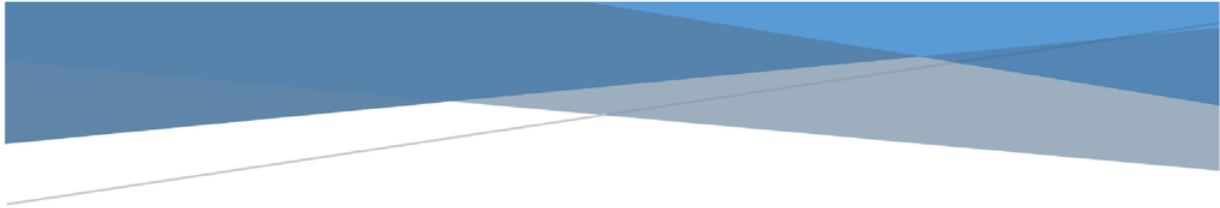


Adam Davies - ESD - Vehicle Data Logger Assignment

by Adam Peter Davies

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(M3X8528) ELECTRONICS SYSTEMS DESIGN

Vehicle Data Acquisition System

Abstract

This report outlines the design of a microcontroller vehicle data acquisition system. The system is intended for car manufactures testing prototype cars. The system must be portable, reusable and robust measuring various car dynamics and information. Sensor selection is made from research using comparison tables to compare chosen parameters. All connectors, power supply and casing material are chosen. The final design is presented in the form of a schematic diagram and a PCB which connects all relevant connectors. Overall the design, although not complete is believed to a success with potential future recommendations to improve the design greatly.

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Table of Contents

1. Introduction	5
1.1. Design Specification	5
2. Background Information	6
2.1. Existing Products	6
2.1.1. Influx Rebel CT	6
2.1.2. VBOX 3i Version 4	7
2.1.3. TTTech PM-200	8
2.1.4. Aim MXG Dash Data Logger	9
2.1.5. Bosch C 60 Data Logger	10
2.2. Product Comparison	11
3. Design Procedure	12
3.1. Engine Temperature	12
3.1.1. Sensor Type Comparison	13
3.1.2. Identified Sensors	14
3.2. Revolutions Per Minute (RPM) and Road Speed	15
3.2.1. Sensor Type Comparison	16
3.2.2. Identified Sensor	17
3.3. Pitch, Yaw and Roll	18
3.3.1. Sensor Type Comparison	19
3.3.2. Identified Sensor Comparison	20
3.4. Suspension	21
3.4.1. Sensor Type Comparison	22
3.4.2. Identified Sensors	23
3.5. Microcontroller Selection	24
3.5.1. Number of Pins	24
3.5.2. Program Memory and RAM	25
3.5.3. Clock Frequency	26
3.5.4. Analogue to Digital Convertor Resolution	30
3.5.5. Final Selection	31
3.6. Connector Selection	32
3.7. Data Sizing	34
3.8. Power Supply	37
4. Final Design	38
4.1. Initial Block Diagram	38
4.2. Circuit Schematic	39
4.3. PCB Layout	44

4.4. Software Diagram	50
4.5. Data Structure	52
4.6. Casing Design.....	53
4.7. Costing.....	56
5. Recommendation and Conclusion	57
6. References	58
7. Bibliography	62
8. Appendix.....	63
8.1. Appendix A	63
8.2. Appendix B	64
8.3. Appendix C	65

Table of Figures

Figure 1: Influx Rebel CT [3]	6
Figure 2: Influx Rebel CT Key Features [3]	6
Figure 3: VBOX 3i [4]	7
Figure 4: VBOX 3i Key Features [4]	7
Figure 5: TTEch PM-200 [5]	8
Figure 6: TTEch PM-200 Key Features [5]	8
Figure 7: Aim MXG Data Logger [6]	9
Figure 8: Aim MXG Features [6]	9
Figure 9: Bosch C60 Data Logger [7]	10
Figure 10: Bosch C60 Key Features [7]	10
Figure 11: Pitch, Yaw and Roll Diagram [25]	18
Figure 12: PIC Selection Screenshot	31
Figure 13: Integral 2GB SD card [44]	36
Figure 14: 7.2V NiMH Rechargeable Battery	37
Figure 15: Initial Block Diagram	38
Figure 16: Power Supply Schematic	39
Figure 17: Temperature Sensor Schematic	40
Figure 18: RPM and Speed Sensor Schematic	40
Figure 19: Suspension Sensor Schematic	41
Figure 20: PYR Sensor Schematic	41
Figure 21: Outputs Schematic	42
Figure 22: Microcontroller Schematic	42
Figure 23: PCB Bottom Layer	44
Figure 24: PCB Top Layer	45
Figure 25: PCB Full View	46
Figure 26: PCB Top 3D View	47
Figure 27: PCB Bottom 3D View	48
Figure 28: PCB 3D View	49
Figure 29: Software Flow Chart	50
Figure 30: Casing by Hammond [46]	53
Figure 31: 3D Casing Front View	53
Figure 32: 3D View Casing	54
Figure 33: Casing Back View	54
Figure 34: Dimensional Drawing of Design	55

Table of Tables

Table 1: Existing Products Comparison	11
Table 2: Sensor Type Comparison for Engine Temperature	13
Table 3: Sensor Comparison for Measuring Engine Temperature	14
Table 4: Sensor Comparison for RPM and Speed	16
Table 5: Sensor Comparison for RPM and Speed	17
Table 6: Sensor Type Comparison for Pitch, Yaw and Roll	19
Table 7: Identified Sensor Comparison for Pitch, Yaw and Roll	20
Table 8: Sensor Type Comparison for Suspension	22
Table 9: Identified Sensor Comparison for Suspension Ride	23
Table 10: Microcontroller Required Pins	24
Table 11: Lines of Code Approximation	25
Table 12: Microcontroller Comparison	31
Table 13: Connector Comparison	32
Table 14: Connector Layout	33
Table 15: Current Draw	37
Table 16: Data Structure Diagram	52
Table 17: Costing Table	56

1. Introduction

The purpose of this report is to outline the design of a microcontroller based vehicle data acquisition system. The design scenario proposed was for the system to be fitted to a production prototype car targeted for the family saloon market. The system however must be portable, re-useable and adaptable for any car. The data gathered will ensure that the designed vehicles are operating within safe working limits and are comfortable as an end product. The data will be collected during a 2 hour test run.

1.1. Design Specification

The following design specification was followed:

1. The system must be portable, re-useable and adaptable to any car type.
2. The system must measure pitch, yaw, roll, road speed, suspension, engine temperature and revolutions per minute (RPM).
3. The system must not interfere or be connected to the vehicles signals or electrical system.
4. The system must use its own power source.
5. The system must store the collected data on non-volatile memory which can be read and cleared.
6. The system must have USB connectivity.
7. The system must be adequately sized and made from robust casing.

2. Background Information

A vehicle data logging system is a system which takes a physical quantity such as temperature, pressure, force etc. and stores the data at intervals too keep track of important information [1]. These systems are used mainly in test track prototyping were manufacturers gain information to improve their car design or compare data with expected results. Other uses include on board diagnostic systems, track racing and rallying [2]. There are many manufactures which design vehicle logging systems these include TTTech, ATI Systems, 2D data recording, AIM Technologies and many more. The majority of current products have input ports for discrete sensors and CAN bus connectivity so the system can be directly connected with a vehicles on board system.

2.1. Existing Products

A selection of popular data loggers are presented in the following sections, outlining the features and benefits. A comparison of each product is made at the end of the section.

2.1.1. Influx Rebel CT

The Influx Rebel CT (figure 1) is designed for a variety of applications including fleet testing, calibration and bench mark testing. It features (figure 2) four analogue ports, four digital ports, 7 CAN buses, an internal 18Hz GPS sensor, accelerometer, internal 3g and Wi-Fi module [3]. It also provides portability and SD card functionality.

Key Features:

- 8x K-type thermocouples (via H-box not supplied)
- 7x analog inputs
- 1x K-Line
- 2x FlexRay channels
- 3x LIN buses
- 7x CAN channels
- Includes internal 18Hz GPS with socket for external antenna
- Includes internal 1kHz XYZ accelerometer +/-16G max
- 4x digital I/O channels
- 4x analog input channels (calibration tool supplied)
- Connects to Module Analyser for on-line CAN Analyser functionality
- J2543 Pass thru drivers available
- SDHC card data storage max size 128GB
- IP65 Dust and splash proof cover – SD card securely housed behind a flip panel
- Supplied with Dialog Configurator, freely distributable data logger configuration application for Windows®



Figure 1: Influx Rebel CT [3]

Figure 2: Influx Rebel CT Key Features [3]

2.1.2. VBOX 3i Version 4

The VBOX 3i (figure 3) applications include performance, handling, safety, comfort and dynamics testing. It features (figure 4) real time results through Bluetooth connectivity, four analogue ports, memory card compatibility, portability and compatible with CAN or discrete sensors [4]. The system uses GPS to measure time, positioning, velocity and lateral speed. Pitch, yaw and roll can be measured through expansions [4].



Figure 3: VBOX 3i [4]

- 100 Hz logging to CF memory card
- High brake stop accuracy up to ± 1.8 cm
- Very low latency: 8.5 ± 1.5 mS
- Oversampled brake/event trigger input (25 nS)
- 4x analogue inputs
- 1x default CAN Bus port for input module expansion
- 1x configurable CAN Bus for vehicle CAN interface or VBOX data output
- Easy to fit and transport
- Real-time result display via serial, USB or Bluetooth
- User configurable logging conditions
- IMU integration
- Wide 7 V to 30 V operating range
- Low current consumption
- Audio voice tagging

Figure 4: VBOX 3i Key Features [4]

2.1.3. TTTech PM-200

The TTTech PM-200 (figure 5) provides an expansive system in which internal sensors can be ordered to be pre-built within the system reducing the need for external sensors. It features (figure 6) USB 3.0 connectivity, 15 analogue, 15 digital and 12 CAN ports. It can be connected to TTTech software via mobile devices so data can be read instantaneously [5].



Figure 5: TTTech PM-200 [5]

PC Interfaces	1 x USB 2.0 High Speed / Master 1 x USB 2.0 High Speed Slave 1 x USB 3.0 Super Speed / Master (can be used as logging medium) - Ethernet (10/100/1000 MBit/s) for quick data transmission to PC - ePCle 2.0 x1
Vehicle Interfaces	12 x CAN (of which 4 can be switched to high speed and low speed) - Optional upgrade with 12 x CAN-FD 3 x FlexRay (channels A/B synchronous and asynchronous respectively) 12 x LIN - Optional 1 x MOST150, SPY mode 15 x analog inputs (12 Bit) 15 x digital inputs (interruptible) 6 x RS232 6 x digital outputs + 3 x analog outputs 2 x Ethernet 1000 MBit/s with hardware time stamp of 1µs
Operating Temperature	-40°C to +75°C
Power Use	1.7A (operating) up to 100 µA (sleep modus) (tentative)
Operating Voltage	6 V to 32 V (protects against outage due to strain)
Dimensions	200 x 280 x 80 mm (L x B x H, height tentative)
Weight	3.2 kg (tentative)

Figure 6: TTTech PM-200 Key Features [5]

2.1.4. Aim MXG Dash Data Logger

Aim MXG (figure 7) is designed for racing applications. This system features (figure 8) analogue and digital inputs and 7 inch screen which displays information to the user instantly. The system can also be directly connected to a vehicles ECU [6], and has optional features such as GPS, CAN and RS32 connectivity.



Figure 7: Aim MXG Data Logger [6]

Resolution	800x480 pixels
Contrast	MXS: 600:1
	MXG: 1000:1
Brightness	700cd/m2 - 1,100 Lumen
Ambient light sensor	Yes
Alarm LEDs	MXS: 6 RGB freely configurable
	MXG: 8 RGB freely configurable
Shift lights	10 integrated freely configurable RGB LEDs
CAN connections	3
ECU connections	CAN, RS232 or K-Line
ECU compatibility	+ 700 industry leading ECUs
Expansion CAN connection	GPS, Channel Expansion, Thermocouple Expansions, Lambda Controller, SmartyCam
Analog inputs	8 fully configurable, max 1,000 Hz each
Digital inputs	4 Speed inputs, lap signal, coil RPM input
Digital outputs	2 (1 Amp max each)
Accelerometer	Internal Three-axial ± 5G + Three-axial Gyroscope
Internal memory	4 GB

Figure 8: Aim MXG Features [6]

2.1.5. Bosch C 60 Data Logger

The Bosch C60 (figure 9) is a system which is primarily used in motorsport. The system features (figure 10) CAN ports, ECU connectivity as well as boasting six analogue input channels [7]. The system has USB and RS-232 connectivity as standard.



