accessed 27 04 2017].

[3] "Wrike," [Online]. Available: https://www.wrike.com/blog/foolproof-project-plan/. [Accessed 09 01 2018].

[4] [Online]. Available: https://www.smartsheet.com/blog/gantt-chart-excel. [Accessed 17 01 2017].

[5] "ST," [Online]. Available: http://www.st.com/content/ccc/resource/sales_and_marketing/presentation/application_presentation/group0/23/a1/94/a3/39/cf/4c/37/introduction_to_electric_motors_pres.pdf/files/introduction_to_electric_motors_pres.pdf/jcr:content/translations/en.introductio. [Accessed 01 11 2017].

[6] "Explain that stuff," [Online]. Available: http://www.explainthatstuff.com/electricmotors.html. [Accessed 10 11 2017].

[7] "Smart Survey," [Online]. Available: https://www.smartsurvey.co.uk/articles/6-steps-to-conducting-an-online-survey. [Accessed 18 08 2017].

[8] "Mind Tools," [Online]. Available: https://www.mindtools.com/pages/article/newTMC_05.htm.

[9] "LKlingston," [Online]. Available: http://lklivingston.tripod.com/essay/intro.html. [Accessed 14 11 2017].

[10] "omega," [Online]. Available: https://www.omega.co.uk/subsection/usb-rs232-rs485-ethernet-all.html?gclid=EAIaIQobChMIgNT-y7HV2gIVDbDtCh1v9wkVEAAYAyAAEgKDPPD_BwE. [Accessed 02 12 2017].

[11] "Wikipedia," [Online]. Available: https://en.wikipedia.org/wiki/Data_acquisition. [Accessed 02 11 2018].

[12] "Mindtools," [Online]. Available: https://www.mindtools.com/pages/article/newTMC_78.htm. [Accessed 04 11 2017].

[13] "EFX kits," [Online]. Available: https://www.efxkits.us/lm35-temperature-sensor-circuit-working/. [Accessed 09 12 2017].

[14] "Social Research Methods," [Online]. Available: https://www.socialresearchmethods.net/kb/measlevl.php. [Accessed 03 03 2017].

[15] "Omega," [Online]. Available: https://www.omega.co.uk/prodinfo/temperature-measurement.html. [Accessed 16 02 2017].

[16] "NPL," [Online]. Available: http://www.npl.co.uk/publications/good-practice-online-modules/temperature/introducing-temperature-measurement/how-is-temperature-measured/. [Accessed 13 03 2017].

[17] "Honeywell," [Online]. Available: https://sensing.honeywell.com/sensors/speed-sensors. [Accessed 15 03 2017].

[18] "National Instruments," [Online]. Available: http://www.ni.com/white-paper/3807/en/. [Accessed 21 04 2017].

[19] "MIDE," [Online]. Available: https://blog.mide.com/6-ways-to-measure-vibrations. [Accessed 21 04 2017].

[20] "Reliability web," [Online]. Available: https://reliabilityweb.com/articles/entry/how_is_vibration_measured. [Accessed 21 04 2017].

[21] [Online]. Available: https://www.micromain.com/maintenance-management-resolutions/. [Accessed 24 11 2017].

[22] "Assetivity," [Online]. Available: https://www.assetivity.com.au/article/maintenance-management/5-keys-to-lean-maintenance-and-improving-maintenance-productivity-part-1-introduction.html. [Accessed 24 11 2017].

Chapter 16 – Appendices

The following documentation was submitted with the memory stick provided with this report.

