

ESD_1

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Electronic System Design 1

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Abstract

The purpose of this task is to design an automotive Portable Data Acquisition System (DAQ) to measure speed (MPH), RPM, engine temperature, suspension as well as Pitch, Roll and Yaw (PRY). The system needs to be portable and independent from the car itself and be controlled by a PIC microcontroller [1]. This report will include a literature review into alternative DAQs already on the market as well as research into an appropriate microcontroller, casing, storage, sensors and connector specification and the accompanying cost. A schematic of the circuit will be designed with the above specifications included along with a flowchart for the software structure on the microcontroller. The end of the report a list of improvements for future iterations will be suggested.

Introduction

DAQ is a method of measuring a physical or electronic event through sensors and controlled by hardware (i.e. a PIC). Acquisition systems can be used for several reasons such as research and analysis, diagnostics, quality testing and design verification and validation. The purpose of this task is to use it for the verification and validation of a prototype family saloon automobile on a tack test run at max speed of 80mph. The DAQ will store data to non-volatile memory which can be read externally and cleared when connected to a USB. The DAQ is independent from the vehicle with a battery supply and sensors that do not require any connection to the vehicle's internal signals.

Literature Review

There are numerous DAQs available however, in this literature review covers 5 alternatives ranging in operation and capability. DEWESoft, [2] a company specialising in designing and selling measurement and analysis equipment including DAQ. The Sirius's and Minituars [3] are all sourced from here. These three have a similar make up in terms of power consumption (all 35W), voltage consumption (9-36V) and all run of 24mA.

Specs	Sirius R2 [2]	Granite 10 [4]	U2651A [5]	Sirius X [6]	Minitaurs [3]
Data Rates				1Gbps	
Max Current	24mA	255mA	260mA	24mA	24mA
Power consumption	35W	6W	6W	35W	35W
Voltage Regulator	9-36V	9-36V	5-35V	9-57V	9-36V
ADC			32-bit digital only	24-bit	24-bit
Analogue Ports	32	8 digital only		32	
Digital I/O	48	8 terminals	00-pin SCSI-II connector		32
Storage ports		USB - SD	USB	SD	SD
Storage	250GB - 1TB	128GB			250GB
Processor	intel i7	NXP IMX^ quad core 1GHz			Intel i3
Battery	2x6.25Ah				
Dimensions	276x172x142mm	21.4x12x7.5mm	120x182.4x44mm	266x149x55mm	266x139x109
Memory	8GB	2GB SRAM			4GB
Weight	2.34kg	1.2kg	0.56kg		3kg
IP Rating	IP20	IEC 6100 class 4		IP20	IP20
Operating temp C	-10 to +50	-40 to + 70	0 to +55	-10 to +50	-10 to +50
Sampling rate				200KS/s	200KS/s
Interfaces	4xUSB, 1x eth, HDMI	ether, USB, micro, serial	USB 2.0	Ethernet	6xUSB, 2x Ethernet, EtherCat

Table 1: Comparison of five different DAQs

Microcontroller

The PIC18F24K50 [1] was chosen as the microcontroller because it offered an array on parameters ideal for the project. The PIC18F24K50 [1] offers 28 Input/output (I/O) pins which is needed for the measurement devices as well as power, storage as well as other peripherals. Out of the 28 pins 24 are needed utilising the chip well. Furthermore, the microcontroller offers 14 analogue pins which can be used for the analogue inputs to be processed by the 10-bit Analogue Digital Converter (ADC).

The ADC is able to multiplex multiple analogue signals via a hold circuit so the different signals can be converted by a single ADC which generates the 10-bit digital signal via successive approximation [1]. This PIC can therefore handle the requirements from the 8 analogue signals produced from the sensors (gyro, wire potentiometer and Passive Infrared (PIR)).

Moreover, there is no need for an external crystal oscillator as the internal oscillator are phase locked looped (PLL) meaning the clock pulses can be multiplied. The normal operating frequency of this PIC is 16MHz but with PLL this speed can be multiplied 4 times to a max lock of 64MHz [1]. The higher clock speed is required due to the small amount of Static RAM (SRAM) available. This PIC only has 2KB SRAM and not all of this can be used for inputting/outputting sensor data to storage. Based on calculations (table 2) the chip would be processing 1601B of data every second (within 2KB limit). However, at this speed the microcontroller will not be able to read the sensors and the other events required to extract meaningful data. At 64MHz the microprocessor can process this amount of data every 0.26ms leaving enough time to process the data and write to storage as well as other computations and extract good data at a higher enough frequency.