Figure 9: Bosch C60 Data Logger [7]

Electrical Data	
Supply voltage	8 to 18 V
Max. power consumption (w/o loads)	10 W at 14 V
Inputs	
Analog channels	6
Input range	0 to 5 V
Resolution	12 bit
Switchable pull up resistor	3 kOhm
Outputs	
PWM outputs (low side switch 2 A each)	4
Sensor supply 5 V ± 1 % (250 mA)	1
Environment	
Software Upgrade	1
GPS input	
Additional analog channels	20

Figure 10: Bosch C60 Key Features [7]

2.2. Product Comparison

The table below (table 1) is a comparison table comparing the five products.

Parameter	VBOX 3i	Influx Rebel CT	Aim MXG	TTTech PM-200	Bosch C60
Physical					
Dimensions (mm)	170 x 121 x 41	126 x 110 x 45	166 x 97 x 46	200 x 280 x 80	105 x 34.5 x 137.5
Weight (g)	900	524	900	3200	495
Power					
Power (W)	5.5	3.6	7.5	20	10
Input Range (V)	7–30	4.7-36	9-15	6-32	8-18
Input/Output					
Analogue	4	4	8	15	6
Digital	2	4	4	15	0
CAN	2	7	3	12	2
Connectivity					
USB	Yes	Yes	Yes	Yes (3)	Yes
SD Card	Yes	Yes	Yes	Yes	No
Bluetooth	Yes	Yes	Yes	No	No
Ethernet	No	Yes	No	Yes	No
WI-FI	No	No	No	No	No
Speeds					
Sampling Rate (Hz)	100	1,000	1,000–10,000	Unspecified	1,000
Other					
Accelerometer	Yes	Yes	Yes	No	No
GPS	Yes	Yes	Yes	No	Yes
Price	£8,999 to £14,899	£6,899	£1,680	£4,890	£4,149.75
Advantages	-Large amount of internal sensors -Minimum external sensors needed	-Portable -Large number of inputs -Connectivity	-Programmable ranges -Large number of inputs -Portable -Display Screen	-Large Number of outputs -Wide operating voltage	-Portable -Compact

Table 1: Existing Products Comparison

From research the majority of products use CAN bus connectivity to connect directly to the vehicles system. They are generally priced highly but do vary depending on specification and applications. For example although the VBOX 3i is the most expensive system it measure the majority of data internally through GPS and built in sensors.

3. Design Procedure

The main design strategy employed was component review and analysis. This method allowed a variety of identified components to be compared via a comparison table. After each component was compared the results were analysed against the design specification. The following sub sections will present the selection process for each specified measurement.

3.1. Engine Temperature

The normal average operating temperature for an engine is around 90°C [8]. A suitable measurement range is regarded as -30°C to 150°C. Below is a list of potential identified sensors:

- **Thermistor:** A semi conductive device in which its resistance is related to temperature change [9]. There are many uses of thermistors in regard to temperature measurement they are used in thermometers, temperature control and compensators [10].
- **Thermocouple:** A device which contains two dissimilar metals joined at one end. One of the wires can be placed on a heated area and the other on a cooler area thus creating a potential difference [11].
- **Infra-Red (IR):** IR sensors measure temperature by emitting a beam which is directed onto a desired object or area. The thermal radiation which is given off by an object consists of mostly IR radiation. The distribution of these frequencies allows the device to provide non-contact temperature measurement [12].
- **Pyro Detectors:** A pyro detector can detect infrared radiation given from heat on an object, in which the device changes its temperature based upon the heat. This then relates into the device producing an electric signal of a particular magnitude relative to the heat.

3.1.1. Sensor Type Comparison

The table below (table 2) compares the identified sensor types.

	Thermistor	Thermocouple	Infra-Red	Pyro Detector
Measurement Range	50°C either side of a centred temperature	Large range from below 0°C to 900°C	Large range of devices from below 0°C to 2600°C	Range from 0 °C to generally 625 °C
Cost	Very In expensive	Fairly inexpensive	Expensive	Medium
Accuracy	Very Accurate	Accuracy generally within 2°C	Very accurate generally 1 °C	Very accurate
Stability	Very Stable at around 0.0009°C	Fairly Stable	Very Stable	Fairly Stable
Sensitivity	High	High	High	Medium
Contact	Yes	Yes	No	No
Score	14	14	16	15

= 3
 = 2
 = 1

Table 2: Sensor Type Comparison for Engine Temperature

The sensor type which has been identified as the best suitable option for measuring temperature is IR. Although IR is generally the most expensive type of sensor listed it has a large measuring range, is very accurate and is stable. Thermistors are disregarded as although they are accurate and very stable they have a poor measurement range, which would not meet the specification. Thermistor as well as thermocouples provide contact measurements meaning it would be required to be fitted to the engine which would also not satisfy the design specification.

3.1.2. Identified Sensors

Presented in the table (table 3) below is a comparison on selected IR sensors.

	UWE UETF-IR- CSL15 [13]	Bosch Infrared TI- 16-r [14]	Process Sensors PSC- CX [15]	Omega OS137A-(2)- V1 [16]	Micro-Epsilon thermoMETER CS [17]
Image					
Input Voltage (V)	5-30	5-30	5-30	12-24	5-30
Output	Analogue	Analogue	Analogue	Analogue	Analogue
Output Voltage (V)	0-5 or 0-10	0-5	0-30	0-5	0-5
Measurement Range (°C)	-40-1030	0-160	-30-900	-18-260	-40-400
Accuracy (°C)	+/-1.5	+/-1.5	+/-1.4	+/-1	+/-1.5
Response Time (ms)	25	30	32	150	25
Cost	£149.99	£654.00	£602	£266.80	£195.99
Score	19	16	16	15	20

 = 3
  = 2
  = 1

Table 3: Sensor Comparison for Measuring Engine Temperature

The chosen IR sensor is the 'thermoMETER CS' by Micro-Epsilon. This sensor is best suited as it provides a measurement range meeting the specification. The supply voltage can also be powered off an optimal 5V supply, which was the reasoning against the Omega OS137A as it has a minimum 12V supply. Another problem with the Omega OS137A is the temperature range only goes as low as -18 °C which would not meet the specification. The other considered sensor being the UWE UETF-IR-CSL15 was disregarded due to the range being -40 to 1030. This may be a problem as it may require a larger AD Convertor when selecting a microcontroller, meaning the Micro-Epsilon is regarded as the best option. The sensor will be implemented by positioning the sensor within range and direction of the engine.

3.2. Revolutions Per Minute (RPM) and Road Speed

Revolutions per minute (RPM) measures how quickly the engine is turning. Measurement ranges in a vehicle are around 500 rpm (idle) up to around 8000 rpm. This range was used as a general guide for component selection. Road speed will be measured within a range of 0 mph to 160 mph and be measured through wheel revolutions. Due to this both speed and RPM will use the same sensors. Presented below are the identified methods to measure speed and RPM:

- **Switch:** Possibly the simplest device which could be used to measure RPM and speed. It can be used to register the revolutions by attaching a latch to the camshaft or wheel to engage the switch. From the number of times the switch is hit the RPM or speed could be calculated and recorded.
- **Coil:** An electronic device which when a voltage is applied creates its own magnetic field. This device could count RPM by using it as a form of relay where a coil could be used to open and close a switch or power circuitry.
- **Hall Effect Switch:** A sensor whose output voltage is affected by the presence of a magnetic field [18]. RPM and speed could be measured using this device by fitting a magnet to the camshaft or wheel.
- **Infra-Red (IR) Reflective:** An IR device together with a reflective property could be used to measure RPM and speed. A potential way to achieve this would be to paint a reflective surface on the camshaft and the wheel. A beam break would not be suitable as there is nothing which will break the beam.

3.2.1. Sensor Type Comparison

The table below (table 4) compares and contrasts the identified components.

	<i>Switch</i>	<i>Hall Effect</i>	<i>Coil</i>	<i>IR (Reflective)</i>
Cost	Inexpensive	Inexpensive	Medium	Expensive
Accuracy	High	High	Medium	High
Contact	Contact	Contact	Contact	No contact
Robustness	Sceptical to wear and tear	Sceptical to wear and tear	Sceptical to wear and tear	Reliable
Size	Small	Small	Can be bulky	Small
Score	11	11	7	13

 = 3  = 2  = 1

Table 4: Sensor Comparison for RPM and Speed

Chosen to measure RPM and speed is an IR sensor. Although IR is the most expensive of identified sensors it provides high accuracy, high reliability and is compact. The main reasoning however for selecting IR is it provides non-contact measurement which is advantageous as no modifications are necessary to the vehicle. All other sensors would require modifications to the vehicle, a switch would require a latch to be fitted to the camshaft or wheel so it can be activated. Similarly a Hall Effect switch would require a magnet to be fitted to the camshaft or wheel. Another concern is that all other sensors have a mechanical nature which means that they are more prone to wear and tear, making IR the most suitable choice.

3.2.2. Identified Sensor

The table below (table 5) compares suitable IR sensors.

	Monarch IRS - Infrared Optical Sensor IRS-W [19]	Schneider XUB1BPB NM12 photo-electric sensor [20]	TT Electronics OPB720B [21]	Onosokki LG-9200 [22]	Zetlab BC 401 RPM sensor [23]
Image					
Speed Range/ Response time	1-1,000,000 RPM	1 ms	2.5 ms	1 ms	0 to 50000 RPM
Operating Range (mm)	12	1,000-5,000	1-152	20-40	2-15
Input Voltage (V)	3.3-15	10-36	4-7	12	5
Output	Digital	Digital	Digital	Digital	Digital
Output Voltage (V)	0-5	0-5	0-3.5	0-5	0-5
Cost	£158.08	£65.69	£103.78	£173.97	£212.83
Score	17	15	15	15	16

 = 3
  = 2
  = 1

Table 5: Sensor Comparison for RPM and Speed

Identified as the most suitable for measuring speed and RPM is the IRS-W sensor by Monarch. Although not the cheapest sensor it provides a large measurement range and an input voltage of 3.3V to 15V meaning it can run off an optimal 5V supply. Although the operating range is just 12 mm the sensor will be fitted in a tight space making it irrelevant. The Schneider XUB1BPB NM12 was not chosen as it has a minimum range of 1 metre, meaning that it would not fit in the engine of the vehicle. The Zetlab BC 401 had a similar specification to the IRS-W, however it was not chosen due to being around £70 more expensive. The chosen sensor will be implemented by painting a reflective strip to the camshaft for RPM and painting a strip on the wheel for speed.

3.3. Pitch, Yaw and Roll

Pitch, Yaw and Roll (PYR) are terms given to the dynamics of a vehicle. This data can give car manufacturers an idea of ride quality. PYR are all based on the orientation of a cars body (figure 11) with pitch being rotation along the lateral axis, yaw being rotation on the vertical axis and roll being rotation along a longitude axis [24].

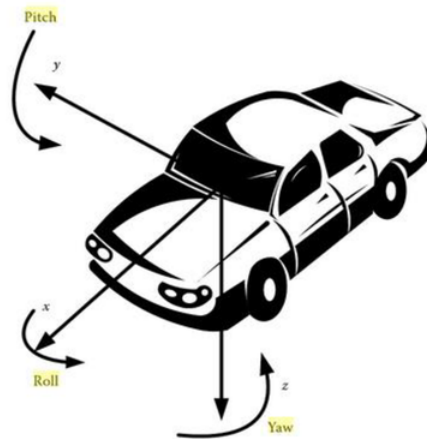


Figure 11: Pitch, Yaw and Roll Diagram [25]

The following sensors were taken into consideration for the design:

- **Accelerometer:** Sensors which produce an electric charge off a force [26]. Accelerometers can measure a static force, vibrations or dynamic force. They can measure the force along different axis, roll could be measured from the x axis, pitch from the y and yaw from the z.
- **Gyroscope:** Sensor which can measure angular velocity. These sensors can be placed at different orientations to measure different axis, meaning that pitch, roll and yaw could be measured from the sensor.