- All Schematics & Coding
- Survey results
- Test results
- All key component Data sheets
- Gantt charts

16.1 Milestone Breakdown

Project chosen and agreed		
Task breakdown	***Outcome***	***Time duration to complete***
Project research	Propose several project ideas to cover the selected criteria	5 weeks
Research background information	Do initial research on the proposed project area	6 weeks
Project brief	Write a project brief for the selected proposed project	4 weeks
Write project proposal	Write a Project proposal for the selected project	8 weeks
Submit proposal	Submit project proposal for review	1 weeks
Proposal approved by Major Project Supervisor	Analyse feedback from project supervisor and work on any gaps	1 weeks
Total Duration		**39 weeks**

Choosing a project - Tasks v's Duration

Research Methodology		
Task breakdown	***Outcome***	***Time duration to complete***
Research onion route	Identify what route of methodology will be used throughout the project	2 weeks
Sources of research going to be used	Identify sources of sources that will be used to complete project.	2 weeks
Total Duration		**4 weeks**

Research Methodology - Tasks v's Duration

Planning		
Task breakdown	***Outcome***	***Time duration to complete***
Identify key Milestones	Identify aspects of the project that are a must – using these as key milestones	4 weeks
Milestone breakdown	Breakdown the milestones to tasks that will allow completion of the milestone	2 weeks
Recourses required for each milestone	Identify what resources will be required to complete each milestone	2 weeks
Total Duration		**8 weeks**

Planning - Tasks v's Duration

Interim viva Part 1		
Task breakdown	***Outcome***	***Time duration to complete***
Produce an Interim Viva part 1 presentation	Produce a presentation for the work carried out at this stage.	1 week
Present presentation to major project supervisor	Present presentation to University supervisors – Make note of feedback and improvements	1 day
Total Duration		**2 weeks**

Interim Viva part 1 - Tasks v's Duration

Background Research		
Task breakdown	***Outcome***	***Time duration to complete***
Motors/Drive Application	Identify what is required from the Main drive motor within the Extrusion process Identify the best applications AC & DC should be used in	6 weeks
AC Motors and Drives & DC Motors and Drive	Outline how the old system works and outline how the new system will work Outline AC & DC motors work	6 weeks
AC & DC Motor failings	Identify main aspects of major motor failings Identify the main signs of motor failings	3 weeks
Condition monitoring	Outline the requirements condition monitoring and its advantages/disadvantages.	3 weeks
Electric motor Data acquisition systems	Identify any motor data acquisition systems already on the market	4 weeks
Workplace survey	Obtain plant based experience/project rational	1 week
Conclusion	Summarise the background research leading into the design specification	1 week
Total Duration		**19 weeks**

Background research - Tasks v's Duration

Design Requirements/Specification		
Task breakdown	***Outcome***	***Time duration to complete***
Identify design requirements	Identify what the Data acquisition system is required to do/measure based on the background information and the original aims/objectives.	16 weeks
Produce a design specification	Conclude the background research and identify key aspects that can be used as a basis of the design	4 weeks
Total Duration		**20 weeks**

Design Requirements/Specification - Tasks v's Duration

Design Research/ component selection		
Task breakdown	***Outcome***	***Time duration to complete***
Motor selection	Identify and select appropriate motor for the use of the project	2 weeks
Motor variable speed	Identify ways of controlling the speed of the selected motor and select	4 weeks
Temperature sensors	Select an appropriate temperature sensor	4 weeks
Speed sensors	Select an appropriate speed sensor	4 weeks
Vibration sensors	Select an appropriate vibration sensor	4 weeks
PIC selection	Select an appropriate PIC for the task	4 weeks
Total Duration		**22 weeks**

Deign Research/Component selection - Tasks v's Duration

Interim viva part 2		
Task breakdown	***Outcome***	***Time duration to complete***
Produce an Interim Viva part 2 presentation	Produce a presentation for the work carried out at this stage.	1 week
Present presentation to major project supervisor	Present presentation to University supervisors – Make note of feedback and improvements	1 day
Total Duration		**2 weeks**

Interim Viva part 2- Tasks v's Duration

Design		
Task breakdown	***Outcome***	***Time duration to complete***
Structure design	Design the layout of the system in such away it is easy to use and motor/sensors are positioned sufficiently	4 weeks
Software/ Hardware design	Design the hardware and software for the chosen data logging system, programming the clock cycles and memory required for the sensor information	8 weeks
Total Duration		**11 weeks**