The PIC18F24K50 [1] offers Serial Peripheral Interface (SPI) which is compatible with the San Disk (SD) card which will be used as the non-volatile memory to store all the data from the sensors. The PIC is Universal Serial Bus (USB) compliant which will be used for interfacing with the system. It is also C code [1] compliant which will make programming then PIC much quicker and easier.

Finally, this microcontroller is recommended for automobile application as it has been tested against the AEC-Q100 requirements [7]. The PIC has been designed and tested to be a suitable quality and robustness to work in automobile applications.

Casing, Storage, Sensors

Casing

The casing needed to be a waterproof enclosure with the ability to house the PCB, batteries, wiring and connectors. The connectors for the external sensors will be housed on a side panel similar to what is shown in figure 1 which is 165x115mm which would be adequate size to fit all 10 female sensor connectors. In reality a cut-out for the connectors to be placed in and then be sealed with silicon, to be made secure and waterproof, is a more likely method of achieving this layout. The casing to house the rest of the components will be the '1200 Protector' Peli-case [8]. This case has exterior dimensions of 270x246x105 and interior dimensions of 241x185x105mm. This should be plenty of interior room to fit the PCB and batteries which have a combined dimension of 178x152x34mm. Furthermore, it will also accommodate for a connector panel for all the connections to be housed. The case is rate IP67 meaning it is water proof against water jets [9].

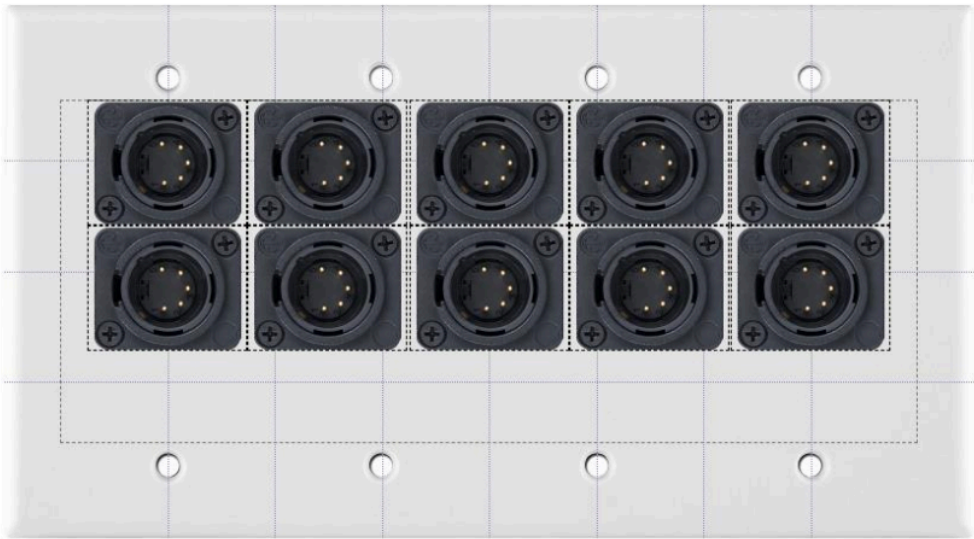


Figure 1: Mock up panel for the side of casing (note these connectors are not accurate but show a mock-up of the spacing)



Figure 2: 1200 Protector Peli-case [8].

Storage

The data from the sensors will be stored on a SD card which will need to store a minimum of 1.16 GB. The reasoning for this is based upon bytes per reading of a sensor, interval of a measurement and the duration of the test. The reading size in terms of bytes for the individual sensors are as follows:

- MPH (optical): 1 Byte.
- RPM (optical): 1 Byte.
- Temperature (PIR): 2 Bytes (10-bit ADC).
- PRY (gyros): 2 Bytes (10-bit ADC).
- Suspension (wire pot): 2 Bytes (10-bit ADC).