3.3.1. Sensor Type Comparison

The table below (table 6) compares the identified sensors regarding pitch, yaw and roll.

	Accelerometer	Gyroscope
Cost	Expensive	Expensive
Accuracy	High	High
Robustness	Fairly	Fairly
Size	Small	Small
Score	9	9

 = 3  = 2  = 1

Table 6: Sensor Type Comparison for Pitch, Yaw and Roll

Both gyro sensors and accelerometers are very similar in all parameters compared. Both are compact, have very high accuracy and are fairly robust. They also would not require any modifications as they can be fitted inside the vehicle if necessary at the correct orientation. Although both sensors have the same advantages a gyroscope is believed to be more suitable for measuring pitch, yaw and roll. This being due to accelerometers measuring force in a particular direction, it would not measure a value if there was no change in speed. A gyroscope will be used in this design.

3.3.2. Identified Sensor Comparison

In the table below (table 7) are the identified potential sensors to measure 'PYR' which are compared.

	McLaren Gyro 3 Axis [27]	Watson PRO GYRO® PRO-152 [28]	Epson M-G350 [29]	Althen CRS03 [30]	KA Gyro sensor KG- 200-5-3- 050-000 [31]
Image					
Sensitivity Range (°/s)	+/- 300	+/- 400	+/- 300	+/- 200	+/- 200
Input Voltage	8–16	8–45	3.3–3.5	4.75–5.25	5V
No of Axis	3	1	3	1	3
Output	Analogue	Analogue	Digital	Analogue	Analogue
Current Consumption (mA)	140	60	30	35	25
Resolution (°/s)	0.3	0.1	0.1	0.1	0.1
Cost	£2200	£932.98 x 3	£1350	£800 x 3	£990
Score	16	15	20	18	21

 = 3  = 2  = 1

Table 7: Identified Sensor Comparison for Pitch, Yaw and Roll

It is believed that the most suitable sensor for measuring pitch, yaw and roll is the KA Gyro Sensor. This sensor is regarded as the best option as it has a three axis output, meaning that only one sensor is needed rather than three separate sensors. The sensor also provides a good range of sensitivity and due to it being built for automotive applications has protective shock resistant casing. The sensor was also chosen over other triple axis gyros such as the Epson M-G350 and McLaren gyro due to it being cheaper and having optimal input voltage supply. The sensor will be implemented within vehicle generally near the rear to measure PYR more accurately.

3.4. Suspension

Suspension in a vehicle maximises the grip and friction between driving surface and tires [32]. The main suspension seating on a vehicle sits on a rotary arm with a ball joint which fluctuates in height depending on road surface. To be able to measure suspension for a variety of cars an average suspension height is used. Approximate suspension height on a flat surface (stationary) is considered 300 mm from the wheel arch. From the central area it can extend to 150 mm either side of this point, making the total rotation length of 300 mm to be accounted for. Below is a list of potential technologies which could be used:

- **Infra-Red:** IR could be used to measure the distance the beam is away from the suspension axil. A reflective approach may be used by placing a reflective surface on the rotary arm of the suspension which will in turn give the distance.
- **Ultrasonic:** Ultrasonic transducer with a receiver and transmitter produces an ultrasound signal generally over 40 kHz [33]. If there is an object in the near vicinity it will reflect the sound back and will be picked up by the receiver. The time taken for the signal to return to the sensor can be used to calculate the suspension height.
- **Variable Resistor:** An extension type variable resistor could be used as it could be attached to the rotary arm of the suspension. It will extend in and out based on the movement made by the suspension creating a varying voltage.
- **Rotatory Encoder:** A rotary encoder works by converting an angular position or movement into an analogue or digital signal. This could be used for measuring the suspension height as it could be fitted to the rotary arm measuring rotation and positional movement which can therefore be used to measure the distance.

3.4.1. Sensor Type Comparison

The component selection table (table 8) below compares the identified component types for measuring suspension.

	IR	Ultrasonic	Variable Resistor	Rotary Encoder
Cost	Expensive	Medium	Medium	Medium
Size	Small	Small	Medium	Small
Accuracy	Low (due to interference)	Low (due to interference)	High	Medium
Robustness	High	High	Medium	Medium
Reliability	Low	Low	High	High
Score	6	7	9	9

 = 3  = 2  = 1

Table 8: Sensor Type Comparison for Suspension

It is believed that the best type of sensor for measuring suspension is a linear potentiometer. Although it shares similar benefits with that of a rotary encoder, there is a concern that a rotary encoder may not provide a full rotational measurement. IR is not considered as a suitable option as although it is used extensively in other applications for distance measurement if any wet conditions are present on the track then the IR signal will be absorbed by the water. A similar reasoning prevents ultrasonic being suitable as wind would interfere and destroy the signal at high speeds.

3.4.2. Identified Sensors

The table below (table 9) compares the identified sensors for measuring suspension.

	LP-22 Series Linear Potentiometer [34]	Altheris 30FLP400A [35]	Multi- Sense MS-19M- 300 [36]	Way Con LZW-B-300 [37]	RS Pro WT22 Series, Linear Potentiometer [38]
Image					
Electrical Stroke	300 mm	400 mm	300 mm	300 mm	300 mm
Supply Voltage	0 V – 36 V	5 V – 500 V	6 – 30 V	0V - 60 V	0 – 100 V
Length	425 mm	470 mm	448 mm	478 mm	416 mm
Resolution	< 0.01 mm	< 0.01 mm	< 0.01 mm	< 0.01 mm	<0.01 mm
Price	£201.89	£178.00	£270.87	£165.91	£ 157.57
Score	14	12	12	13	15

 = 3  = 2  = 1

Table 9: Identified Sensor Comparison for Suspension Ride

Regarded as the most suitable sensor for suspension is the RS Pro WT22 series 5kΩ linear potentiometer. This sensor provides a 300 mm electrical measurement range which meets the design specification. Although the majority of compared sensors provide a functional measurement range it is more compact and is around £50 cheaper than the LP-22 potentiometer. Both the Altheris sensor and Way-con LZW were disregarded as they have a length of 478 mm and 470 mm respectively meaning that they would not fit under the wheel arch of the vehicle when the suspension is at its lowest. The sensor will be implemented by fitting the sensor in between the wheel arch and on the rotary joint of the suspension.

3.5. Microcontroller Selection

For this system an 8 bit microcontroller will be used. To select a microprocessor for the system the following information is required:

- Number of pins
- Program memory
- RAM
- Clock frequency
- Analogue to digital convertor resolution

3.5.1. Number of Pins

The number of pins required is summarised in the table below (table 10).

Analogue Inputs	9
Digital Inputs	2
Digital Outputs	1
Serial Peripheral Interface	3
Power	2
USB	2
RS232	2
Total	20

Table 10: Microcontroller Required Pins

It is decided that an internal clock will be used as it would provide less components on the PCB therefore decreasing cost of land. A RS232 and USB ports will be required to provide connectivity to PCs. Also a SPI port is needed to connect the SD card for data storage. In total 20 pins would be required. However allocation of around 24 to 28 pins is more feasible to allow for potential future additions.

3.5.2. Program Memory and RAM

Approximations of program memory and RAM are required. Program memory will be required to hold eight analogue to digital conversions, timers, counters and loops as well as initialising ports and registers. Approximation of both RAM and program memory are shown below:

Average program language is around 1 Byte per 1 character, on average one line is 25 characters long.

Therefore:

$$1kB = \text{approx. } 40 \text{ lines}$$

The table below (table 11) shows the approximate number of lines required:

Code	Approximate number of lines
A/D Conversion	8 lines x 8
Timers	4 lines x 8
Loops	15 to 30 lines
Counters	10 to 30 lines
Other Code	50 to 150 lines
Total	306

Table 11: Lines of Code Approximation

So:

$$\text{Program Memory} = 306 \text{ lines} \times 25 = 7.7 \text{ K}$$

To allow for any errors and for future improvements the program memory will be doubled:

$$\text{Program Memory} = 16 \text{ K}$$

The RAM for the system is approximated using the program memory information.

So:

$$\text{RAM} = 160 \text{ Bytes}$$

Although both RAM and program memory may have been over approximated, this is to allow for any additional code and features.

3.5.3. Clock Frequency

To calculate the clock frequency an approximation method is used. Below is a breakdown of instructions required for an Analogue to Digital conversion.

Select Channel = 4 instructions

Wait = 30 us

Convert = 1 instruction

Wait = 6 us

Read Conversion = 12 instructions

Store Data = 100 instructions

Total instructions = 117 + 36 us = 153 us

This would be repeated for all analogue inputs.

For temperature A/D convertor is needed:

Therefore:

Cycles per second = 153 × 4 = 612 cycles per second

Cycles per 10 seconds = $\frac{612}{10} = 61.2$ cycles per 10 seconds

For suspension A/D convertor required:

Therefore:

Cycles per second = 153 × 4 = 612

612 × 1000 times a second = 612,000 cycles

612,000 × 4 readings taken = 2,448,000 cycles per second

For PYR A/D conversion required:

Therefore:

$$\text{Cycles per second} = 153 \times 4 = 612$$

$$612 \times 500 \text{ times a second} = 306,000 \text{ cycles}$$

$$612,000 \times 3 \text{ readings taken} = 918,000 \text{ cycles per second}$$

Speed and RPM are both digital signals therefore do not need an A/D conversion. However they need to be read and applied to a counter loop.

$$\text{Read Sensor} = 4 \text{ instructions}$$

$$\text{Add to Counter} = 1 \text{ instruction}$$

$$\text{Speed RPM calculations} = 4 \text{ instructions}$$

$$\text{Store data} = 100 \text{ instructions}$$

$$\text{Total instructions} = 109 \text{ instructions}$$

For speed, say diameter of wheel is 20 inches.

Therefore:

$$\pi \times 20 = 62.8 \text{ inches}$$

$$1 \text{ foot} = 12 \text{ inches}$$

$$1 \text{ mile} = 63,360 \text{ inches}$$

So at 160 mph:

$$\frac{160 \text{ miles}}{1 \text{ hour}} \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{12 \text{ inches}}{1 \text{ foot}} \times \frac{1 \text{ Revolution}}{\pi 20} \times \frac{1 \text{ hour}}{60 \text{ minutes}} = 2689.1 \text{ rpm}$$

$$\frac{2151.26}{60} = 44.81 \text{ revs per second}$$

So there will be 44 pulses per second.

So at 1mph:

$$\frac{1 \text{ miles}}{1 \text{ hour}} \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{12 \text{ inches}}{1 \text{ foot}} \times \frac{1 \text{ Revolution}}{\pi 20} \times \frac{1 \text{ hour}}{60 \text{ minutes}} = 16.8 \text{ rpm}$$

$$\frac{16,8}{60} = 0.28 \text{ revs per second}$$

So there will be 0.28 pulses per second.

To achieve a greater ratio four reflective strips will be painted to the wheel to measure lower speeds with greater accuracy.

So with four reflective strips:

At 1mph:

$$0.28 \times 4 = 1.12 \text{ pulses per second}$$

At 160mph:

$$44.8 \times 4 = 179.2 \text{ pulses per second}$$

So at max speed:

$$109 \times 179.2 = 19,532.8$$

$$19,532.8 \times 4 = 78,131.2 \text{ cycles per second}$$

RPM at max is 8,000 revs per minute:

Therefore:

$$\frac{8000}{60} = 133.33 \text{ pulses per second}$$

$$133.33 \times 109 = 14,532.97$$

$$14532.97 \times 4 = 58,128 \text{ cycles per second}$$

Total cycles per second:

$$Total = 61.2 + 2,248,000 + 918,000 + 78,131 + 58,128 = 3,302,320 \text{ cycles per second}$$

Add other cycles ~ 4,000,000 cycles per second

Although a clock running at 4 MHz would be deemed as sufficient it is better to over speculate.