Design - Tasks v's Duration

Implementation		
Task breakdown	***Outcome***	***Time duration to complete***
Build project structure	Physically build the project as per the structure design	2 weeks
Test and upload hardware/software	When the hardware/software has been designed, test and load required programs for the system to run	4 weeks
Total Duration		**6 weeks**

Implementation - Tasks v's Duration

Evaluations		
Task breakdown	***Outcome***	***Time duration to complete***
Research Analysis	Critically analyse the research sections. Comparing findings with the actual operating set points of the new and old system	3 weeks
Overall Evaluation	Conclude the comparison in data verses operation limits. Evaluate findings based on the aims and objectives	3 weeks
Future recommendations	Summarise the report and findings and suggest if the move to an AC drive is the correct way forward for the extrusion process.	3 weeks
Reflection	State the learnings from the report and findings	4 weeks
Total Duration		**10 weeks**

Evaluations - Tasks v's Duration

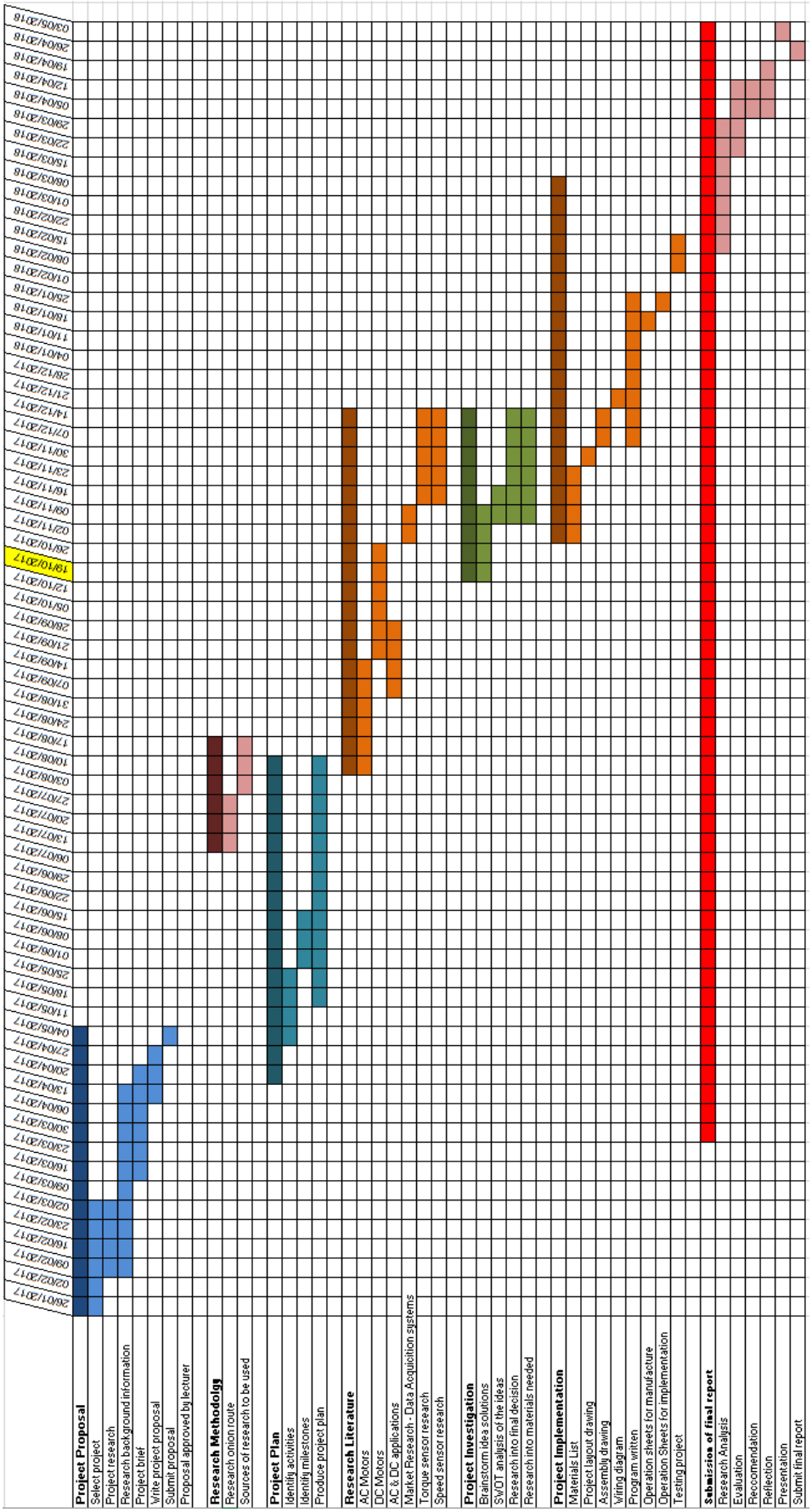
Report submission		
Task breakdown	***Outcome***	***Time duration to complete***
Generate Major project report	Generate a report outlining all aspects of the project in a professional manor	53 weeks
Submit project report	Submit a hard copy, electronic copy of the final report	1 day
Total Duration		**53 weeks**

