

Oliver Kucyj ESD assignment 1

by Oliver Kucyj

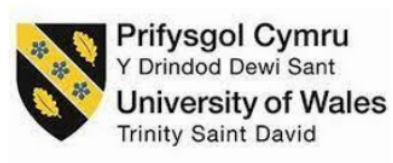
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Electronic System Design

Motor Vehicle Data Logger

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1 Abstract

This report will investigate vehicular data acquisition systems and detail the design of one aimed specifically at saloon cars, although it will be capable of monitoring other types of road vehicles. It will measure the coolant temperature, suspension travel on all 4 wheels, the car speed, engine speed and the pitch, roll and yaw of the car. This data will all be stored onto an SD card which can be read by plugging it into a computer via USB C. It will be a portable system with a rechargeable battery.

At the end of the report, improvements are recommended for the next iteration of the product.

2 Introduction

This report will investigate portable vehicular data acquisition systems. Existing products will be researched before designing a product to measure the coolant temperature, engine speed, car speed, suspension travel, pitch, roll and yaw. The system must be designed to store data from these sensors at suitable intervals and must have a USB interface to allow the data to be read. The report will compare numerous different sensors which could be used and will also provide a basic overview of how the system will operate.

The specification states that the system should be designed for saloon cars, however it should be adaptable for any vehicle class.

3 Portable vehicular data acquisition systems

3.1 What are portable vehicular data acquisition systems for?

Portable vehicular data acquisition systems (DAQs) can be installed onto a vehicle to monitor its performance. They monitor vehicle performance for in depth analysis afterwards [1].

They are common for enhancing vehicle performance in track racing. Without the DAQ, the data would need to be analysed in real time whilst driving. A DAQ system allows the data to be stored for future in depth analysis [2]. A DAQ can measure data from many different types of sensor. This data can then be used to optimise car performance and monitor vehicle safety.

A portable vehicular DAQ system will help to reduce costs thanks to shorter cable lengths and minimized installation times. Many products on the market achieve this by reading data from the vehicles existing sensors via a CAN (Controller Area Network) channel. An alternative method they use to reduce cable length is to use data loggers as shown in figure 1.

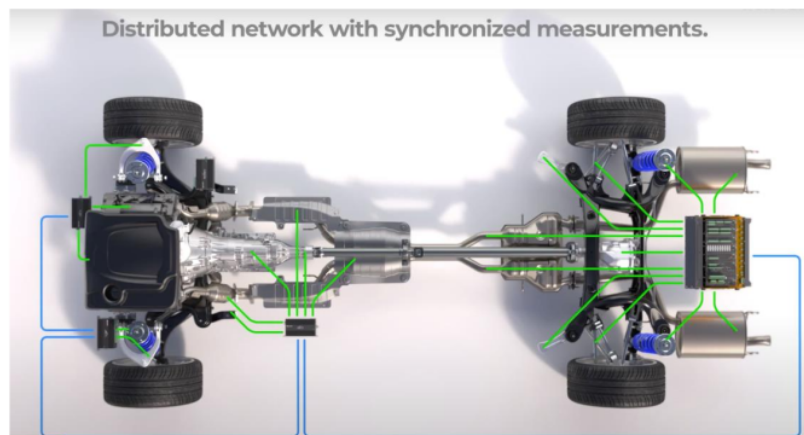


Figure 1 – Distributed network with synchronized measurements [3]

A modern method of testing used is Road Load Data Acquisition (RLDA). This involves test runs on test tracks or public roads under extreme conditions to gather information on the environmental inputs the vehicle will be subject to [4]. This is commonly done on pre-production prototype cars. An example of a portable vehicular DAQ is shown in figure 2. This system is modular, allowing adaptability.

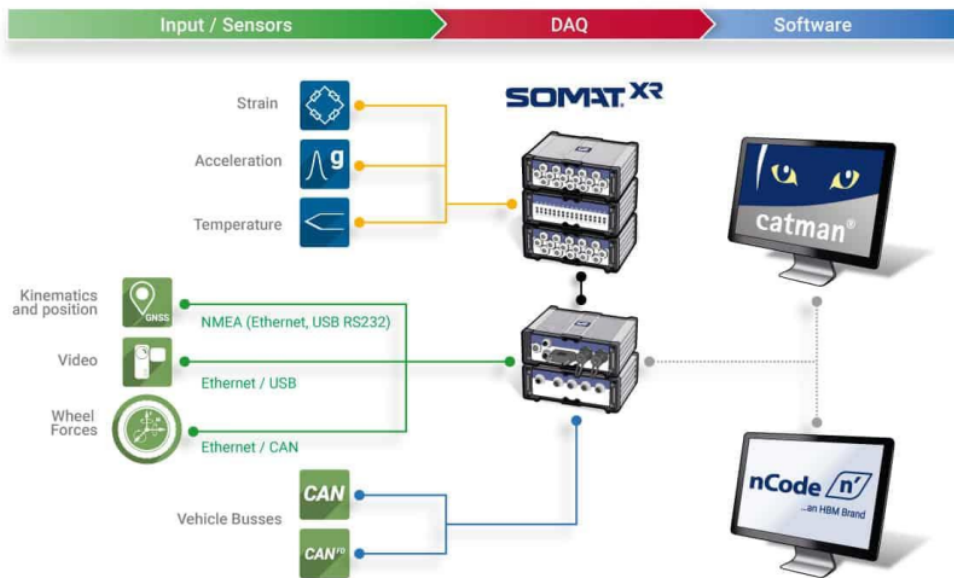


Figure 2 - Example of a data acquisition system [5]

3.2 What functionality do portable vehicular DAQs on the market offer?

There are many portable vehicular DAQs on the market, each with common functionality along with unique features. Table 1 compares 3 portable vehicular DAQs.

Feature	Granite 10 [6]	Dewsoft R8 line [7]	Captronic IVDAS [8]
Operating temperature	-40°C - +70°C	-40°C - +85°C	-40°C - +70°C
Storage	128GB SSD	Built in SSD	--
Storage expansion	Up to 16GB	--	--
GPS	Yes	Yes	Yes
Power requirements	9.6 – 32V DC	Battery powered	--
CAN channels	5	8	Yes
USB	yes	Yes	Yes
I/O	8 digital 8 pulse counters	Up to 128 analogue 64 counters 192 digital 64 analogue outputs	Analogue and digital
Sample rate	--	1MS/sec	--
Protection	--	IP67	IP67
Additional comments	Real time clock	Can connect any sensor type Video connection 24-bit sampling	Configurable E.G. sample rate. Many sensors are compatible, such as strain gauge, thermocouple, vibration, digital inputs.

Table 1 – portable vehicular data acquisition systems

4 System block diagram

Figure 3 shows the system block diagram. This highlights the key components and their interactions. This diagram highlights the required IO ports.

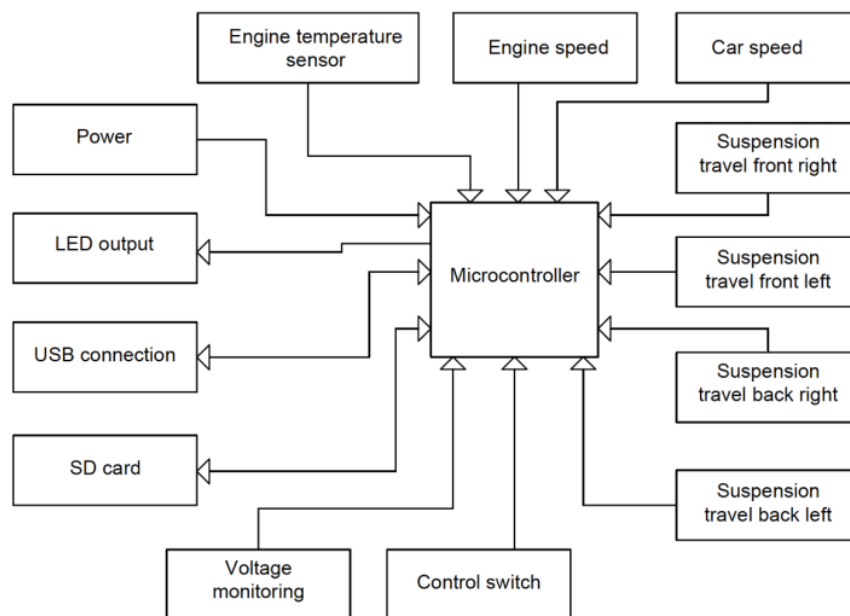


Figure 3 – System Block Diagram

5 Choosing a microcontroller

To identify the microcontroller, the microchip comparison tool was utilized [9]. The following criteria was set:

- 8-bit 
- 5V
- 7 ADC inputs 10-bit
- 2 SPI ports
- 1 USB module
- 2 input capture modules

The input capture modules will measure the pulsed input from the speed measurements. They will store the time taken for a pre-set number of pulses as opposed to counting pulses. This can then be used to calculate the RPM [10].