As seen above all the digital inputs require 1 byte but all the analogue inputs require 2. This is because the ADC uses a 10-bit number which requires a second byte to be used to compute this size of data. Some measurements require more than one sensor, i.e. there are three gyros being used (each dimension) and four wire potentiometers (each axial). Therefore, 18 Bytes are required to take one measurement from each sensor.

Next the interval of reading must be established to understand how many bytes need to be read in a certain period. This interval will not be constant across all the sensors as requirement for each measurement is different. For example; under the test conditions when the car is travelling at max speed of 80mph, the temperature reading most likely does not need to be read as quickly as the suspension which will move a lot more frequently at these speeds. Based upon how frequently the engine temperature changes whilst at its operating temperature, it was established that measurement interval of every 15 seconds would be sufficient to capture any meaningful temperature changes. This would be the slowest interval and so all storage calculations would be taken relative to this timing.

The MPH and RPM optical sensors would be measured at a second interval based upon once again the test condition whereby not a lot of high frequency change is going to be expected in this area and so the granularity is not required. Any major changes that may occur should be captured in this window. The PRY was chosen to be taken at 5ms. At this speed the measurement is taken every 0.18m which seems fast however changes in direction, especially yaw, can happen very quickly at 80mph. Therefore, at 5ms interval was needed. Finally, the suspension was measured every 50us which at test speeds equates to ever 1.8mm. This may seem a very small amount however small bumps, potholes or potentially Cats-Eyes can be very small in size and could be missed if the interval is larger than this.

In the 15 second period, the interval of the temperature sensor measurement, there would be:

- temperature reading - 1
- MPH readings - 15
- RPM readings - 15
- PRY readings - 3000
- Suspension readings – 300,000

This totals 303,016 readings every 15 seconds. This equates to 2,418,032 Bytes or 2.4 MB every 15 seconds. Which is 9.67 MB every minute. Across the 2-hour testing window would require the SD card to have minimum storage requirement of 1.16 GB. A suitable SD card would be the SD Ultra 32GB SDHC Memory Card with up to

120 MB/s [10]. While this may seem excessive it provides good performance at no greater expensive over a 2GB alternative costing only £8.30 [10].

Sensor	Rep time (s)	Bytes per reading	Reading per 15s	Bytes/15s	
temp	15	2	1	2	
gyro*3	0.005	6	3000	18000	
sus*4	0.00005	8	300000	2400000	
rpm/mph	1	2	15	30	
total Byte B in 15s				2418032	
15*4 = 1 min				4	9672128
2hr testing				120	1160655360
Convert to MB/2Hr					1160.65536
					MB/2hr

Table 2: Storage size calculations

Sensors

MPH/RPM:

To measure the speed of the vehicle an optical sensor was used as it would be simplest to implement and easier to maintain over other devices such as ones of a mechanical nature. The chosen sensor was the SD-VOP02-000 Optical Speed Sensor [11]. This sensor was chosen as it is contact free and has desirable specs included minimum detectable size of 4mm and a measuring distance of 18-120mm [11]. Furthermore, it can run off a 12V supply and can run off 30mA which conform to power and current specifications of this DAQ. With regards to protection according to the data sheet this sensor is reverse polarity proof, short circuit proof and IP67 rated, giving the same water protection capabilities as the casing [8] [9]. The sensor is small as well, 32x16x12mm, making it suitable to be attached inside a wheel arch.

The measurement of RPM will be done by the same sensor as it will be measuring a similar rotational event just with a different application and therefore no major changes in sensor are required.

Temperature:

To measure the engine temperature of the automobile the PIR sensor to be used is the Callex PC21MT-0 [12]. The sensor is small and cylindrical with dimensions of 18x103mm so like the optical sensors is suitable to fitting in a confined space that is expected to be near the engine. Furthermore, the operating temperature can be between -20°C - 500°C which considering most automobile working temperature is between 75°C-105°C [13], this is plentiful. Having a temperature sensor which can achieve low temperature measurements is useful to determine how long the car is able to get to working temperature from being turned on. The sensor can run off 12V and draws no more than 20mA which enables it to be off the same power supply as the optical sensors. Furthermore, this sensor has a measuring distance between 100mm to 1000mm at a 240ms response time. The sensor is not designed to sense reflective materials such as metal surfaces however, as most modern engines are

covered in a plastic protective cover so this does not present a problem. This sensor also has an IP65 rating [9] making it as waterproof as the other sensors.