Report submission - Tasks v's Duration

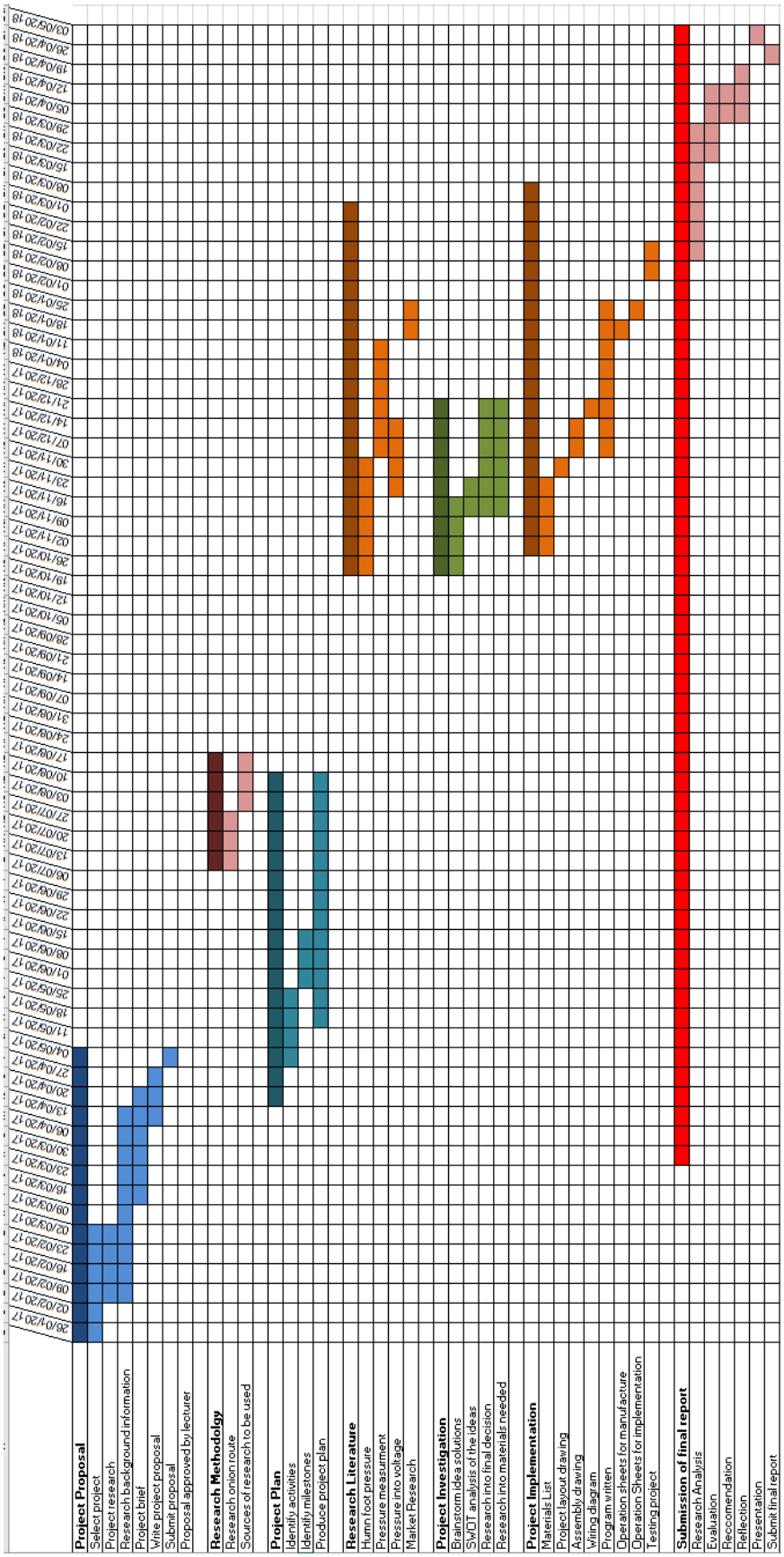
Final Viva		
Task breakdown	***Outcome***	***Time duration to complete***
Produce an Final Viva presentation	Produce a presentation for the work carried out at this stage.	8 week
Present presentation to major project supervisor	Present presentation to University supervisors – Make note of feedback and improvements	1 day
Total Duration		**8 week**