Program memory was not mentioned in the search as minimal memory will be required. The data processing and calculations will happen on the computer side of the system. 

The ATmega16U4 & ATmega32U4 were the only s. The ATmega16U4 will be used  [11].

	ATmega32U4 Microchip delete	ATmega16U4 Microchip delete
Family	8-bit MCU	8-bit MCU
CPU Type	8-bit AVR MCU	8-bit AVR MCU
Max CPU Speed (MHz)	16 MHz	16 MHz
FPU		
Operation Voltage	(2.7V-5.5V)	(2.7V-5.5V)
Temp Range	(-40 to 85)	(-40 to 85)
Pin count	44	44
Program Memory Size (KB)	32 Flash	16 Flash
Error Correction Code Program Flash		
SRAM	2.5 KB	1.2265625 KB
Data EEPROM/HEF (Bytes)	1024	512
Internal DRAM Type		
Internal DRAM Amount (MB)		
Low Power		
ADC Input	12	12
Max ADC Resolution (Bits)	10	10

Figure 4 – Microcontroller comparison tool [9]

6 Circuit design & sensor selection

6.1 Measuring the coolant temperature

6.1.1 Choosing a temperature sensor

Two commonly used industrial temperature sensors are PT100/PT1000 RTDs and thermocouples. In a PT100 and PT1000, the resistance varies with temperature linearly. In a PT100 at 0°C, the resistance is 100Ω. In a PT1000, at 0°C, the resistance is 1000Ω [12]. RTDs offer high accuracy, stability, and repeatability. Being a resistive element, RTDs are self-heating. This can cause small measurement errors. They can be connected in 2, 3 or 4 wire configurations. 3 and 4 wire connections account for errors due to wire resistance but require an Op-amp to read the output.

Thermocouples consist of 2 dissimilar metals connected at one end in a twisted pair configuration. A very small, temperature dependant voltage is induced in the measurement junction proportional to the temperature [13]. They can measure higher temperature ranges than the RTD, have faster response times and are more resistant to shock and vibration. They are less accurate than RTDs.

Ideally, this circuit will not include op-amps to keep the voltage at 5V. The incentive of faster response times from the thermocouple does not offer any major benefit to this application as the engine temperature will not change rapidly. An RTD will be used. Table 2 compares 2 potentially suitable RTDs.

Parameter	PT100 TS2659 [14]	PT1000 TM5601 [15]
Measuring range	-30°C to 180°C	-40°C to 150°C
Protection	IP67	IP68
Accuracy	$\pm (0,15 \text{ K} + 0,002 \times t)$	$\pm (0,15 \text{ K} + 0,002 \times t)$
Response time (s)	3/8	1/3
Housing	Screw in sensor	Screw in sensor
Shock resistance	--	50g (11ms)
Vibration resistance	--	20g (10-2000Hz)
Resistance at 0°C	100 Ω	1000 Ω
Ω/°C	0.39 Ω/°C	3.9 Ω/°C
Includes cable?	Yes	No
Cost	£72.60	£97.32

Table 2 – Temperature sensor comparison

Overall, the PT1000 sensor is preferred. The higher base resistance allows power consumption to be minimized, whilst the increased $\Omega/^{\circ}\text{C}$ makes it more suitable for 2-wire configurations, which saves using a comparator to read a wheatstone bridge.

6

The PT1000 sensor can be screwed onto the engine. It does not come with a cable so this must be purchased separately.

6.1.2 Circuit implementation

Figure 5 shows the circuit implementation. A 1K resistor is used to create a voltage divider with the sensor. This will give the output a resolution of $5\text{mV}/^{\circ}\text{C}$ whilst keeping the current low. The 10-bit ADC can measure increments of 4.8mV , providing 1°C accuracy which is sufficient for engine temperature measurement.

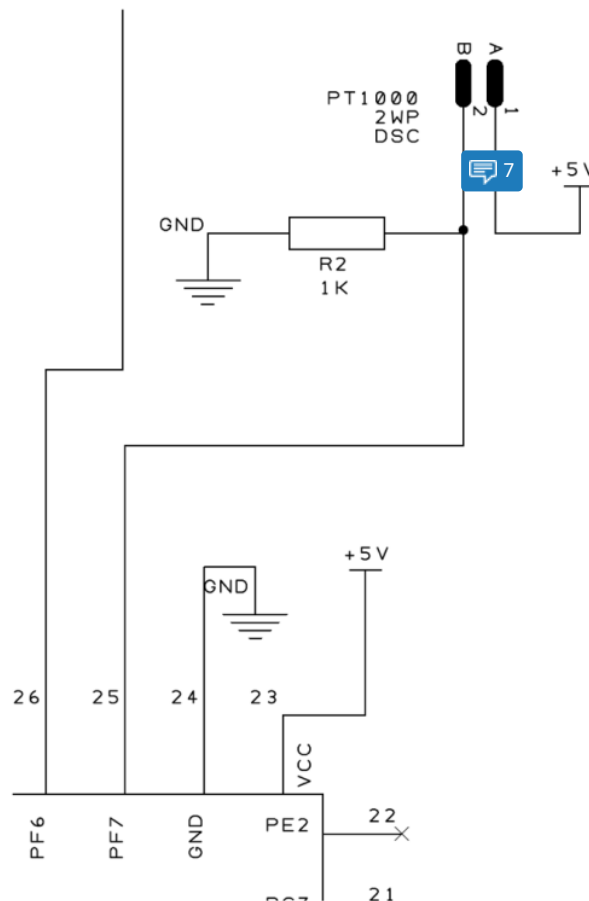


Figure 5 – PT1000 configuration

2.1.3 Sampling parameters

The resolution will be 1°C. The full measurement range of -40°C to 150°C will be stored in 1 byte of data. Realistically, it is likely that a temperature range from -5°C to 105°C would be sufficient to monitor the temperature from start up through operation in t

The sensor response time is 1 third of a second. A sample rate of 1Hz will be sufficient.

6.2 Measuring suspension travel

6.2.1 Choosing a sensor

Linear potentiometers will be used to measure suspension travel. These variable resistors attach to the suspension. Figure 6 shows the working principle.

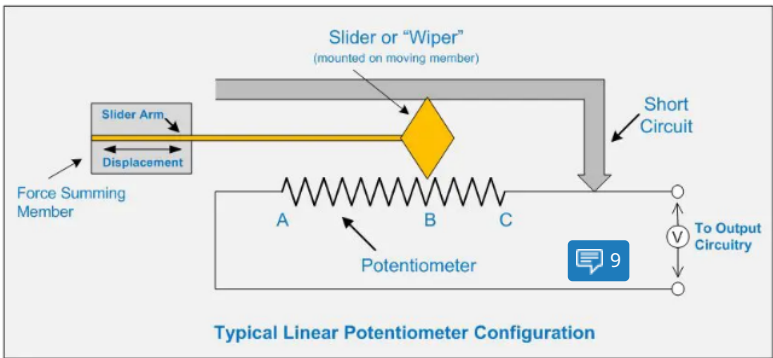


Figure 6 – linear potentiometer [16]

The 'wiper' moves along the resistive element, moving point B. the voltage across point A and B can be used to calculate the position of the suspension travel.

Table 3 shows a comparison of 3 linear potentiometers which could be used.

Parameter	HGSI LPPS-22-150 [17]	SUS-POT-150-RJ [18]	2D sensors SA-LP150D-000 [19]
Measuring range	150mm	150mm	150mm
Operating temperature	-40°C to 95°C	-40°C to 105°C	-40°C to 100°C
Protection	IP64	IP65	IP66
Shock resistance	50g (single hit)	-	40g for 10ms
Vibration resistance	20g	-	12g (1kHz)
Resistance	5kΩ	-	3kΩ
Min current	5/5000 = 1mA	-	5/3000 = 1.7mA
Max current	5/100 = 50mA	-	5/100 = 50mA
Max operating speed	5m/S	10m/s	10 m/s
Non-linearity	0.25%	0.5%	0.15%

Cable length	1m	30cm with 4m extension available as an extra	1m
Retracted mounting distance	1000mm	229mm	260mm
Weight (g)	190	--	85
Cost	£169.60	£225	--

Table 3 – Linear potentiometer comparison table

The SUS-POT-150-RJ does not have enough data on the datasheet to make an informed decision. The IP rating of the HGSI LPPS-22-150 is too low. The sensor from 2D sensors will be used. The cable is only 1m long. This will need to be extended for the sensors attached to the rear suspension.

6.2.2 Circuit implementation

Figure 7 shows the linear potentiometer implementation. The 100Ω resistor is designed to stop the circuit from shorting out when the potentiometer resistance is 0Ω. All outputs are connected to the ADC.