A clock running at 12 MHz to 16 MHz would be regarded as more than sufficient to run the microcontroller off. This will also insure that if any other sensors are added in future applications the microcontroller can still run efficiently.

3.5.4. Analogue to Digital Convertor Resolution

The Analogue to Digital convertor resolution required is calculated below, it is only a concern for suspension, PYR and engine temperature. Both speed and RPM are digital:

Suspension – Supply 5V, 300 mm max length

So:

$$\frac{5V}{300mm} = 0.01667 V/mm$$

Therefore:

$$8 \text{ bit Resolution} = \frac{5}{256} = 0.01953 V$$

Not enough, so:

$$10 \text{ bit Resolution} = \frac{5}{1024} = 0.0043 V$$

10 bit required for suspension

Temperature – Supply 5V, -40 to 400°C

So:

$$\frac{5}{440} = 0.01136 V/^{\circ}C$$

Using previously calculated equations 10 bit is required for temperature.

PYR – Supply 5V, +/-200°/s

So:

$$\frac{5}{400} = 0.0125 V/^{\circ}s$$

Using previously calculated equations 10 bit is required for PYR.

A 10 bit analogue to digital convertor is required for the system. Please refer to appendix A for voltage graphs for each component.

3.5.5. Final Selection

The screenshot below shows entering all the parameters into 'Microchips' search engine to find the ideal microcontroller (figure 12). Also below (table 12) is a comparison table comparing the microcontrollers identified.

Product	Buy	Status	Documents	SK Pricing	Program Memory Size (Kbytes)	RAM (bytes)	EEPROM / HEF	Pin count	Max. CPU Speed MHz	Peripheral Pin Select (PPS)
PIC18F24K50	\$	In Production		\$1.65	16	2048	256 / HEF	28	48	No
PIC18F25K50	\$	In Production		\$1.76	32	2048	256 / HEF	28	48	No
PIC18F45K50	\$	In Production		\$1.99	32	2048	256	40	48	No

Figure 12: PIC Selection Screenshot

	PIC18F24K50 [39]	PIC18F25K50 [39]	PIC18F45K50 [39]
Image			
Price per 5K	£1.26	£1.35	£1.52
A/D Resolution	10 bits	10 bits	10 bits
A/D Channels	14	14	25
Program Memory	16 Kbytes	32 Kbytes	32 Kbytes
Internal Oscillator	16, 32 MHz	16 MHz	16 MHz
RAM	2048 bytes	2048 bytes	2048 bytes
Number of Pins	28	28	40
Score	21	19	15

= 3
 = 2
 = 1

Table 12: Microcontroller Comparison

The microcontroller which is best suited for the design is the 'PIC18F24K50'. It is cheaper than both other microcontrollers and matches against all specified parameters. Although the other microcontrollers would be suited to the design they are regarded as over kill. For example if the 'PIC18F45K50' which is a 40 pin device was chosen most of the pins would not be in use.

3.6. Connector Selection

Connectors for this design should have characteristics suitable for light outdoor use, be rugged and durable. They should be a minimum rating of IP65 to ensure these characteristics are met. The table below (table 13) compares a variety of connectors which potentially may be used.

	TE Connectivity / DEUTSCH HD10 [40]	Souriau UTP Series [41]	Binder Snap-in IP67 Connectors (620 Series) [42]	Lemo L connector series [43]
Image				
IP Rating	68	65	67	67
Contact Ranges	3 – 9	4 - 23	3 – 8	3 - 9
Material	Plastic	Plastic	Plastic	Plastic
Fitting Type	Twist	Twist	Twist	Twist
Price	£5.90 - £14.99	£7.90 - £13.99	£9.23 - £15.80	£11.90 - £24.60
Score	15	14	14	13

 = 3  = 2  = 1

Table 13: Connector Comparison

The connectors which will be used in the final design are 'Deutsch HD10'. The connectors provide a range of contact configurations and are cheaper than the other compared connectors. They are also a twist fitting type making maintenance and fitting easy. For the design each sensor will have its own configuration and be colour coded. This to prevent users mistakenly plugging wrong sensors into incorrect connectors to avoid potentially damaging internals. The table below (table 14) shows the connector configurations which will be used.

Measurement/Sensor	Pins Required	Connector Selection (HD10 series)	Image [40]
Front Right	3	3-16/3-96 3 size 16	
Front Left	3	3-16/3-96 3 size 16	
Rear Right	3	3-16/3-96 3 size 16	
Rear Left	3	3-16/3-96 3 size 16	
Engine Temperature	4	5-16 5 size 16	
Pitch, Roll and Yaw	5	6-12 6 size 12	
Speed	4	4-4 1 size 4 3 size 16	
RPM	4	4-4 1 size 4 3 size 16	

Table 14: Connector Layout

3.7. Data Sizing

Data from the system will be stored on non-volatile memory. Below are the interval times which each measurement reading will be taken:

- Engine Temperature: One reading every 10 seconds
- RPM: One reading every 1 second
- Suspension: Four readings every 1 ms
- PYR: Three readings every 0.2 ms
- Road Speed: One reading every 1 second

Below is a summary of the calculations used in calculating the required non-volatile memory for the system.

Engine Temperature: Reading once every 10 seconds which will be stored as an integer.

For approximation say an integer value is 4 bytes.

So:

$$\text{Readings in 2 hours} = \frac{7200}{10} = 720 \text{ readings}$$

Therefore:

$$\text{Memory required for temperature} = 720 \times 4 = 2,880 \text{ Bytes}$$

Speed: Reading once every second which will be stored as an integer value.

So:

$$\text{Readings in 2 hours} = \frac{7200}{1} = 7,200 \text{ readings}$$

Therefore:

$$\text{Memory required for speed} = 7200 \times 4 = 28,800 \text{ Bytes}$$

RPM: Reading once every second which will be stored as an integer value.

So:

$$\text{Readings in 2 hours} = \frac{7200}{1} = 7,200 \text{ readings}$$

Therefore:

$$\text{Memory required for RPM} = 7200 \times 4 = 28,800 \text{ Bytes}$$

Suspension: Four readings once every 1 ms stored as integer value.

So:

$$\text{Readings in 2 hours} = \frac{7200}{0.001} = 7,200,000 \text{ readings}$$

Therefore:

$$\text{Memory required for Suspension} = 7,200,000 \times 4 = 28,800,000 \text{ Bytes}$$

Therefore:

$$\text{Total Memory} = 28,800,000 \times 4 = 115,200,000 \text{ Bytes}$$

PYR: Three readings once every 2 ms stored as integer value.

So:

$$\text{Readings in 2 hours} = \frac{7200}{0.002} = 3,600,000 \text{ readings}$$

Therefore:

$$\text{Memory Required for PYR} = 3,600,000 \times 4 = 14,400,000 \text{ Bytes}$$

Therefore:

$$\text{Total Memory} = 14,400,000 \times 3 = 43,200,000 \text{ Bytes}$$

Total Memory required:

$$\begin{aligned} &2,880 + 28,800 + 28,800 + 115,200,000 + 43,200,000 \\ &= 158,460,480 \text{ Bytes or } 158.46 \text{ MB} \end{aligned}$$

This is the total amount of non-volatile memory needed for an individual two hour run. However due to SD cards being relatively cheap and assuming that the user would require more than one test run a 2GB SD card is recommended as a minimum. A 2GB SD card will store just over 12 two hour test runs. A suitable SD card is the Integral 2GB micro SD card with adapter (figure 13). The card is cheap and is of the recommended size. A 3.3V voltage regulator is required to satisfy the SD cards operating voltage. A standard 7803 voltage regulator will be used to produce a 3.3V supply for the SD card module.



Figure 13: Integral 2GB SD card [44]

3.8. Power Supply

The system must be powered from its own battery source. All sensors run off 5V which means that a battery which can produce 5V supply is needed. To select a suitable battery however the total current the circuit will draw must be calculated which is outlined below (table 15).

Sensor	Max current draw
Micro-Epsilon thermoMETER CS	4 mA
Monarch IRS - Infrared Optical Sensor IRS-W x 2	40 mA x 2
KA KG Gyro Sensor	25 mA
RS Pro WT22 Series, Linear Potentiometer	1.4 mA x 4
Microcontroller	Approx. 150 mA (max)
LED	25 mA
Total	289.6 mA

Table 15: Current Draw

For the system to last two hours a battery source with a 5V rating and which has a mA/h rating of 579.2 mA/h. A 7.2V NiMH rechargeable battery with 2000 mA/h by RS (figure 14) has been identified as a suitable source. This battery would be more than ample and would cope if future additions are added to the design. The source would allow the system to operate for just under 7 hours. Due to all sensors working off a 5V supply a voltage regulator will be used to keep the voltage a steady 5V, a standard 7805 regulator will be implemented in the design. [45]



Figure 14: 7.2V NiMH Rechargeable Battery

4. Final Design

This section presents all the final circuit designs including a circuit schematic, a PCB layout, data structure, software structure and casing diagrams.

4.1. Initial Block Diagram

Below is a block diagram of the full system (figure 15).

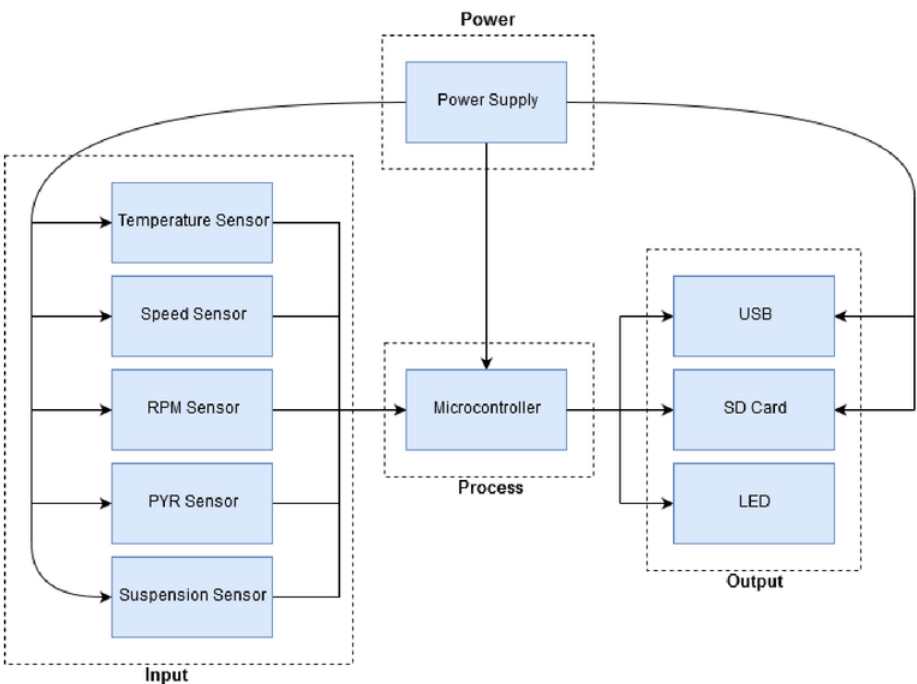


Figure 15: Initial Block Diagram

4.2. Circuit Schematic

The schematic was designed using CAD package 'Proteus'. Due to the size of the schematic the circuit has been broken down into sections. Please refer to 'appendix B' for a full circuit layout.