Final Viva - Tasks v's Duration

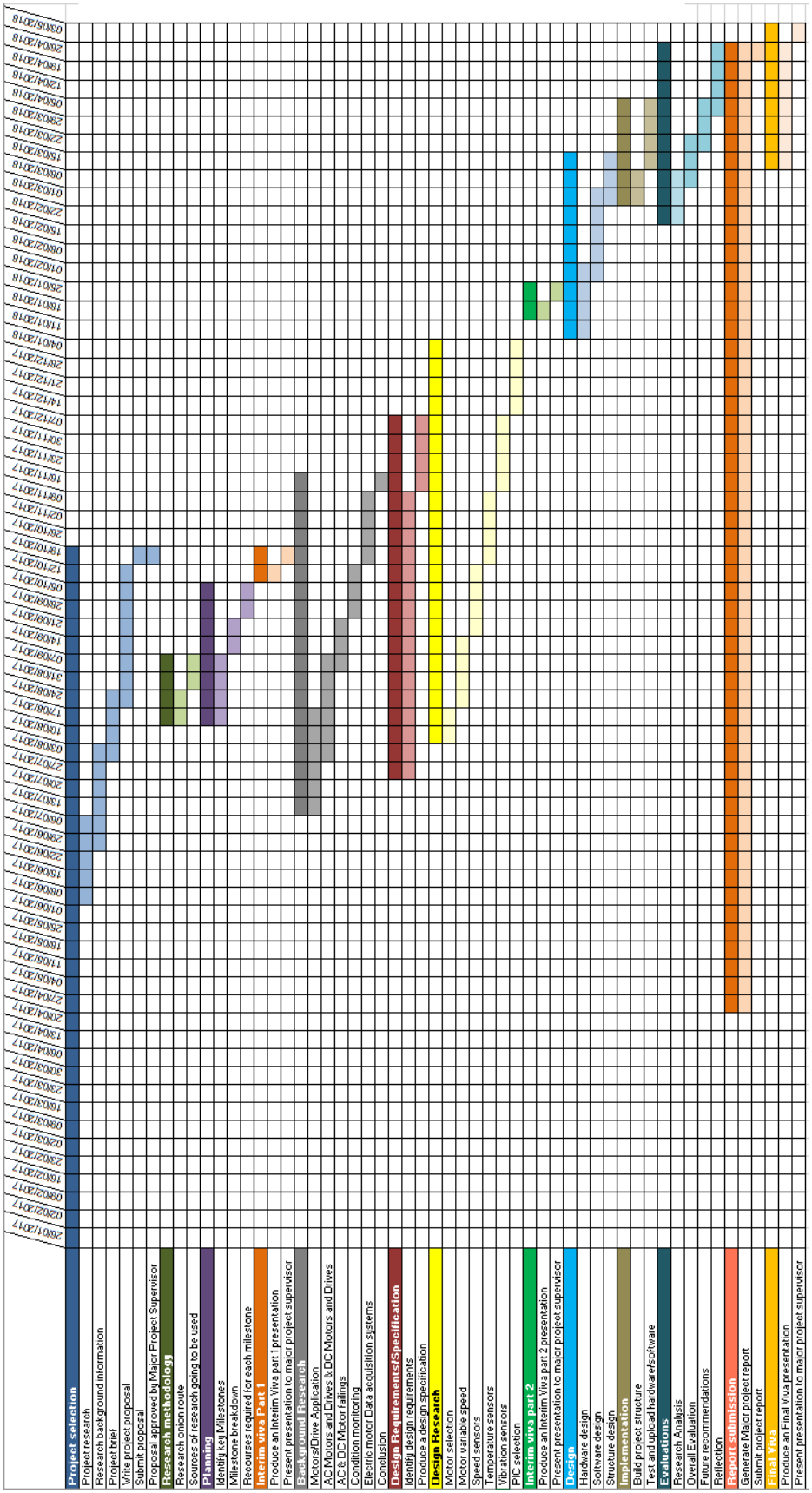
16.2 Gantt Chart - Proposal



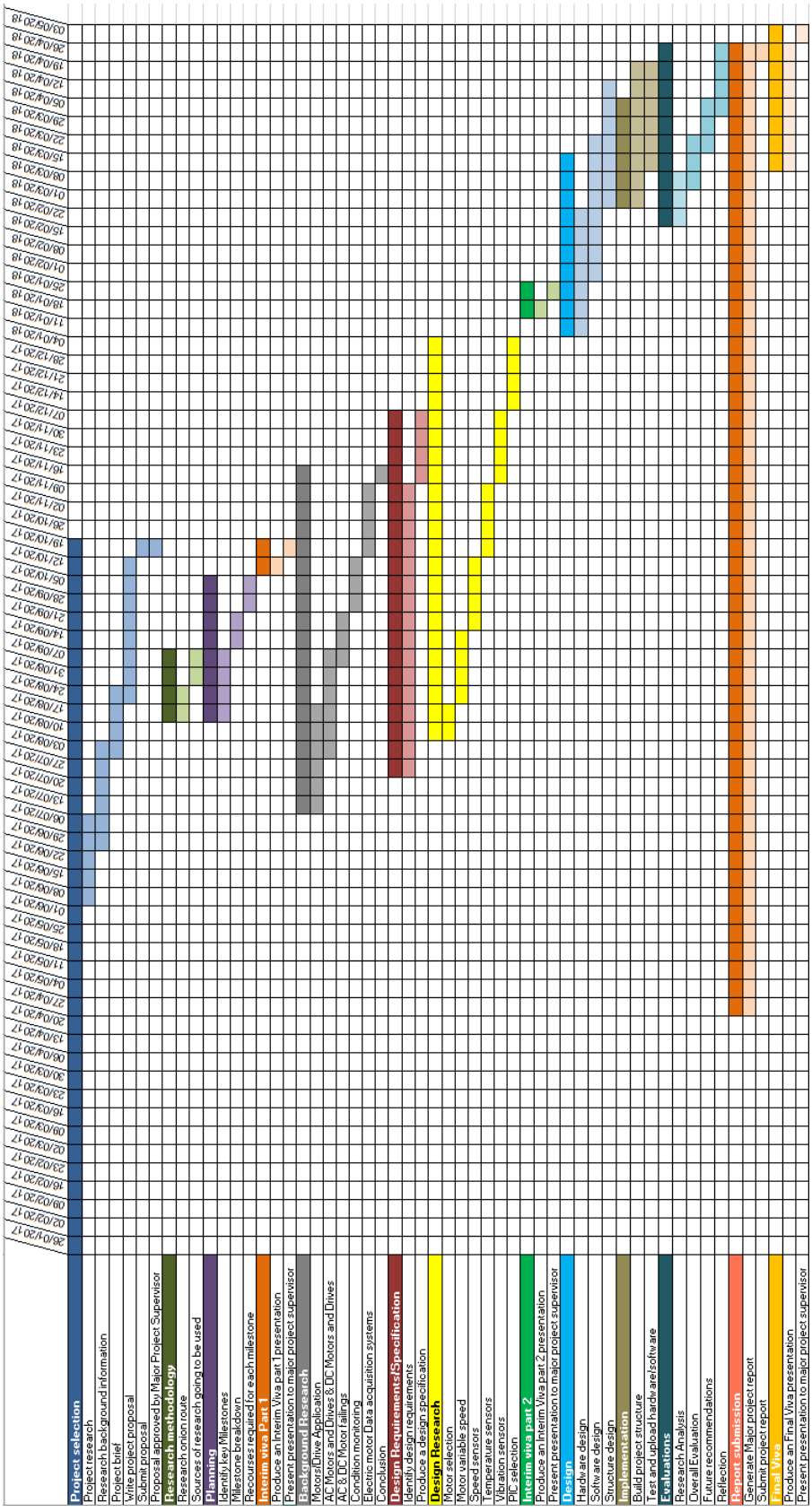
16.3 Gantt Chart - Interim Viva 1



16.4 Gantt Chart – Interim Viva 2



16.5 Gantt Chart – Final



16.6 Survey Results

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☑
- Engineer ☐
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☐
- No ☑

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☐
- Noise ☐
- Vibration ☑
- Casing integrity ☑
- Other ☑

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☑

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☑
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☐
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☑
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☑
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☐
- No ☑

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☐
- Torque ☐
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☑
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☑
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☐
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☑
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☑
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☑
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☑
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☑
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☒

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☒
- 10+ years ☒

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☒

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☒