PRY:

The PRY sensor will be a Baumer GIM140R sensor gyroscope [14] which is a 1-dimensional gyroscope and thus three Baumer sensors are needed to measure all the three dimensions. The Baumer can measure a complete 360° with a resolution of 0.2°. At this accuracy, the sensor will be able to detect subtle movement in the car's movement which is to be expected on a track environment. The gyro can run off a 12V power supply and consume 8mA which is compatible with the selected power supply. This gyro also has reverse polarity protection and is short circuit proof. At 48x14x45mm the Baumer is a small sensor that can easily be attached to the vehicle and operating temperature of -40 to 85°C. Finally, the Baumer has an IP67 rating making it as waterproof as the other sensors [14].

Suspension:

For suspension measurements four SP1-12-3 wire potentiometers [15] will be used. The potentiometers can run off 5V which with the use of a voltage regulator which will already be used to supply the PIC, can run off the 12V power supply used by the other sensors. The potentiometers have dimensions of 73x56x45mm making it the largest sensor. This potentiometer has a wire length of 317mm which should be a sufficient length on a smooth track surface.

Connectors

Each connector on the PCB would be a pin connector (except for SD) and they would be designed to be reverse bias proof. This would be achieved by the connector assignments being symmetrically allocated meaning that no matter which way the connector is plugged onto the board the connections will always be correct. Furthermore, all the connectors which serve different purposes will have different size connectors to distinguish easily between the different sensors. The only exception for this is for the MPH and RPM optical sensors which are both six pins. This decision was made in order to simplify the design stage as both use the same sensors and therefore would mean the same circuitry would be used so there was no chance of internally damaging the PCB.

The PCB would be mounted in the Peli-case via screws and the pin connections would be connected to the female counterparts. These female pin connectors would have a wire attached to a connector type compatible with the sensor. The connector would be a female connector which would in turn be connected to the male counterpart which would be wired to the sensor. This means suitable female pin connectors and both male and female sensor compatible connectors needed to be purchased for each sensor. The pin connectors will not have to be waterproof as these will be internal and protected from the casing. The other sensor connectors will have to be.

The two optical sensors use a circular 4 pin male Binder 719 4PM [11] connector incorporated into the wiring. Therefore, only a female connector needed to be purchased for each sensor. The connectors are IP40 [9] rated which translates to

being splash proof. The PIR temperature sensor is a 3-pin connector on the board so a 3-pin female is needed, as well as a 2-pin connector for the sensor. The connector chosen was the RS Pro SY13 Male and Female cable mount connectors [R]. These connectors are IP67 [R] rated. The 2-pin connector is rated to 13A and 250V, well within the safe working parameters of the circuit. The 3-pin female pin connector was a Molex 3 Way PicoBlade [16].

The RS PRO SY13 5 Pin and 4 pin [17] variant was selected for the gyroscope and wire potentiometers as they offer the same protection as the 2-pin used on the PIR sensor. To connect to the PCB a Molex 5 Pin and 7 Pin female connectors will be used respectively.

Sensor	Connector	Pin Connector	IP rating	Max Conn Voltage (V)	Max Conn Current (A)
MPH	Blinder 719 4PM	Molex 6	40	60	3
RPM	Blinder 719 4PM	Molex 6	40	60	3
TEMP	RS PRO SY13 2 pin	Molex 3 way	67	250	13
Gyro	RS PRO SY13 5 pin	Molex 5	67	250	13
Sus	RS PRO SY13 4 pin	Molex 7 to 7	67	250	13