Power Supply:

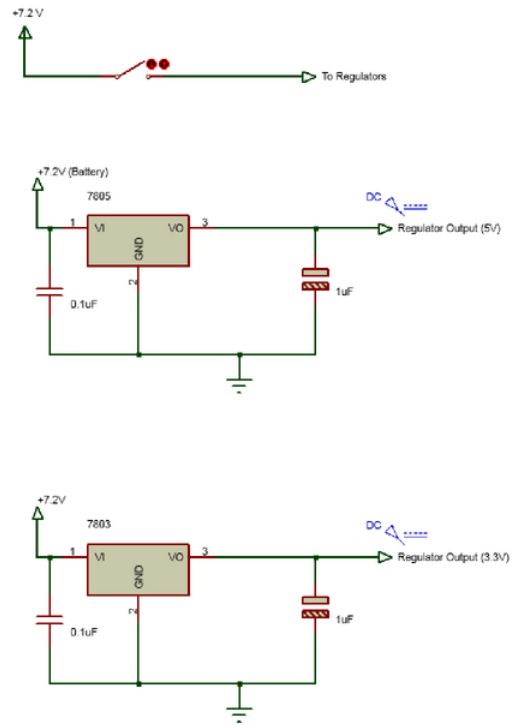


Figure 16: Power Supply Schematic

This section of the design (figure 16) shows the power input to the system. The power is supplied off a 7.2V battery with a switch connected to allow the user to switch off the system. The battery is then fed into a 7805 voltage regulator to supply 5V for the sensors and a 7803 regulator to supply 3.3V to the SD card.

Temperature Sensor:

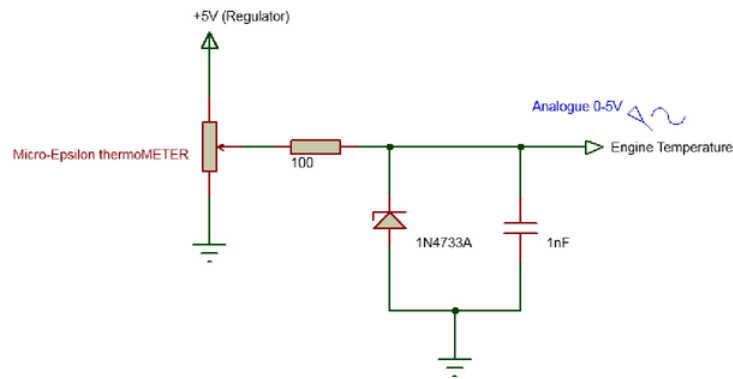


Figure 17: Temperature Sensor Schematic

The temperature sensor (figure 17) requires 5V which is supplied from the 7805 regulator. The output is then fed into a voltage clamp to prevent any surges and fix the voltage to 5V. The clamp is made up of a 1N4733A diode a 100 ohm resistor and 1nF capacitor. The sensor has an analogue output which is a 0-5V signal.

RPM and Speed Sensor:

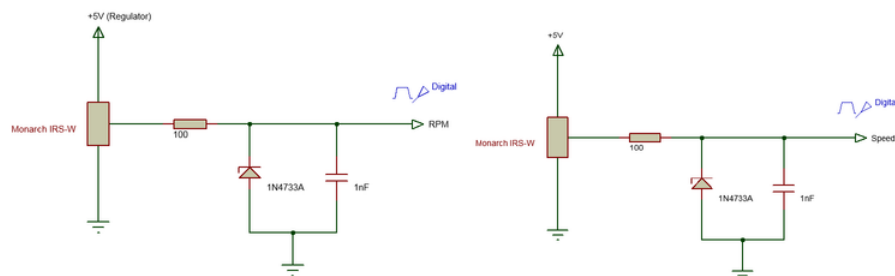


Figure 18: RPM and Speed Sensor Schematic

Both RPM and speed sensors (figure 18) require a 5V supply voltage which is supplied from the 7805 regulator. A voltage clamp is used on the output. Both signals are digital outputs and are fed directly to an I/O pin in the microcontroller.

Suspension Sensors:

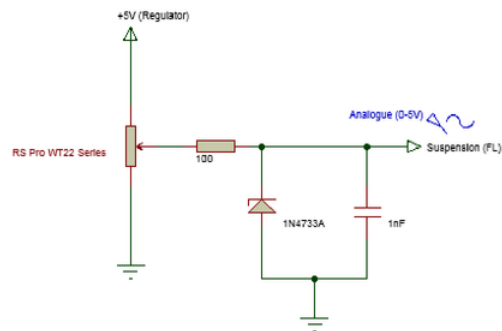


Figure 19: Suspension Sensor Schematic

There are four suspension sensor (figure 19) situated in the design. Each sensor requires 5V which is supplied off the 7805 regulator. A voltage clamp is used with the output being an analogue voltage at 0-5V.

PYR Sensor:

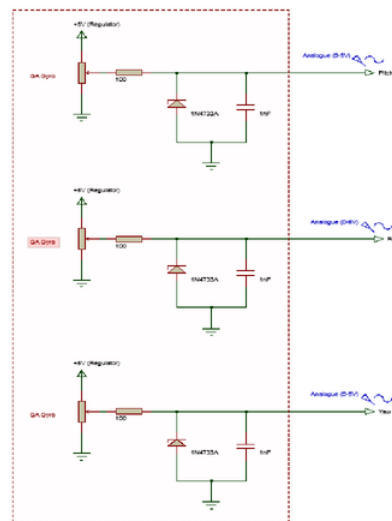


Figure 20: PYR Sensor Schematic

The gyro sensor (figure 20) requires a 5V supply which is taken from the 7805. The sensor has three axis analogue outputs where a voltage clamp is used on each axis.

Outputs:

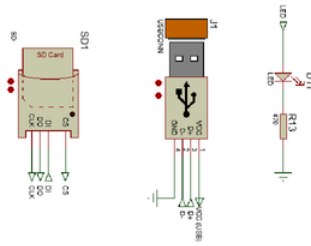


Figure 21: Outputs Schematic

The outputs (figure 21) for the system are mainly from the USB and SD card. The USB supply voltage is taken from the microcontrollers built in USB output regulator. D+ and D- are connected to the related pins on the microcontroller. The SD card requires a 3.3V supply which is taken from the 3.3V regulator. Din and Dout are connected to the relevant pins as with the clock. The LED is connected to provide indication that the system is on. It is connected through the microcontroller with a 470 ohm current limiting resistor to ground.

PIC18F24K50:

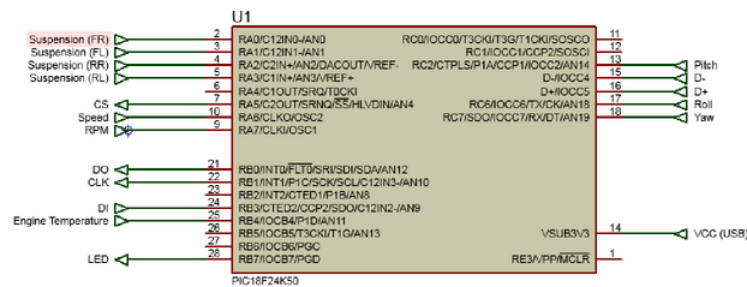


Figure 22: Microcontroller Schematic

The microcontroller (figure 22) shows all the input and output connections. Suspension sensors are connected to port RA0 to RA3 which are set as analogue input ports. The speed sensor is connected to port RA6 and RPM to RA7 which are just digital inputs. The temperature sensor is connected to RB4 which is set to an analogue input. Pitch is connected to RC2, Roll to RC6 and Yaw to RC7 which are all set to analogue inputs. The USB is supplied off pin 14 which is a USB regulated output, with pin D+ and D- being connected to 15 and 16 respectively. The SD Card pins Dout and Din are connected to pin 21 and 24, which are both configured as SD card inputs and outputs with the clock pin connected to 23. The LED output is connected to pin 28 which is set as an output pin.

Noise:

Although the circuit is stable there is a concern for noise especially with the RPM sensor as it is fitted in the engine. Although a differential amplifier maybe used to reduce the noise it would require more components and increasing the size of the PCB. To reduce the noise shield casing may be used. There is also a shield connection on the RPM and speed sensors which can be connected to an external casing or node. This will then act as a drain to reduce any noise within the system.

4.3. PCB Layout

Shown below are the PCB layout designs (figures 23 to 28) which were designed using 'Easy-PC'.