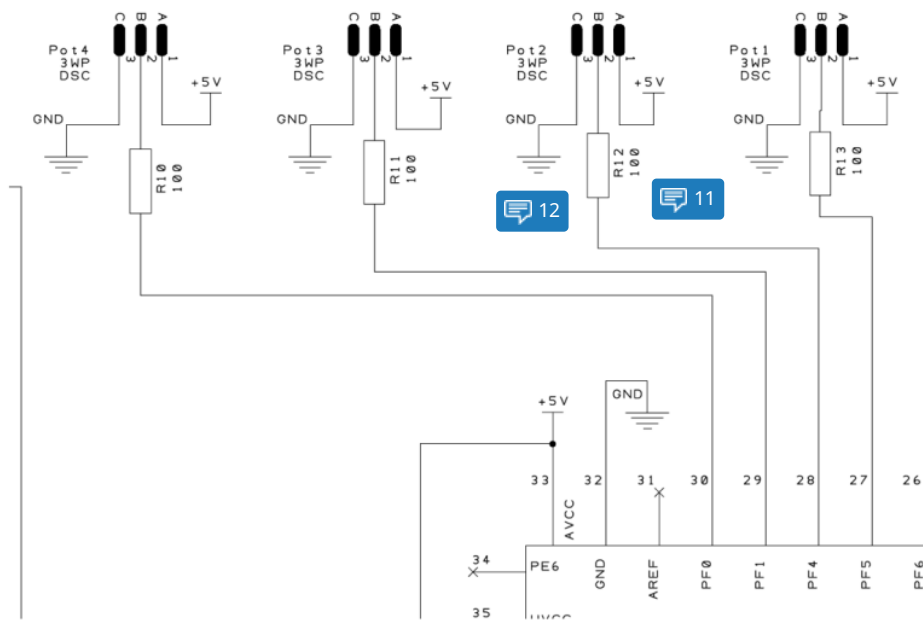


Figure 7 – Linear potentiometer implementation

6.2.3 Sampling parameters

The measurement range is 150mm. The ADC is 10-bit, so storing a value with a resolution of 0.2mm will not be a problem. This will allow small movements in the suspension travel to be detected.

The sample rate will be 10KHz. This allows precise, high-resolution graphs demonstrating the suspension travel on a test run to be generated. This same sample rate will be used for all sensors besides the temperature sensor.

6.3 Measuring Pitch, Roll and Yaw

6.3.1 Choosing a sensor

Measuring pitch, roll and yaw is a complex operation. MEMS (Micro-electromechanical system) accelerometers are commonly used to measure pitch and roll. An example is the variable capacitance accelerometer shown in figure 8. It consists of a fixed electrode and a moveable electrode. Between these electrodes is an air gap, creating capacitance. The moveable electrode moves with acceleration. This changes the airgap, hence changing the capacitance. Unfortunately, accelerometers cannot measure yaw.

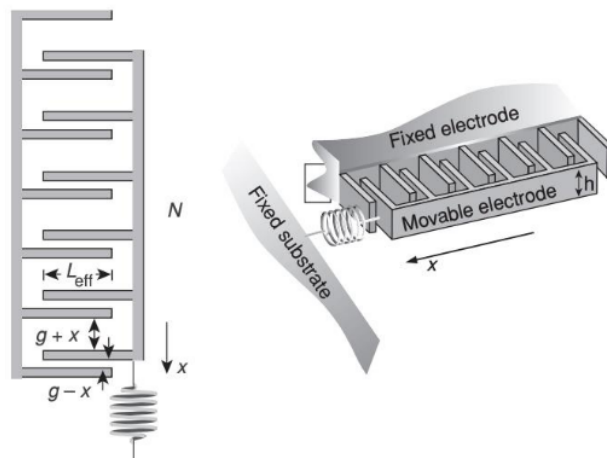


Figure 8 – VC MEMS accelerometer working principal [20]

Another option is the Gyroscope. A gyroscope measures rotational motion. It consists of two orthogonal axis. These are the driving axis and the sensing axis. There is a proof mass connected to these axes, as shown in figure 9. The proof mass can only move in the

direction of the driving axis or the sensing axis. The driving axis uses electrodes to oscillate the proof mass, it will oscillate in the direction of the driving axis. External rotation causes the oscillation to change direction to the sensing axis. This is known as the Coriolis effect. The sensing electrodes can measure the Coriolis force which is produced as a result of the driving electrodes and external rotation. This is a highly simplified overview of the gyroscope principals of operation.

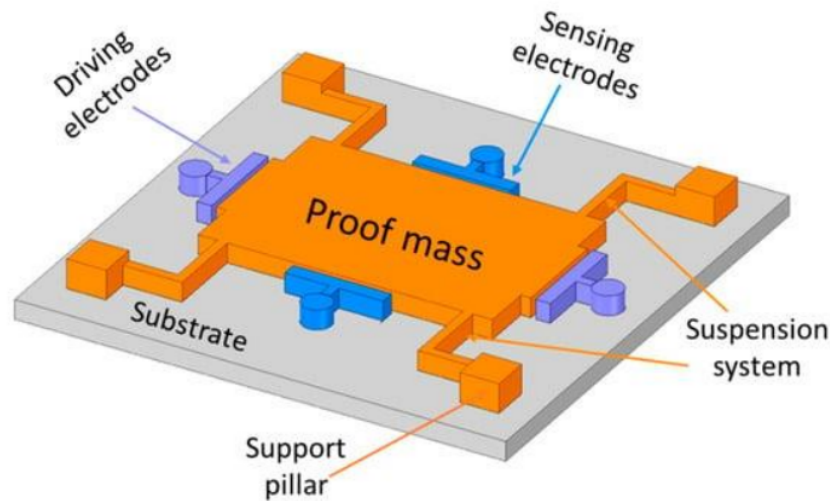


Figure 9 – Gyroscope principal of operation [21]

The gyroscope can measure pitch roll and yaw, so it can be used for this project. The output of a gyroscope is the angular rate in degrees per second. One of the common issues with gyroscopes is the drift, the effects of which can be minimised through calibration.

Table 4 shows a comparison of 2 gyroscopes which could be used.

Parameter	Adafruit L3GD20H breakout board [22]	ST I3G4250D [23]
Measuring range (dps)	User selectable +/- 250 +/- 500 +/- 2000	User selectable +/- 245 +/- 500 +/- 2000
Measurement axis	X, Y, Z	X, Y, Z
Sensitivity (mdps/digit)	8.75 @ 250 dps 17.5 @ 500 dps 70 @ 2000 dps	8.75 @ 250 dps 17.5 @ 500 dps 70 @ 2000 dps

Operating temperature	-40°C to 85°C	-40°C to 85°C
Input voltage	3-5V	2.4 to 3.6V
Current	6.1mA	6.1mA
Non-linearity	0.2%	0.2%
Communications	SPI or I2C	SPI or I2C
Dimensions (mm)	30.65 x 19.11 x 3	4 x 4 x 1.1
Weight	2.02g	Negligible
Additional comments	Additional 3.3V output	--
Cost	£12.23	£9.31

Table 4 – Gyroscope comparison table

The functionality parameters of these two options are very similar, they would both be suitable for measuring the roll pitch and yaw. However, MEMS gyroscope chips are only available in 3.3V which would be difficult to integrate into a 5V circuit. The Adafruit breakout board takes the L3GD20H and configures it to work with 5V circuits, making it ideal for this application.

The measuring range is selectable. This application will only require 250 degrees per second measuring range as it is only measuring the roll pitch and yaw. This allows improved device sensitivity, with 8.75 milli degrees per second/digit. This means that a change as small as 8.75 milli degrees per second could be detected.

The microcontroller will require an SPI or I2C module.

6.3.2 Circuit implementation

Figure 10 shows the implementation of the gyroscope module. Figure 11 shows the module circuit diagram. The module will communicate with the microcontroller via I2C protocol.