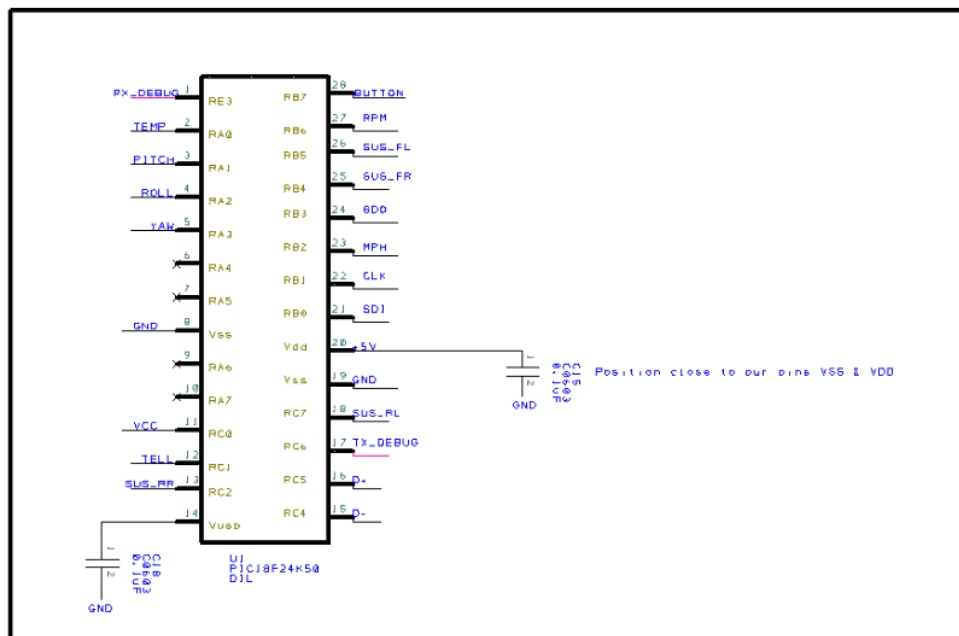
Table 3: Table of connectors for the sensors

Circuit Diagram

The schematics below are from Easy-PC [18] showing the individual areas of operation for the whole DAQ PCB circuit. Figure 3 shows the PIC18F24K50 [1] pin connection for all the relevant external signals as well as the other peripheral such as SD storage. All the analogue signal, i.e. suspension, are connected to analogue pins which are connected to the 10-bit ADC [R]. SD cards use the SPI communication protocol [R] and so needed to be connected to the SPI compliant pins labelled SDI, SDO and CLK which gives the SD clock pulses for the reception of data. USB uses a serial communication and so will be attached to the serial ports 'D+ & D-' for Tx and Rx of data. The PIC18F24K50 datasheet [1] provides information for getting started including the connection of such pins under certain conditions. For the conditions used for this task the datasheet informs that the VDD and Vsub must be connected to ground via a capacitor.

Figure 4 and 5 shows the schematic for the inputs of temperature and the digital inputs for MPH and RPM. The circuit shows a low pass filter to block any high frequency noisy components which may superimpose onto the digital signal. Also, in the schematic is a 5.1V Zener diode which is used to protect the microcontroller from any surges in voltage. Figure 6 & 7 shows additional signal conditioning using a non-inverting operational amplifier (op-amp) [19] to boost the voltage of analogue signals if required.

Microcontroller



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Temperature/ PIR Sensor Connection