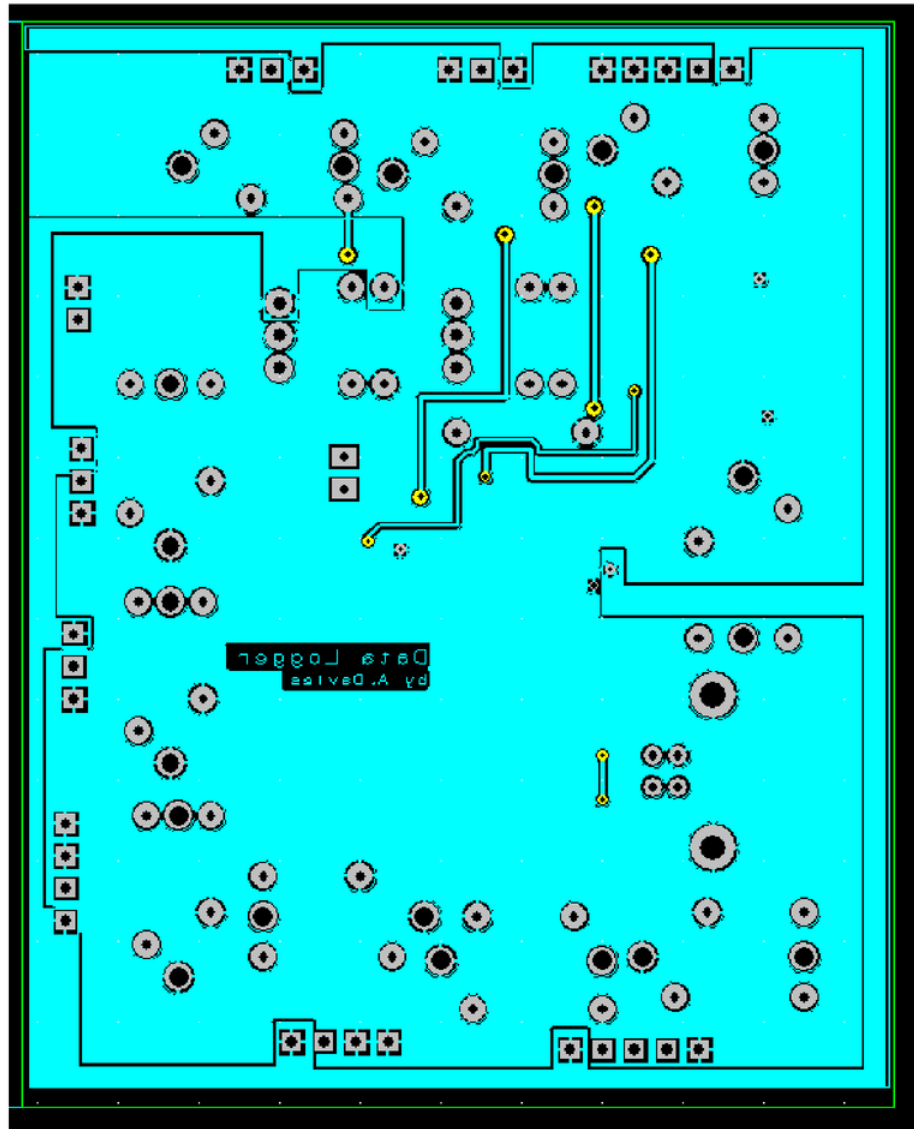


Figure 23: PCB Bottom Layer

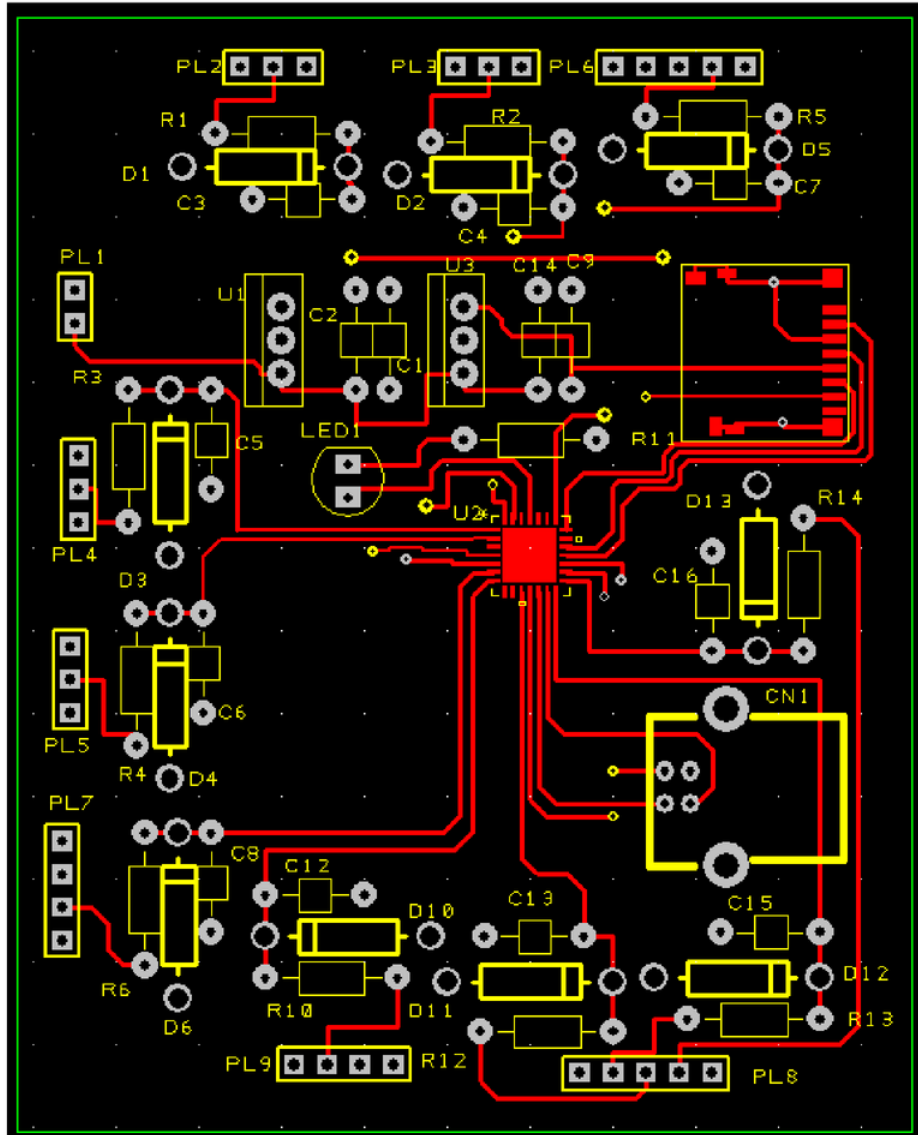


Figure 24: PCB Top Layer

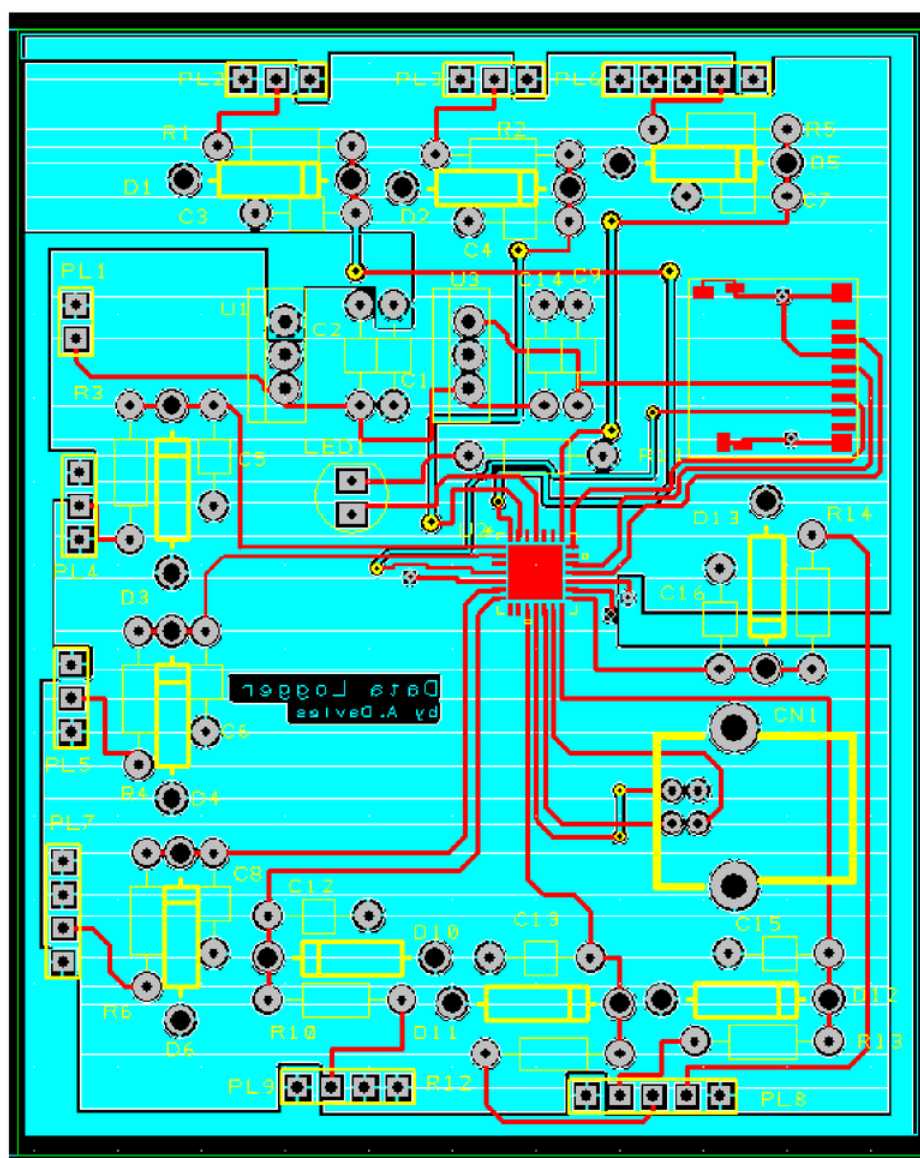


Figure 25: PCB Full View

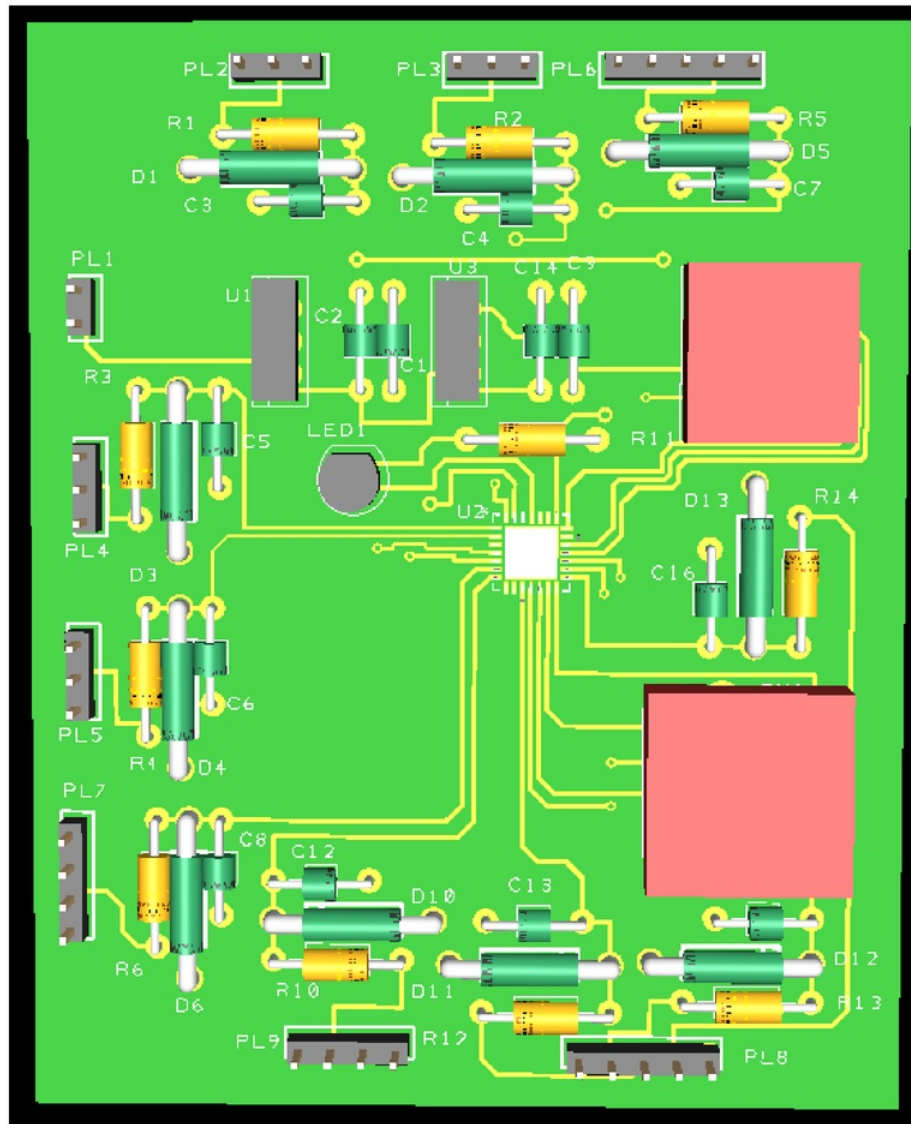


Figure 26: PCB Top 3D View

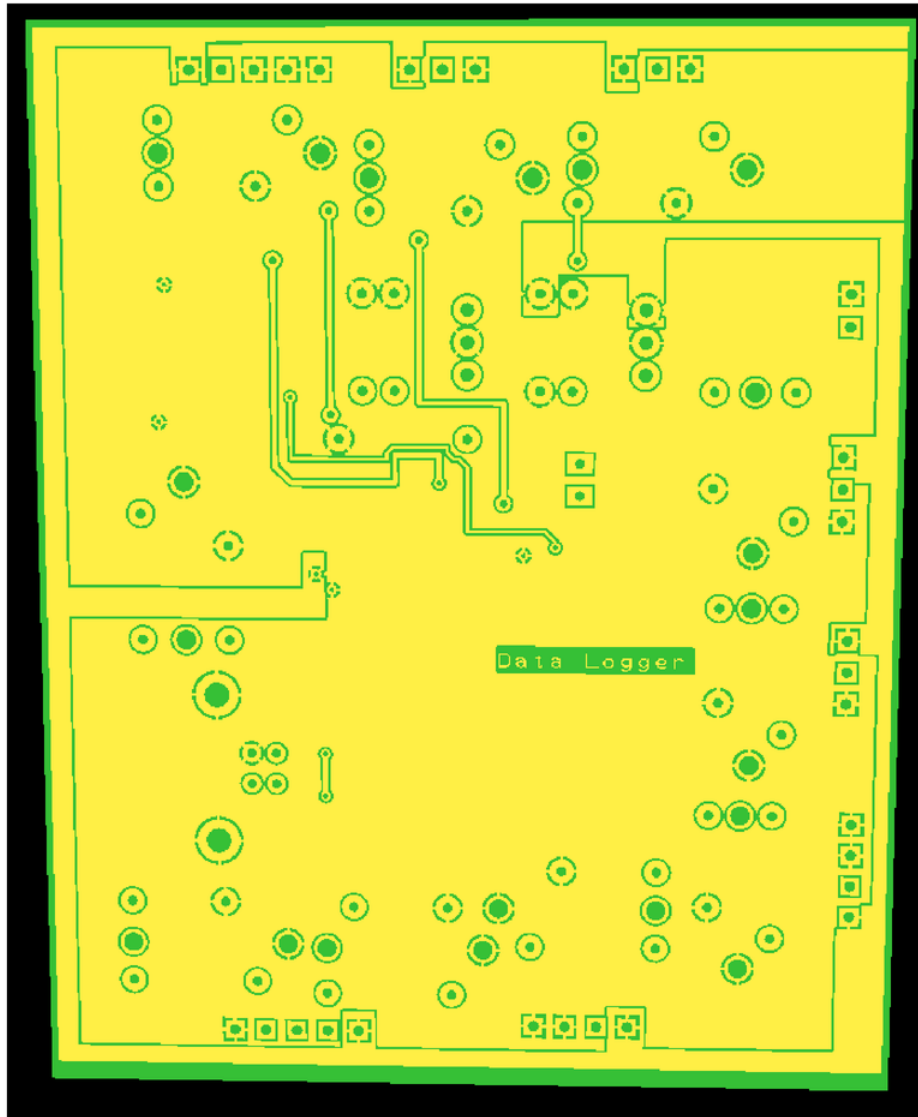


Figure 27: PCB Bottom 3D View

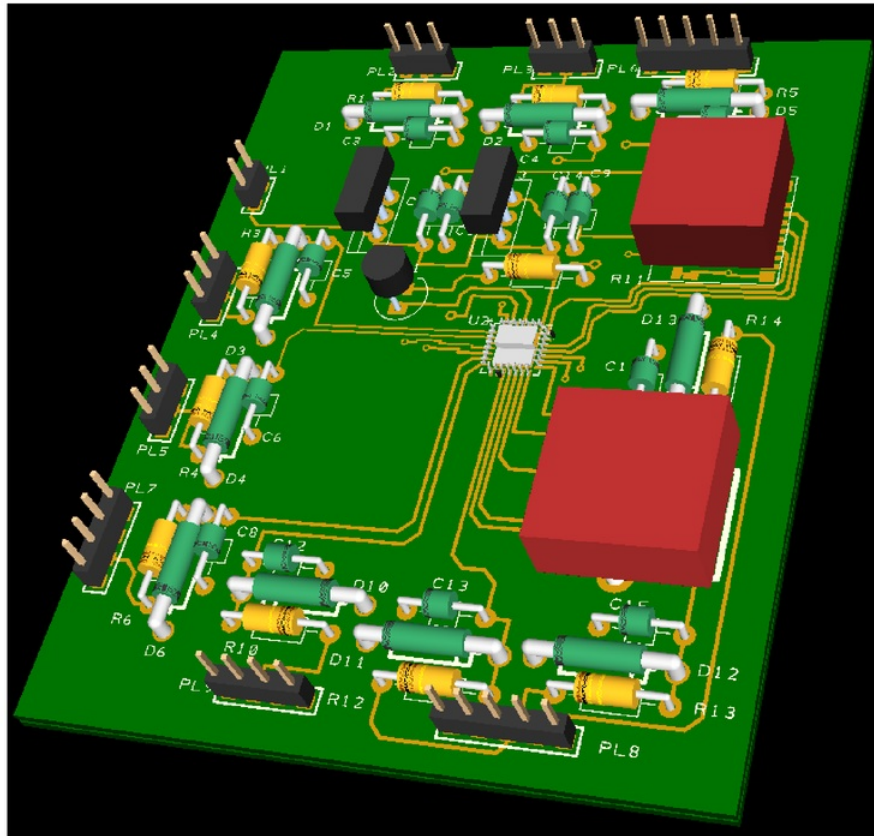


Figure 28: PCB 3D View

The PCB design uses a surface mount microcontroller to reduce the space on the board. All connectors are connected on the outside of the board for good practice. All signals are taken through copper tracks on the surface of the board which connects all the sensors and output connections to the microcontroller. To optimize the nets when designing the PCB a dummy layer for 0V and 5V were used to allow for copper to be poured. The copper on the base of the board connects 0V and 5V reducing the on surface connections. The USB and SD ports will require extension cabling so they can be fitted to the front of the casing to make them accessible for the user.

4.4. Software Diagram

Shown below (figure 29) is a structured flow chart showing how the program will operate.

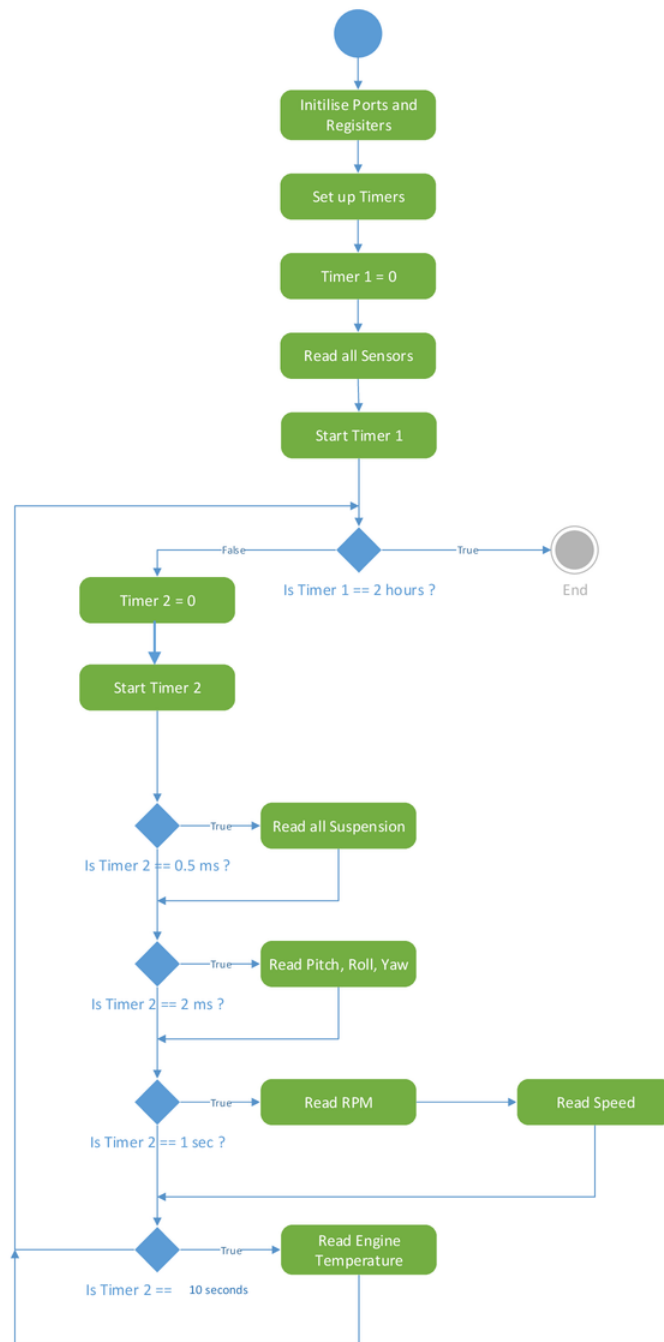


Figure 29: Software Flow Chart

The software structure diagram shows how the program will run and read the data at the respected time intervals. There are two timers which are set, timer 1 controls the outer loop to reset the system and the second timer controls the data recording which after 10 seconds is reset and started again. If the system has reached 2 hours it will stop recording the data. For more simple flowcharts please refer to 'appendix C'.