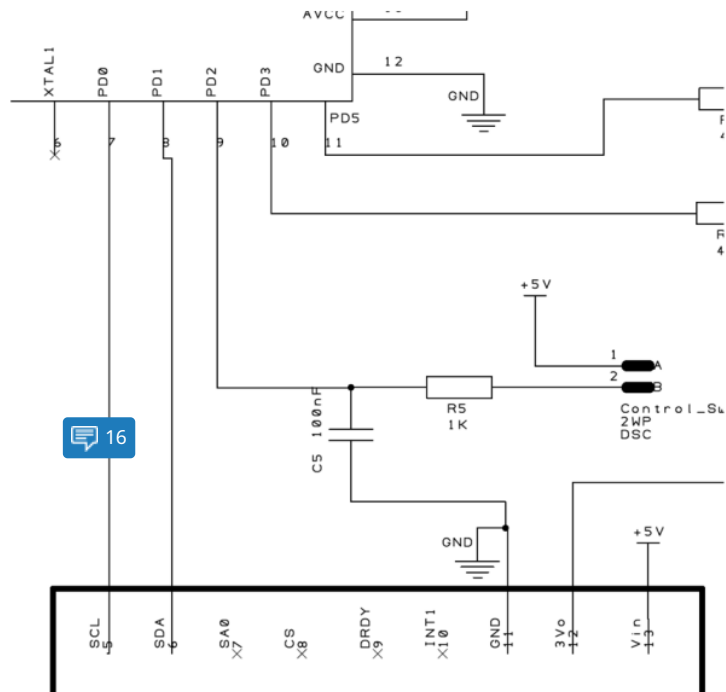


Figure 10 – Adafruit gyroscope implementation

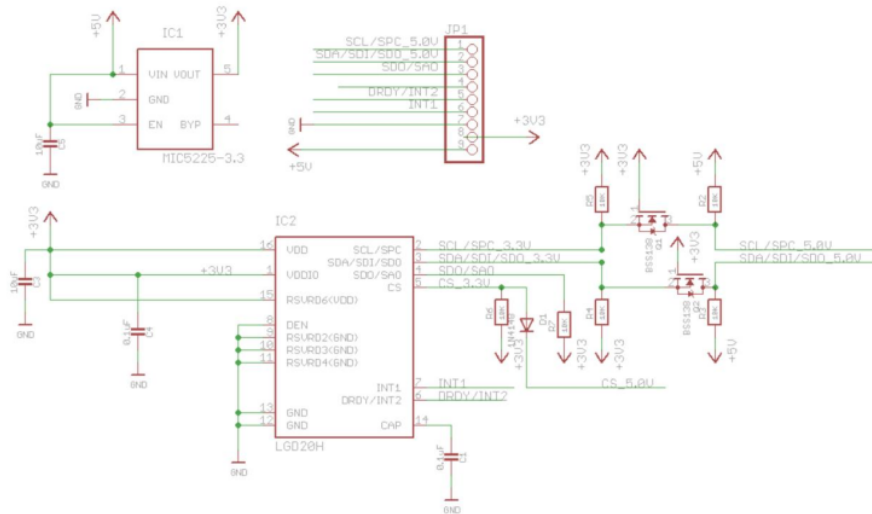


Figure 11 – Adafruit gyroscope circuit diagram [22]

6.3.3 Data sampling parameters

This is a digital reading so there is no restriction imposed by the ADC. The measuring range selected is 250dps which allows 8.75mdps sensitivity. This can be stored with 2-bits of storage.



6.4 Measuring the car and engine speed

6.4.1 Choosing a sensor

To calculate the car speed, the RPM of the wheel must be measured. To calculate the engine speed, the engine RPM must be measured. The same method can be used for both measurements.

There are many methods of measuring rotational speed. Some of the most common methods utilize inductive proximity sensors, Hall Effect Sensors (HES) or light sensors.

A Diffused light sensor contains a transmitter and receiver built into one housing. A piece of reflective tape would need to be attached to the teeth of the gear. This tape will reflect the signal back to the sensor every time it passes, providing a pulsed signal to the microcontroller proportional to the speed. This will not work with this application because the reflective element would be difficult to implement in harsh weather conditions. A thru-beam sensor could be used, but this would increase the installation complexity as the transmitter and receiver are separate.

The inductive proximity sensor and HES offer very similar functionality and are both suitable for this application.

The inductive proximity sensor creates an electromagnetic field. When a ferrous or non-ferrous material passes the proximity sensor it interferes with the electromagnetic field. This will then switch the sensor output on until the material is past the sensor. They are not ideal for high-speed applications, which is where the HES is the preferred option [24]

A HES will detect when it is within a magnetic field by measuring the disruption of electrons on a thin metal plate. This allows it to detect the presence of ferrous materials. The HES is well suited to high-speed applications however it is susceptible to magnetic interference.

Table 5 compares 2 inductive sensors and 1 HES.

Parameter	PEPPERL+FUCHS NBB 2-8GM30-E2 [25]	2D sensors SD- V01M8-000 [26]	Aim X05SNVDW712 [27]
Switching frequency	Up to 6000Hz	800Hz	-
Assured detection range	1.62mm	1 to 2 mm	0.5 to 2.5mm
Operating temperature	-40°C to 85°C	-50°C to 80°C	-25°C to 70°C
Protection	IP67	-	IP67
Mounting type	Screw on M8	Screw on M8	Screw on M8
operating current	0 to 100mA	-	-
Voltage	5 to 30V	12V	10 to 30V
Output type	PNP	-	-
Cable length	2m	300mm	200mm
Dimensions (mm)	30 x 8	35 x 8	35 x 8
Cost	£147.58	-	£110

Table 5 – comparison of HES and inductive sensors

Overall based on this comparison table, the inductive proximity sensor by Pepperl+Fuchs is the most suitable. It is compatible with 5V systems and can handle switching frequencies up to 6kHz. It can be screw mounted via an M8 thread allowing for easy installation. This comes with 2m of cable so this will not need extending.

6.4.2 Circuit implementation

Figure 12 shows the circuit implementation. The output is a digital PNP output, so the load must be connected to ground. They are both connected to an input capture module.

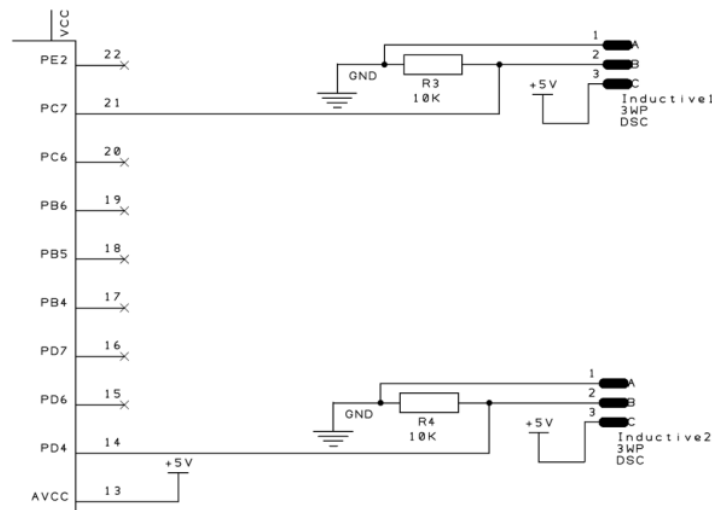


Figure 12 – Inductive proximity sensor circuit implementation

6.4.3 Data sampling parameters

The value from the input capture module will be at its highest when the car is traveling 1mph since the time between pulses will be longest. There are many variables such as wheel diameter and number of spokes which can affect the value stored. Assuming a wheel diameter of 16" there will be 21 revolutions per minute at 1mph. This means there will be 1 full revolution every 4.76 seconds. Assuming there is just 1 spoke per rpm, which is unlikely, this is the highest value which is likely to be seen.

At the other end of the scale, the second sensor will be exposed to high speeds. The engine RPM could be as high as 8000RPM. This would equate to a revolution every 7.5ms and there could be multiple pulses per revolution.

Whilst a precision of 1 revolution at very high speeds may not be essential, a 2-byte number must be stored. Knowing this, a value with a range of 0-5s and a resolution of 0.1ms will be stored.

6.5 Data storage

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This system must store a large quantity of data, so a microSD card will be required. For simplicity, the microSD card breakout board from Adafruit can be connected to the PCB [28]. This is shown in figure 13. This allows any microSD to be plugged in. It works with a 5V input and will communicate with the microcontroller via SPI.

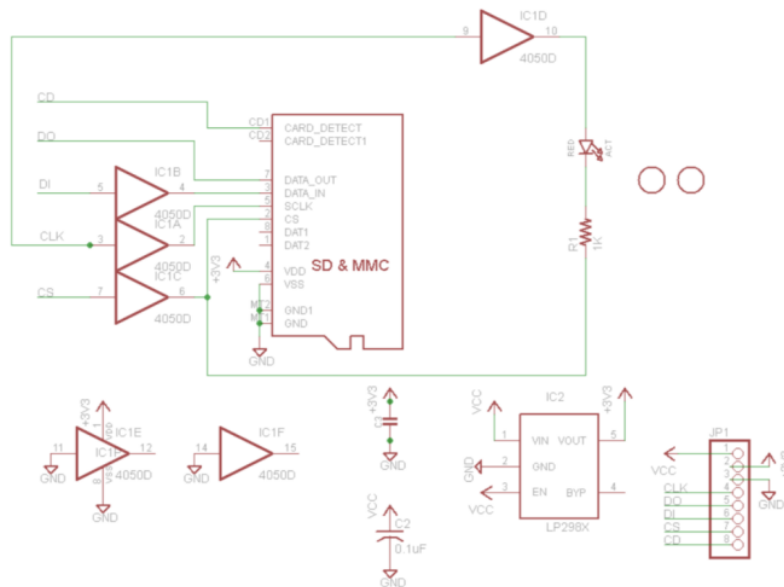


Figure 13 – Adafruit microSD card breakout board circuit diagram

Table 6 shows the storage requirements. It must store 0.648GB of data every hour. To operate for 2 hours as specified, it requires 1.296GB of storage. A 2GB SD card will be sufficient [29]. This could be swapped if the customer wanted more storage.