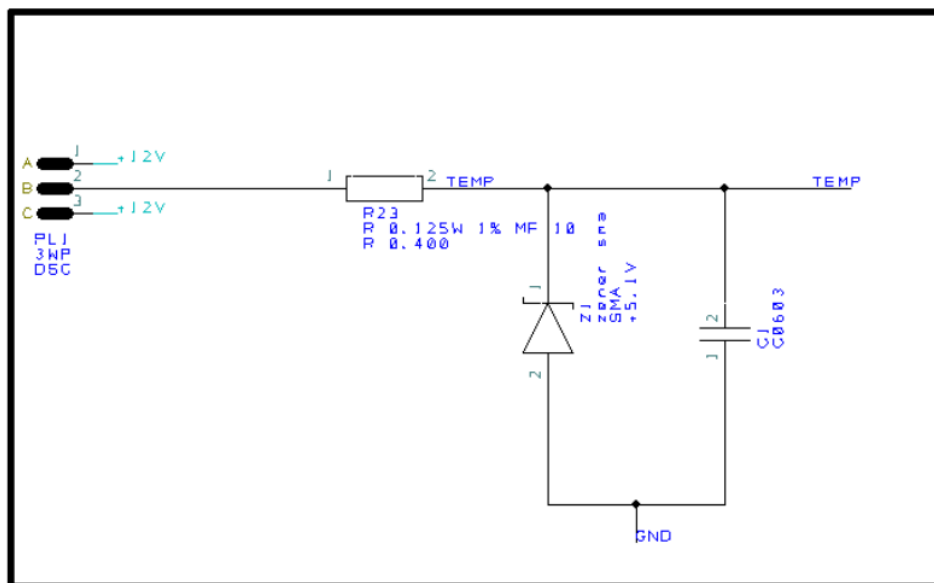


Figure 4: Temperature connection and signal conditioning schematic

MPH & RPM/ Optical Sensor Connection

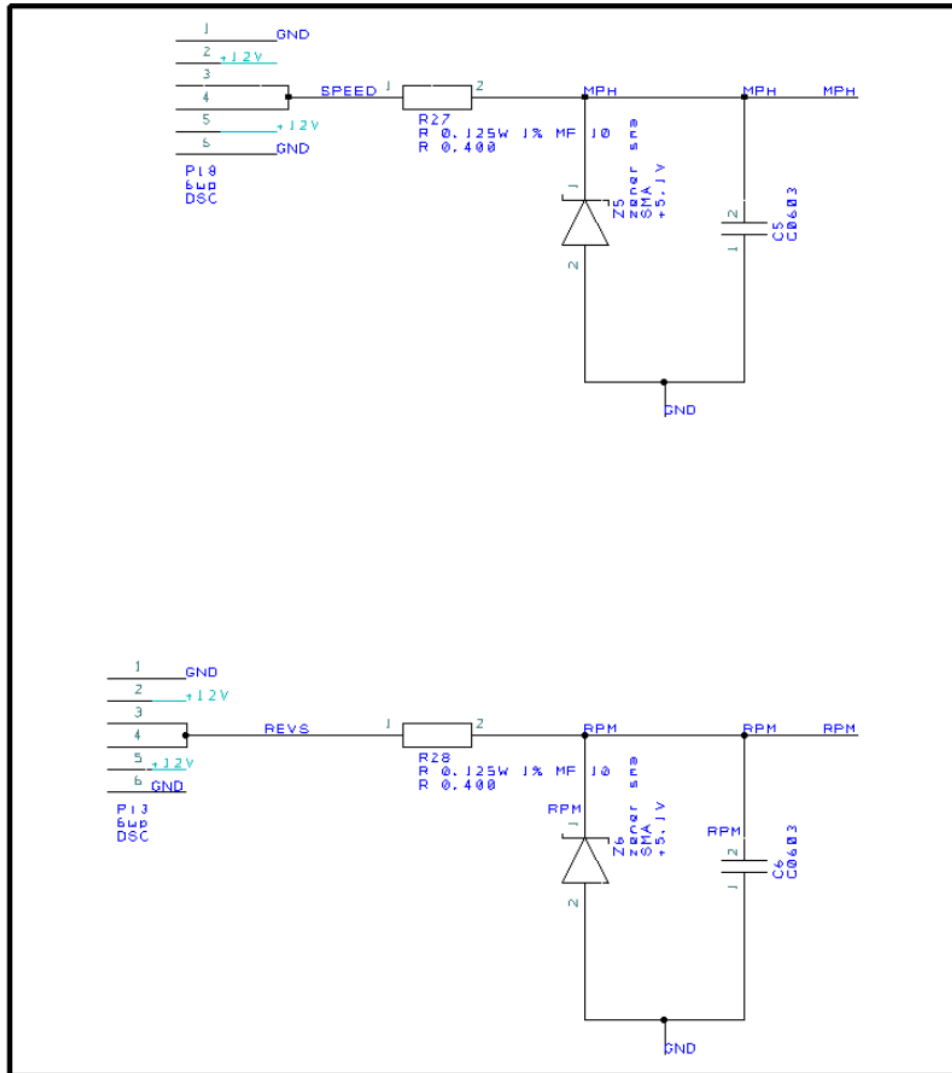


Figure 5: MPH & RPM connection and signal conditioning schematic

The figure displays four circuit diagrams, each showing a different input voltage source connected to a 7805 voltage regulator. The input voltage sources are 3V, 4V, 5V, and 6V. The output of the 7805 regulator is connected to a 5V output terminal. The diagrams are labeled 'Circuit 1', 'Circuit 2', 'Circuit 3', and 'Circuit 4'.