4.5. Data Structure

The table (table 16) below shows a graphical representation of how the data will be stored.

0	T	RS	RPM	P	R	Y	FR	FL	RR	RL
1							FR	FL	RR	RL
2				P	R	Y	FR	FL	RR	RL
3							FR	FL	RR	RL
4				P	R	Y	FR	FL	RR	RL
...	Until 500 ms									
500			RPM	P	R	Y	FR	FL	RR	RL
501							FR	FL	RR	RL
502				P	R	Y	FR	FL	RR	RL
...	Until 1,000 ms									
1,000		RS	RPM	P	R	Y	FR	FL	RR	RL
1,001							FR	FL	RR	RL
1,002				P	R	Y	FR	FL	RR	RL
...	Until 10,000 ms									
10,000	T	RS	RPM	P	R	Y	FR	FL	RR	RL
10,001							FR	FL	RR	RL
10,002				P	R	Y	FR	FL	RR	RL
...	Repeated until 7200000 ms									

Table 16: Data Structure Diagram

4.6. Casing Design

For the casing to meet the design specification it must have characteristics similar to the connectors, it must be rugged, durable and light in weight. The casing must fit the PCB which measures 65 mm x 85 mm and the battery pack which is 33 mm x 54 mm. This means the casing should be sized at least 120 mm x 100 mm. A suitable material for the casing is aluminium. Aluminium is light in weight and durable. Waterproofing casings can be bought which are sealed and have an IP rating of 65. A suitable casing choice is Hammond 1455N1602 aluminium instrument enclosure case. This casing is light weight, waterproof and has an IP rating of 65 which is shown below (figure 30).



Figure 30: Casing by Hammond [46]

Although there are a variety of casings on the market the casing will be designed to be tailored to fit the PCB and battery pack. The casing design will be made using aluminium. Shown below (figure 31 to 34) is a dimensional diagram and 3d diagrams produced.