Measurement	Range	Resolution	Bytes	Sample rate	Bytes per second
engine temp	190°C	1°C	1	1	1
Engine rpm	5s	0.0001s	2	10000	20000
wheel rpm	5s	0.0001s	2	10000	20000
suspension travel	150mm	0.2	2	10000	20000
suspension travel	150mm	0.2	2	10000	20000
suspension travel	150mm	0.2	2	10000	20000
suspension travel	150mm	0.2	2	10000	20000
Pitch	250dps	0.00875 dps	2	10000	20000
Roll	250dps	0.00875 dps	2	10000	20000
Yaw	250dps	0.00875 dps	2	10000	20000
Total bytes per hour					648.0E+6

Table 6 – Required data storage

6.6 Powering the device

As this device is portable, it must be battery powered. Table 7 shows the estimated average power consumption. It is 249.8mAh. This will vary based on the temperature, inductive proximity sensor speed and linear potentiometer position. Other passive components and regulator efficiencies will also influence the power usage. To account for this, a battery with more than enough power to sustain the device for 2 hours will be used. The 3.7V, 3000mAh 18650 battery from The Pi Hut [30]  22. It will power the driver for around 12 hours and does not add much size or cost to the design.

Sensor	Avg Power consumption (mA)	Quantity	Total (mA)
Temp sensor	2.5	1	2.5
Potentiometer	25	4	100
Inductive proximity sensor	50	2	100
Gyroscope	6.1	1	6.1
SD card module	40	1	40
Microcontroller	1.2	1	1.2
Total			249.8

Table 7 – Estimated device power consumption

As an additional feature, the battery level will be monitored by the microcontroller via an ADC input. It will provide low battery warnings and shut the system off when the battery gets too low. To do this, one of the ADC inputs is connected between the RC filter and the voltage regulator. The flowcharts in appendix A explain the operational functionality which will be used.

It will implement CC-CV (Constant Current Constant Voltage) charging. This is a common method used to charge Li Ion batteries. The battery will initially charge with a constant current however once the voltage reaches 4.2V it will maintain 4.2V until the current drops to the termination current. At this point charging is complete and the chip will disconnect the battery from the USB. Using CC-CV charging will prolong the battery lifespan and safety.



Figure 14 – Adafruit Li-Ion charging module circuit diagram

6.8 Operator control

6.8.1 Control switch

There must be an external control switch ²³ The IP rated MP0037 switch from Bulgin will be used [32]. Figure 15 shows the circuit implementation. The basic NO switch sends a pulsed signal to the microcontroller. The RC circuit is used to debounce the peak caused by the pulse. Without this, a single pulse could oscillate before settling, potentially causing the microcontroller to receive multiple signals.

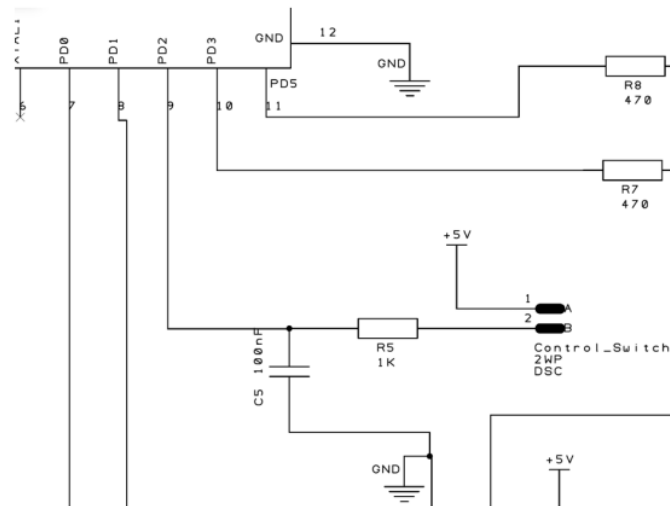


Figure 15 – Control switch circuit implementation

6.8.2 LED indication

A tricolour LED will be used to indicate to the user the state of the system.

The RS PRO tricolour IP rated LED will be used [33]. This contains a green and a red LED. Powering both LEDs provides a yellow light. The operational conditions for this will be shown in the flowcharts in Appendix A.

Figure 16 shows the circuit. The LEDs do not work with 5V, so the 3.3V output from the gyroscope is ²⁴ used. The optocouplers allow the 5V microcontroller output to provide ground for the 3.3V LEDs.

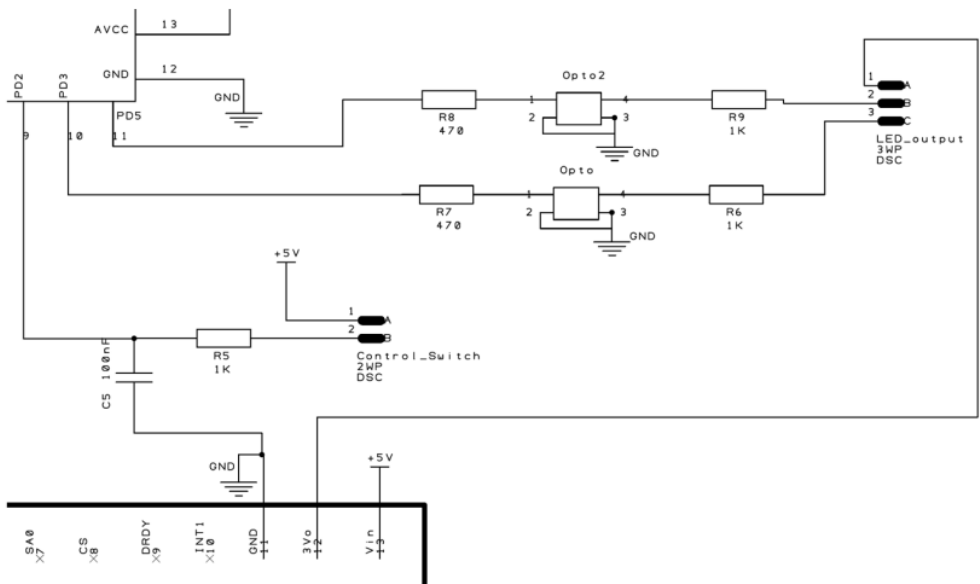


Figure 16 – LED output circuit

6.9 Overvoltage protection, filtering, and voltage regulation

Figure 17 shows the circuit for overvoltage protection, filtering, and voltage regulation. The overvoltage protection is provided by a 5.1V Zener diode [34], which will pull any voltage over 5.1V to ground. The voltage regulation is provided by an LM7805 [35] regulator. The filtering is provided by an RC circuit. The sample rate is 10kHz. The Nyquist frequency is half the sample rate, so $F_c = 5\text{kHz}$. Equation 1 calculates the resistor value for the RC circuit based on a 2.2nF capacitor.

$$F_c = \frac{2}{(2 \times \pi \times R \times C)}$$

$$R = \frac{2}{(2 \times \pi \times F_c \times C)}$$

$$R = \frac{2}{(2 \times \pi \times 5000 \times 2.2 \times 10^{-9})} = 14468.6312\Omega$$

$$F_c = \frac{2}{(2 \times \pi \times 15000 \times 2.2 \times 10^{-9})} = 4823\text{Hz}$$

Equation 1 – Cut-off frequency

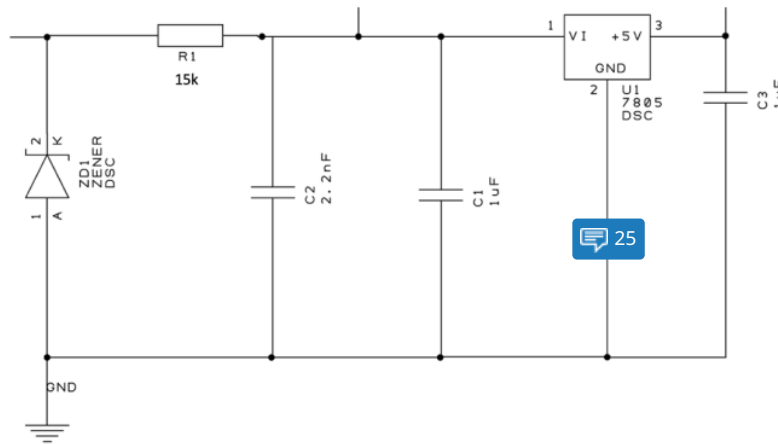


Figure 17 – Overvoltage protection, filtering, and voltage regulation circuit.

6.10 Final design comments

That concludes the system design from an electrical point of view. The full circuit schematic can be found in appendix B. Appendix C & D show the top and bottom layer of the PCB respectively. Appendix A shows the operational flowchart for the system and highlights the basic principles of the software.