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☒
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☒
- Temperature ☒
- Torque ☒
- Noise ☐
- Vibration ☒
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☒
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☑
- 10+ years ☐

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☑

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☑
- No ☐

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☐
- Vibration ☑
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☑
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☑
- 10+ years ☐

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☑

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☐
- No ☑

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☑
- Vibration ☐
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☑
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☑
- 10+ years ☐

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☑

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☐
- No ☑

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☑
- Vibration ☐
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☑
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☑
- 6-10 years ☐
- 10+ years ☐

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☑

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☐
- No ☑

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☑
- Vibration ☐
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☑
- Motor failures ☑
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☑
- Engineer ☐
- Technician ☐

2. How long have you worked at the organisation?

- 1-5 years ☐
- 6-10 years ☐
- 10+ years ☑

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☑
- No ☐

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☐
- No ☑

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☐
- No ☑

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☐
- Temperature ☑
- Torque ☑
- Noise ☑
- Vibration ☐
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☐
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐

Please Tick the correct answer.

1. What is your position within the organisation?

- Manager ☐
- Engineer ☐
- Technician ☑

2. How long have you worked at the organisation?

- 1-5 years ☑
- 6-10 years ☐
- 10+ years ☐

3. Do you know the main differences between the new AC main drive and the old DC main drive?

- Yes ☐
- No ☑

4. Do you think a data acquisition system would be beneficial for the performance of the main drive motor?

- Yes ☑
- No ☐

5. Do you think a data acquisition system would be beneficial for the reliability of the main drive motor?

- Yes ☐
- No ☑

6. If a data acquisition system was to be produced, what measurements do you think would be key to measure for the main drive process? If you have no knowledge of the new system is minimal, please relate to the existing main drive process.

- RPM ☑
- Temperature ☑
- Torque ☑
- Noise ☑
- Vibration ☐
- Casing integrity ☐
- Other ☐

7. What do you think contributes the most to downtime within the chemical plant in which you work?

- General electrical failures ☑
- Motor failures ☐
- Conveyor failures ☐
- General mechanical failures ☐
- Staff ☐
- Other ☐