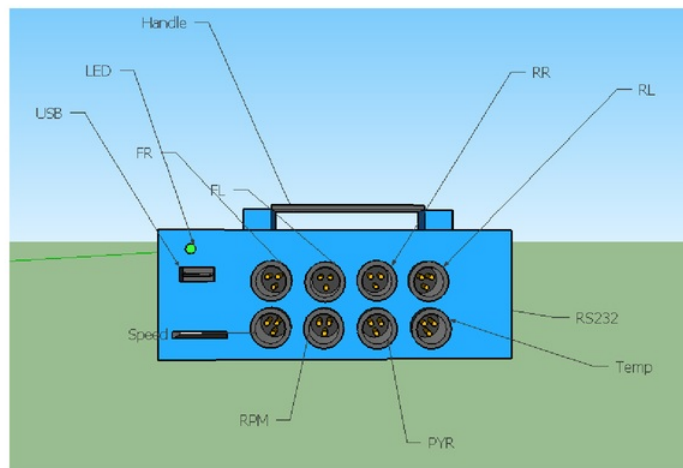


Figure 31: 3D Casing Front View

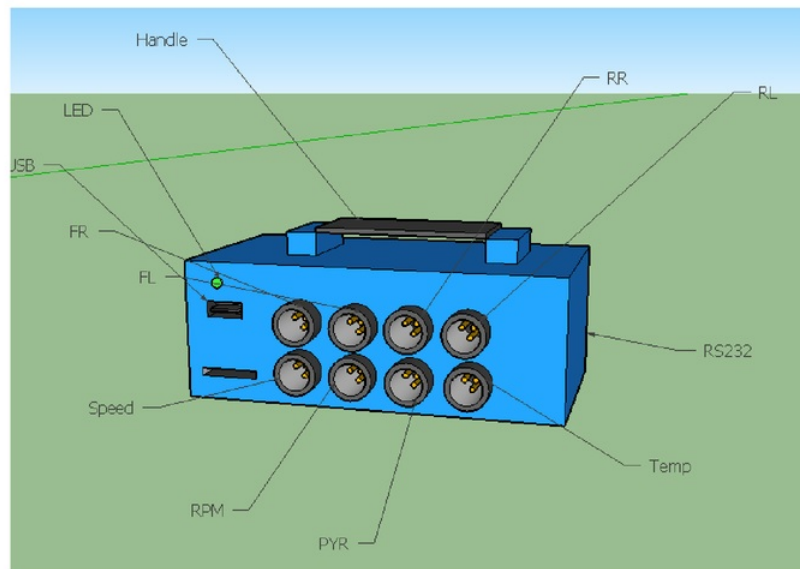


Figure 32: 3D View Casing

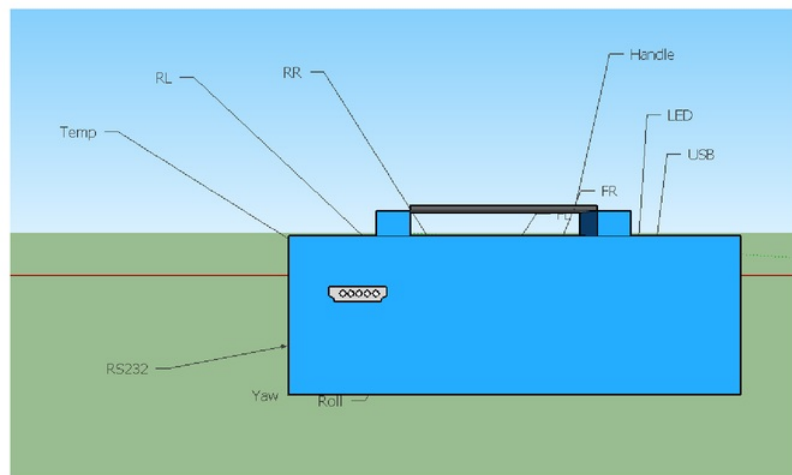


Figure 33: Casing Back View

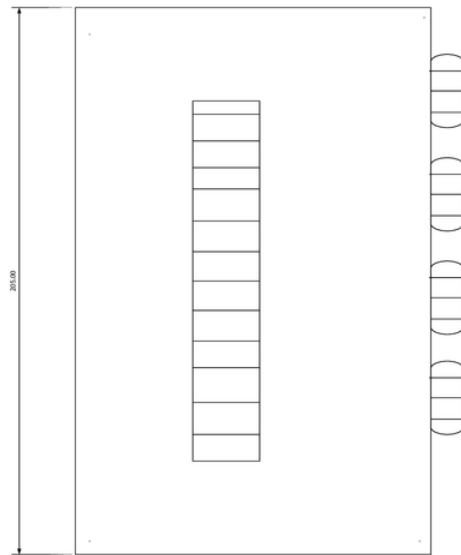
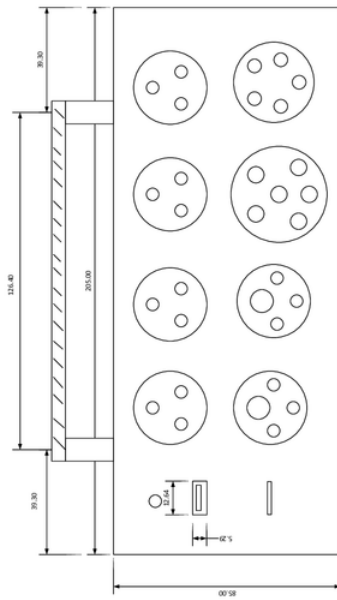
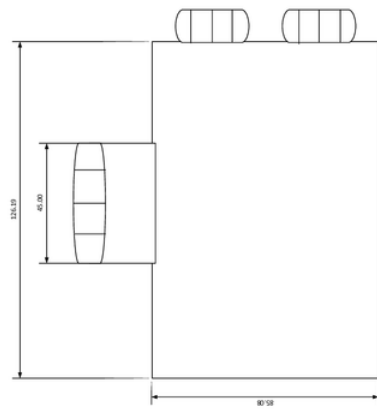


Figure 34: Dimensional Drawing of Design

4.7. Costing

The costing for the system is outlined in the table below (table 17).

Component	Quantity	Price
Micro Esplion Thermometer CS	1	£195.99
Monarch IRS - Infrared Optical Sensor IRS-W	2	£316.18
KA Gyro sensor KG-200-5-3 050-000	1	£990
RS Pro WT22 Series, Linear Potentiometer	4	£630.28
HD10 3-16	4	£23.44
HD10 5-15	1	£6.32
HD10 4-4	2	£11.97
HD10 6-16	1	£9.23
PIC18F24K50	1	£1.26
7.2V NiMH 2000ma/h Pack	1	£18.30
SD Card Module	1	£3.64
Integral 2GB SD Card	1	£14.99
USB Module	1	£4.15
RS232	1	£7.89
Green LED	1	£1.00
1N4773A Diode	10	£6.20
100 Ω Resistor	10	£6.90
1nF Capacitor	10	£1.00
1uF Electrolytic Capacitor	2	£0.42
0.1uF Capacitor	2	£0.40
7805 Voltage Regulator	1	£0.81
7803 Voltage Regulator	1	£0.81
Switch	1	£1.79
Casing	1	£40
PCB	1	£8.60
Total		£2,301.57

Table 17: Costing Table

The total price of the system is around £2,300. This is believed to be competitive when comparing it to current data logging systems. This includes all discrete sensors with the system which some existing products charge extra for. This price would be decreased depending on bulk buying and bulk manufacturing.

5. Recommendation and Conclusion

Overall the design is believed to be a success the sensors chosen measure all parameters through the full data range. The overall cost of the project is reasonable and competes well with existing products on the market. However there could be improvements made to the design.

One of the improvements could be to implement a display. This would allow the user to instantly view recorded data on site. This potentially would be fairly easy to achieve as a LCD screen could be used with some form of user input. Another potential improvement could be to use wireless sensors. This would be an advantage as cables would not have to be run and routed from the sensor to the device. This would require a Wi-Fi or other wireless module. A potential problem with this is that each sensor would have to have wireless compatibility.

Although the system designed is believed to be fairly accurate and measures within specification it could be improved. This could potentially be achieved by using a higher resolution so more values can be read from analogue sensors. With increased software design a recommendation could be to build a piece of software which displays all the information recorded so the data is not just raw data. The software would have an advantage as it could graphically display all data. Systems currently on the market mainly use built in GPS modules to measure data. This reduces the need for external sensors and could reduce the cost. However although these future improvements would greatly enhance the design and system it is still regarded as successful.

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8. Appendix

8.1. Appendix A

Suspension



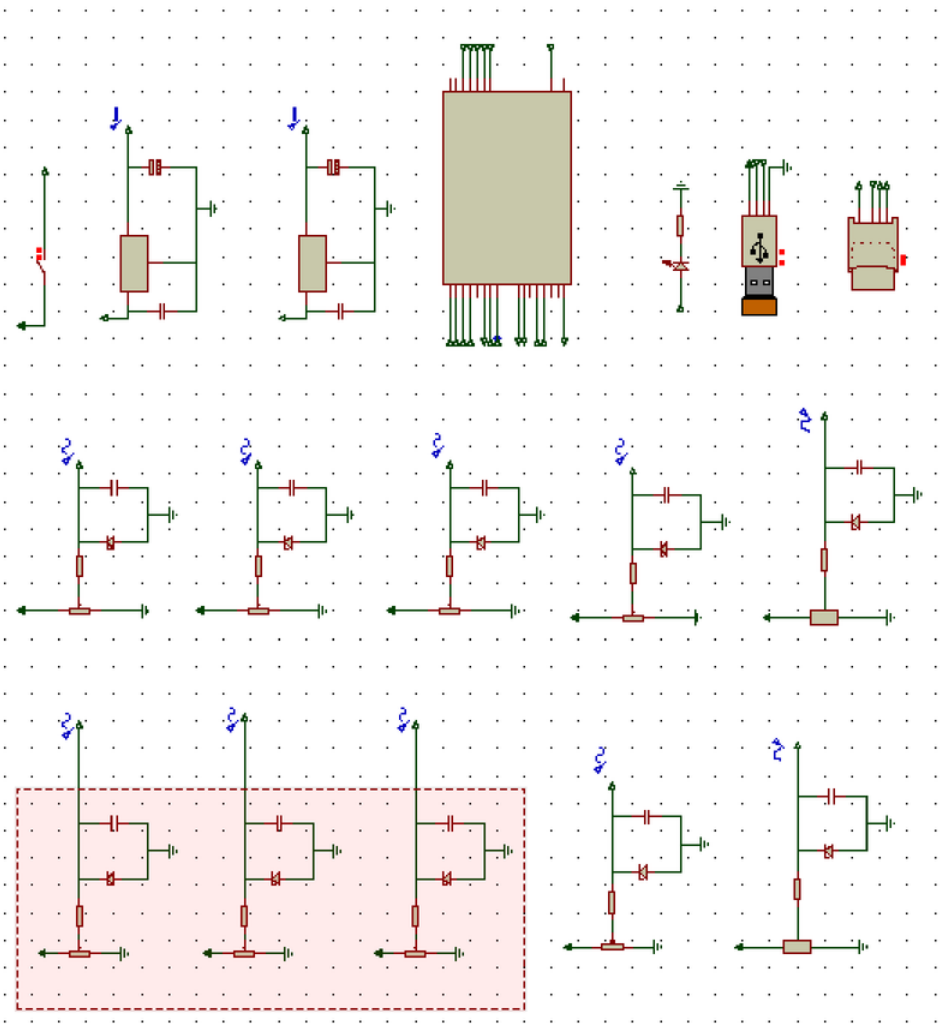
PYR



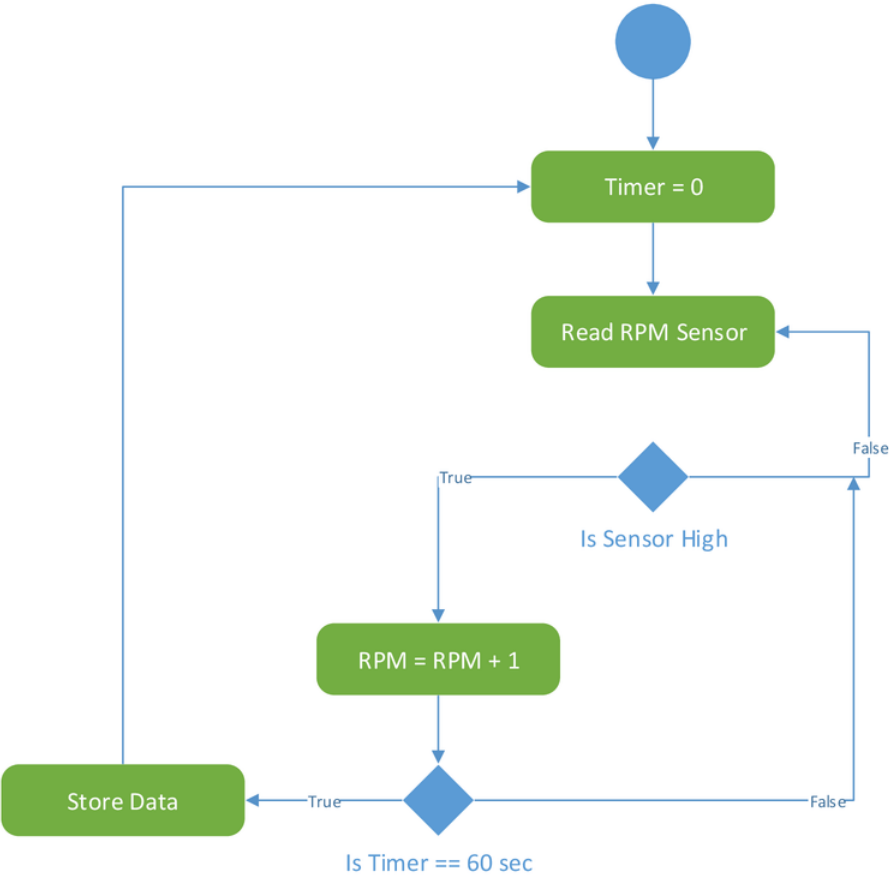
Temperature



8.2. Appendix B



RPM Subroutine



Adam Davies - ESD - Vehicle Data Logger Assignment

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

68/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

PAGE 43

PAGE 44

PAGE 45

PAGE 46

PAGE 47

PAGE 48

PAGE 49

PAGE 50

PAGE 51

PAGE 52

PAGE 53

PAGE 54

PAGE 55

PAGE 56

PAGE 57

PAGE 58

PAGE 59

PAGE 60

PAGE 61

PAGE 62

PAGE 63

PAGE 64

PAGE 65

PAGE 66

GRADING FORM: SMU GENERIC_GJ

ADAM PETER DAVIES

67.90

RESEARCH-INFORMED LITERATURE



Good literature review of available systems with a good comparison table of relevant information.68%

6.8

KNOWLEDGE AND UNDERSTANDING

-  Good overall schematic design but a few problems can be seen. The netnames and arrows in the schematic(Proteus) show that the di of the SDcard is an input on both end and the dO is an output on both ends. The D+and D- for the USB are shown as inputs on both ends these should both be bi-directional. A little more care is needed. 68%

17

ANALYSIS

-  Good selection of microcontroller. Good selection of sensors showing calcs for eash one with a very nicely laid out table showing the selection of sensors to be chosen from with an image or illustration of each. Reasonable case selection but there is no discussion or reflection of other cases. Good selection of connectors. 66%

23.1

PRACTICAL APPLICATION AND DEP.

-  Costings nicely put forward as a table with price but without supplier of component. Good attempt at future enhancements.65%

13

SKILLS FOR PROFESSIONAL PRAC.

-  The report is well presented with very well presented tabled data and structure diagrams. A good selection of references. 80%

8