The PCB was exported as a Gerber zip file and uploaded to JLC for a price. The Quote from JLC was £20. This is expensive and the price could have been reduced with more careful PCB design.

7 Specifying a box and connectors

7.1 Specifying the box

As per appendix C, the PCB is going to be 332mm x 133mm. This mild steel, IP66 terminal box from RS will be ideal [36]. It is 400mm x 200mm x 120mm. Figure 18 shows a bracket to mount the PCB. Spacer dampers can be used to space the PCB from the bracket and reduce vibrations

A bracket will also need to be created which will allow the box to be secured to the underside of the car bonnet

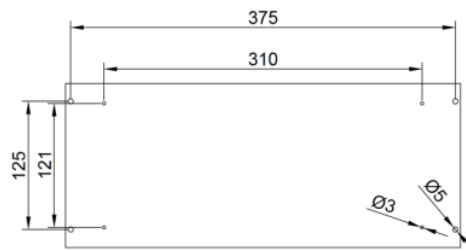


Figure 18 – PCB bracket

7.2 Specifying the connectors

7.2.1 External connectors

To connect all sensors to the box, suitable connectors must be installed. There will be 6 x 3 wire inputs and 1 x 2 wire input. The RS PRO circular connectors are available in 2 [37] and 3 [38] contact arrangements and are ideal for this application. They come in sets with both the male and female side included. They are IP68 rated designed for industrial applications in harsh environments. The 3-pin connectors require a 21mm hole, the 2-pin connector requires a 17mm hole. There is plenty of room to install all 7 connectors onto the box. It is good practice to install the female connector on the side supplying power, so the female connectors will be installed onto the box. This reduces the risk of shorting pins out.

7.2.2 PCB connectors

The PCB connectors are required for interfacing connections between the PCB and the external connections. As per the circuit schematic, the system requires 2 x 2 pin connectors and 7 x 3-pin connectors. The JST PH range of connectors are suitable. They are small, compact, and designed for through hole PCBs. They have a small latch to prevent the connector from shaking off with vibration. The datasheet [39] covers male and female, 2-way and 3-way connectors as well as the crimps. The part numbers used can be found in the BoM.

Considering the application will involve such high vibration levels and these connectors will not need moving once replaced, they should have silicone applied after installation to hold them in place.

8 Bill of Materials

Table 8 shows the Bill of Materials (BoM). The total cost of the system will be £2831.09.

COMPONENT	PART NUMBER	QUANTITY	TOTAL COST
PT1000	TM5601	1	£97.32
PT1000 connecting cable	EVC001	1	£13.80
Linear potentiometer	HGSI LPPS-22-150	4	£678.40
Adafruit Gyroscope breakout board	L3GD20H breakout board	1	£12.23
Inductive proximity sensor	NBB 2-8GM30-E2	2	£295.16
MicroSD card breakout board	NA	1	£6.14
2GB MicroSD card	TS2GUSDC	1	£11.86
18650 lithium-ion rechargeable cell 3000mAh 3.7V	The Pi Hut 105184	1	£7
Adafruit Li Ion charger module	USB Lilon/LiPoly charger (v1.2)	1	£10.23
Battery holder 18650	Keystone 1042P	1	£4.56
External switch	MP0037	1	£16.21
Red, Yellow Green IP rated LED	220-8961	1	£18.89
Microcontroller	ATmega16U4	1	£4.12
Resistor 10K Ω	NA	2	£0.10
Resistor 1.5K Ω	NA	1	£0.05
Resistor 1k Ω	NA	4	£0.20
Resistor 470 Ω	NA	2	£0.10
Resistor 100 Ω	NA	4	£0.20
Capacitor 100nF	NA	1	£0.20
Capacitor 2.2nF	NA	1	£0.20
Capacitor 1uF	NA	3	£0.60
Zener diode 5.1V	BZX79-C27,113	1	£0.13
5V regulator	LM7805	1	£0.71
Optocoupler	HCPL-817-50BE	2	£0.82

IP rated USB port type C	231-7949	1	£50.96
2-contact circular connector	124-6691	1	£21.53
3-contact circular connector	124-6693	6	£211.74
RS PRO Mild Steel terminal box IP66	749-1882	1	£97.36
M3 spacer	R30-6700994	4	£1.72
Custom made installation bracket - 1.2mm aluminium	NA	1	£1 estimate 27
JST PH series through hole PCB head 2 contacts	B2B-PH-K-S(LF)(SN)	2	£0.11
JST PH series through hole PCB head 3 contacts	B3B-PH-K-S(LF)(SN)	7	£0.27
JST PH series through hole PCB head 3 contacts	B4B-PH-K-S(LF)(SN)	1	£0.21 28
JST PHR Female connector housing 2- way	PHR-2	2	£0.06
JST PHR Female connector housing 3- way	PHR-3	7	£0.38
JST PHR Female connector housing 4- way	PHR-4	1	£0.07
JST PH series female crimp terminal	BPH-002T-P0.5S	29	£0.7
Programming header 2 x 3 pins	PPRPT-10877	1	£1
PCB from JLC	NA	1	£16.14
Assorted cables for wiring external connectors to the PCB, custom made to the correct length	NA	1	£2 estimate
Design hours	Engineers time	50	£1250
Total Cost			£2831.47

Table 8 – Bill of Materials

9 Conclusion

Overall, this design project has been a success. A DAQ has been created which is capable of accurately measuring and storing the key specified data on Saloon prototype vehicles. It can run beyond the specified 2-hour running time due to an over specified SD card and battery at minimal additional cost. The system has the added feature of a rechargeable battery too. It is easy to control with a single control switch.

The system fits into a box which can be installed into the engine bay of the car. The cables can then be run to the required positions from the engine bay. The cost of the system was rather high however this will always be the case when costing for a single device. The engineering hours, which take up a large portion of the cost, are a one-off investment. To add to this, component costs can be reduced when manufacturing in bulk.

There are certainly some improvements which could be made with more time to work on the design. These are listed below.

- PCB size – The PCB is far bigger than it needs to be, it could be difficult to install because of this. The size could be reduced by moving components closer together and replacing the Adafruit modules with the actual circuit
- Power consumption when switched off - The sensors are permanently powered. This will unnecessarily drain the battery. A MOSFET could have been installed to disconnect the sensors when data logging mode is not active.
- The research conducted in section 3 suggests that many of the systems of the market utilize a CAN bus too, allowing the system to take advantage of existing sensors from the cars data bus.
- The signal quality could have been improved by adding an RC filter to each input.

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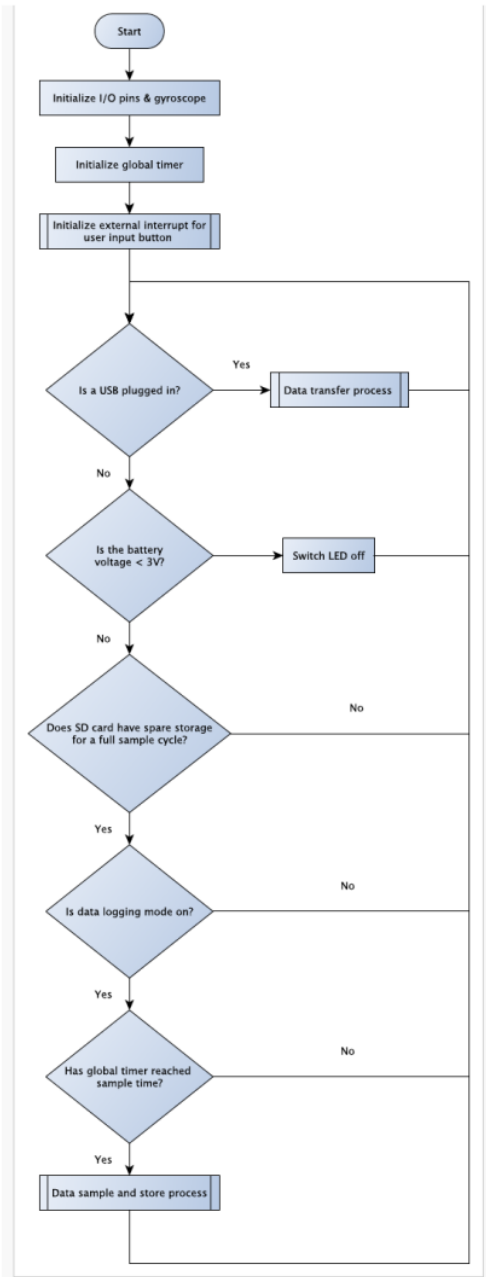
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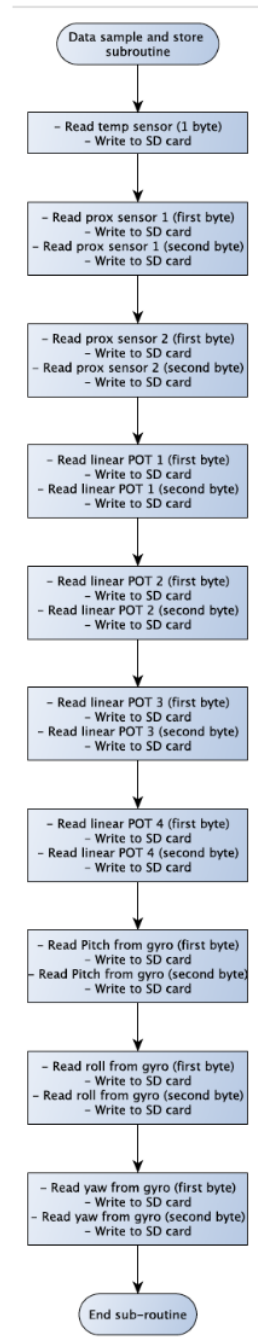
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Appendix A – Flowcharts

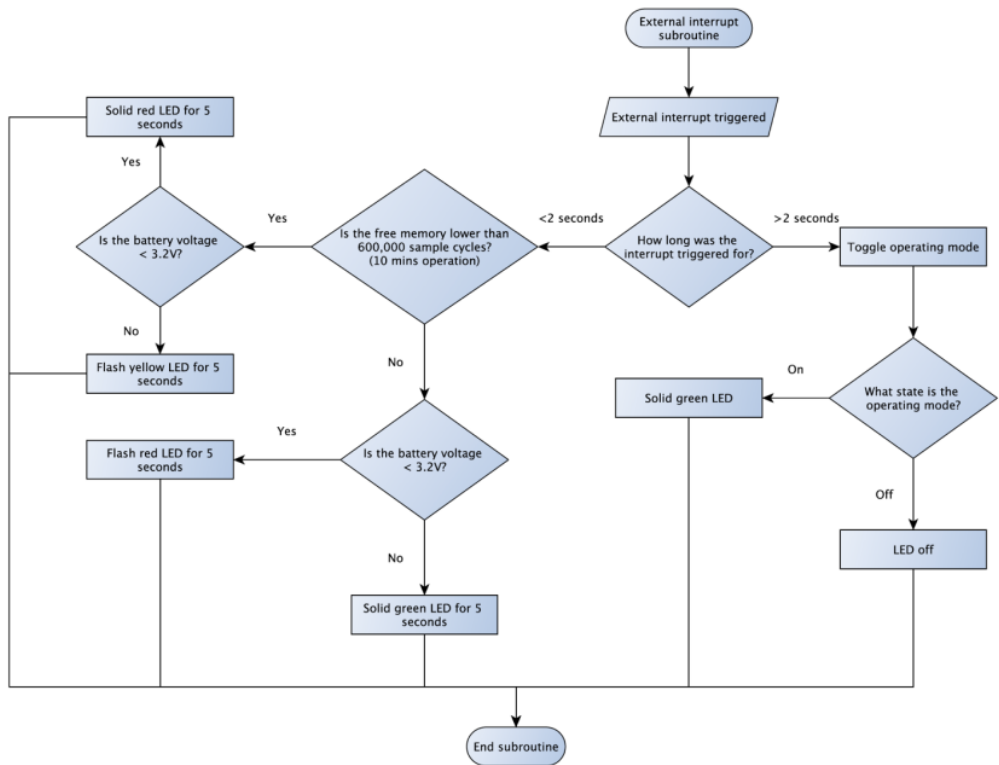
This is the flowchart for the main system operation.



This is the flowchart for Sampling and storing data.

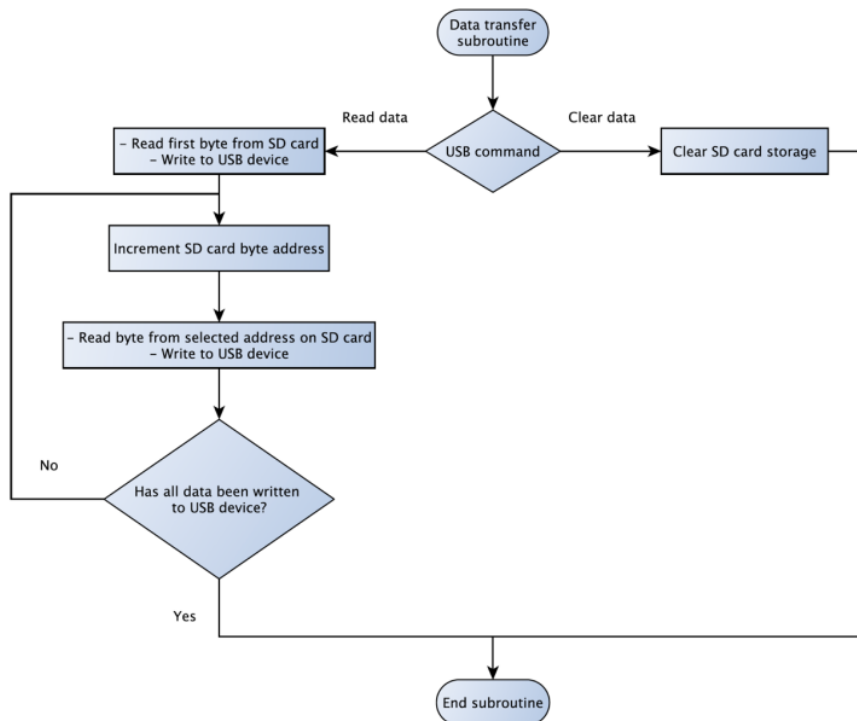


This is the flowchart for the external switch and LED operation.

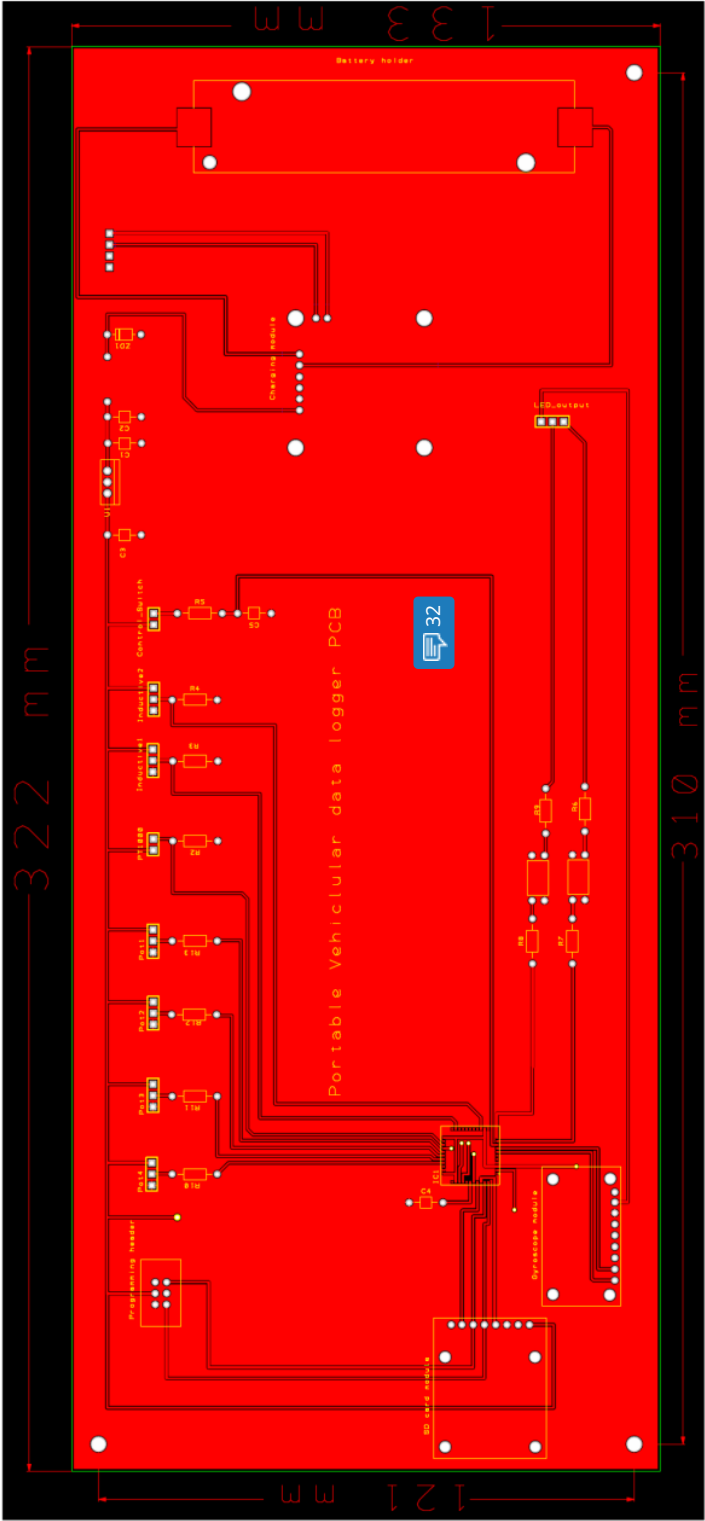


Oliver Kucyj – ESD assignment 1

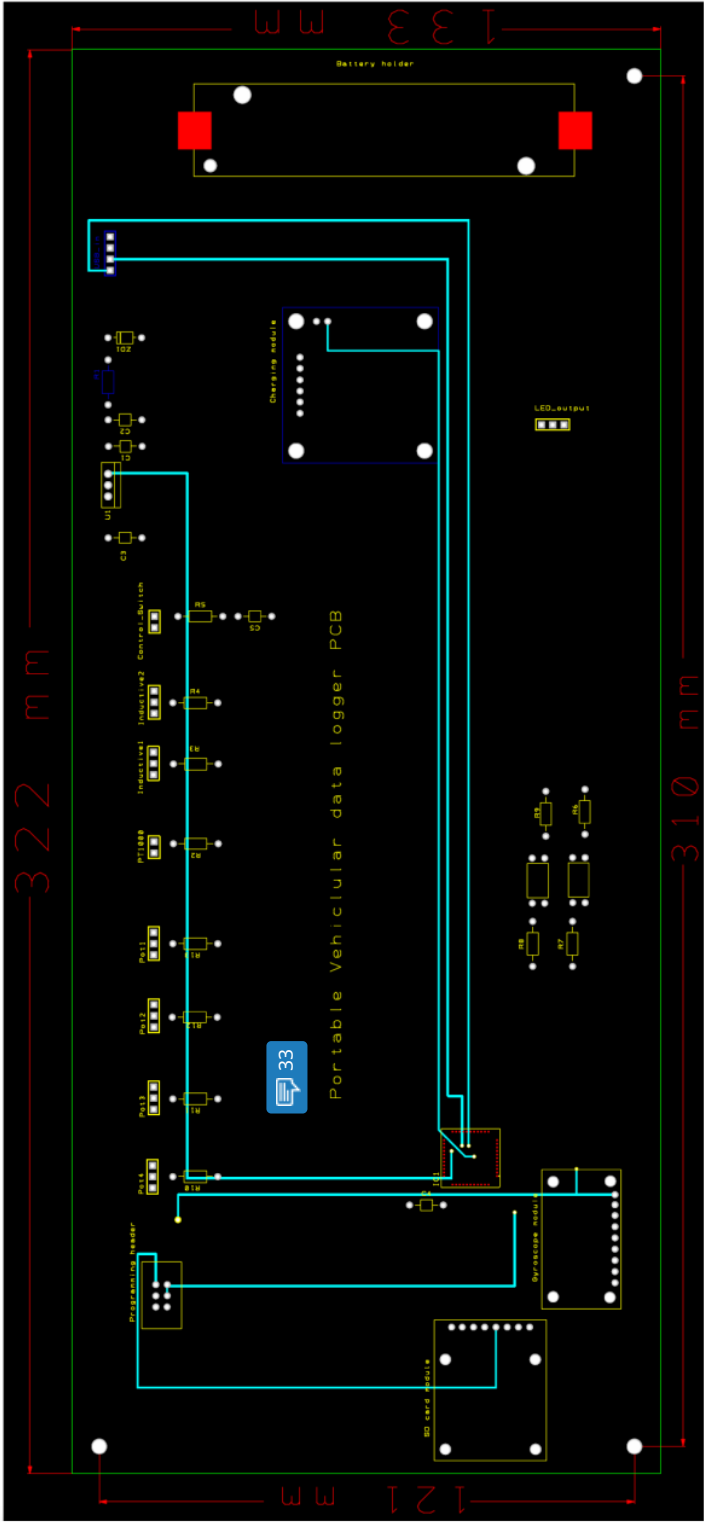
This is the flowchart for the USB data reading process.



Appendix C – PCB top layer



Appendix D – Bottom Layer



Oliver Kucyj ESD assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

59/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10



Comment 1

8-bit what?



Comment 2

How do you know that at this stage? You should consider the programme functionality and operation before making comments like this.



Comment 3

This does not fit with the assignment brief.

"Microcontroller
selection from the 8bit PIC range"



Comment 4

Why?

PAGE 11



Comment 5

There are op-amps which will operate on 5V

PAGE 12



Comment 6

How? This requires a threaded hole in the engine. You can't just drill a hole in the engine of a test car to mount a sensor. A different sensor which does not require this type of mounting would have been better. Temperature can be measured using non-contact methods, or via a small sensor clamped to the engine.



Comment 7

using a 1k ohm resistor would only limit the current to $5/2000 = 2.5\text{mA}$ which is a large amount of current for a sensor. A higher value for R2 and an op-amp would have improved this.

PAGE 13



Comment 8

As engine coolant systems are generally pressurised systems, the temperature inside them can go above 105C without the water boiling. Personally I would have allowed this to be as high as 160C - to allow enough range for the system to measure the temperature.



Comment 9

This is a rheostat, not a potentiometer



Comment 10

Is 150mm enough range? this is only +/- 75mm of movement.

PAGE 14



Comment 11

In the image above (Fig 6) the sensors only have two connections, but here you have three. Which ones does it connect to? Why have a series resistor to the DAQ to prevent shorting instead of a series resistor to make it a potential divider?



Comment 12

Your circuit does not include over voltage protection or filtering to remove electrical noise

PAGE 15



Comment 13

Is this enough? That is only +/- 75mm of travel.

PAGE 16

PAGE 17



Comment 14

Not difficult at all - there are level shifting devices for logic signals, a zener diode, capacitor and resistor would be enough to create a regulated power supply. Some microcontrollers wouldn't even need the logic level converters as they have a very wide range of logic high input voltages.



Comment 15

Why?

You should state "As the sensors use I2C or SPI to communicate with the controller, a I2C or SPI module will be required."

It is possible to use I2C and SPI WITHOUT a specialised hardware module, it just takes a bit more software development.

PAGE 18



Comment 16

For I2C to work properly, you should use pull up resistors on the SCL and SDA lines. This is because the drivers in the micro and the peripherals are all open drain outputs.

This is to prevent bus contention - the resistors pull the line high and the devices can only pull the lines low preventing supply to ground short circuits through devices (one pulling high and one pulling low on the same line)

PAGE 19



Comment 17

No restriction on what?



Comment 18

Do you mean 2 bytes?

Two bits would only allow you to store:

00

01

10

11

PAGE 20



Comment 19

Personally I think this is not a bad option, given the application of the system. It is not meant to be a permanent fixture in the vehicle. It should not leave a trace when it is removed.

PAGE 21



Comment 20

What will this be screwed on to?

PAGE 22

PAGE 23



Comment 21

How much?

PAGE 24



Comment 22

But your circuit requires 5V not 3.7V. Will you be using a DC-DC converter to increase the voltage to 5V?

PAGE 25

PAGE 26



Comment 23

... to do what?



Comment 24

Does the gyroscope power supply have enough spare capacity for you to do this safely?

But you know how much current they use, so you could use a current limiting resistor in series with it to drop the voltage across.

If you used a common cathode LED (instead of a common anode which you have), you could have powered it from a 5V I/O pin on your micro just using a series resistor to drop the voltage.

PAGE 27

PAGE 28



Comment 25

This circuit confuses me a little. Why is there a zener diode AND a voltage regulator? Where does this circuit fit into the system? What is its purpose?

The 2.2nF and 1uF capacitors are in parallel, so they'll add to give a 1.0022uF capacitor.

PAGE 29

PAGE 30



Comment 26

That is a huge box!!!

PAGE 31

PAGE 32

PAGE 33



Comment 27

From the drawing above, I'd say more like £20



Comment 28

Should this be 4 contacts?



Comment 29

What about the software function and the case design?

PAGE 34

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40



Comment 30

Good range of references

PAGE 41



Comment 31

This should all be in the body of the report as it was something specifically asked for in the assignment brief.

PAGE 42

PAGE 43

PAGE 44

PAGE 45

PAGE 46



Comment 32

This PCB is much bigger than it needs to be. You could make this a lot smaller and save a lot of money - people pay for functionality not material cost, if you can provide the same functionality for cheaper then you can increase your profits.

PAGE 47



Comment 33

The bottom leg of R10 is connected to the bottom copper track between the micro and U1.
I'm not sure it should be

GRADING FORM: SMU GENERIC_SMOSEY

OLIVER KUCYJ

58.75

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied

7

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Knowledge is accurate with a good understanding of the field of study.

13.75

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



"Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity and significance of evidence. Ability to communicate ideas and evidence accurately and convincingly.

Sound, convincing conclusions / recommendations

21

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A good and appropriate application of standard methods, materials, tools and/or techniques.

Good appreciation of the context of the application, with some use of examples, where relevant.

11.2

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate effectively in a suitable format, but may have minor errors.

Mostly coherent work but could be structured better.

5.8