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Gyroscope/PRI Connections

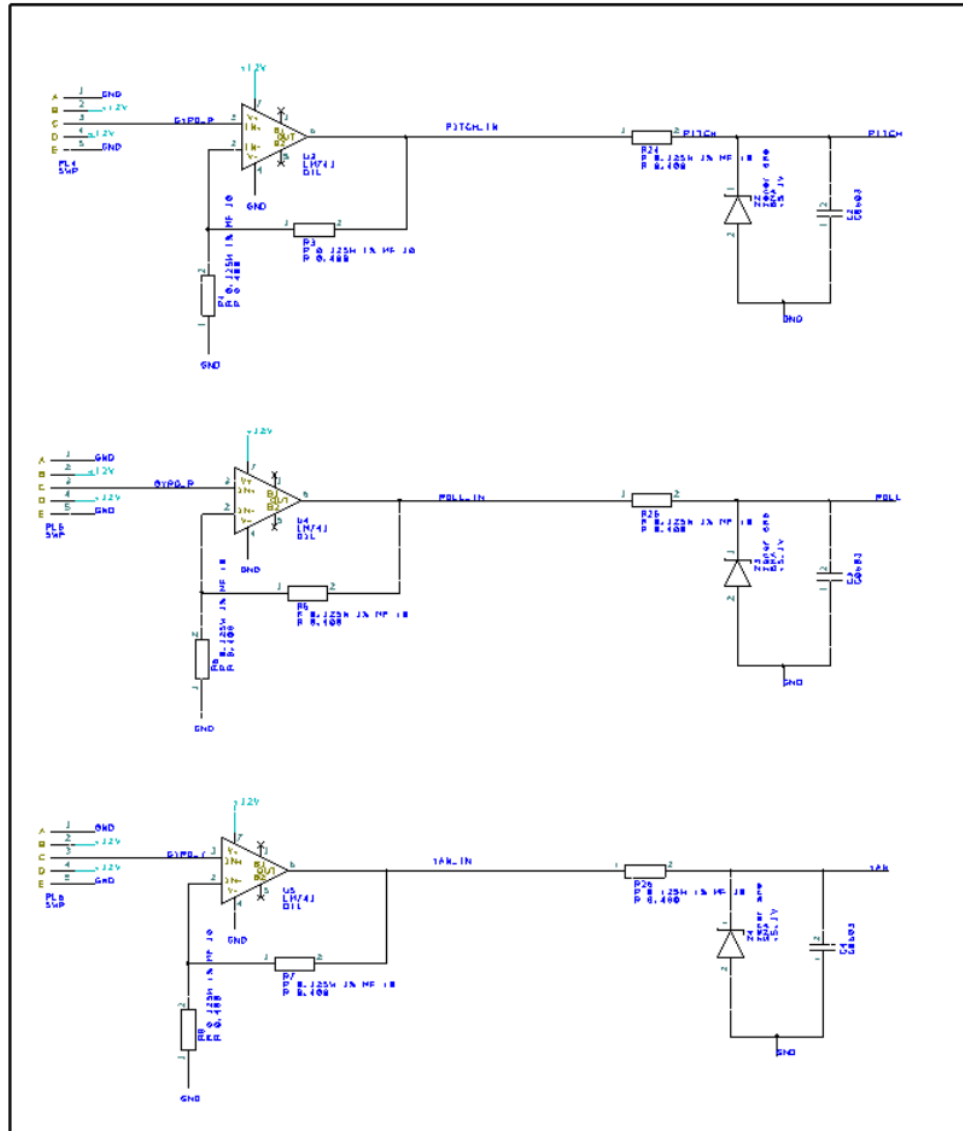


Figure 7: Gyroscope analogue signal processing conditioning

Power Supply & Voltage Regulators

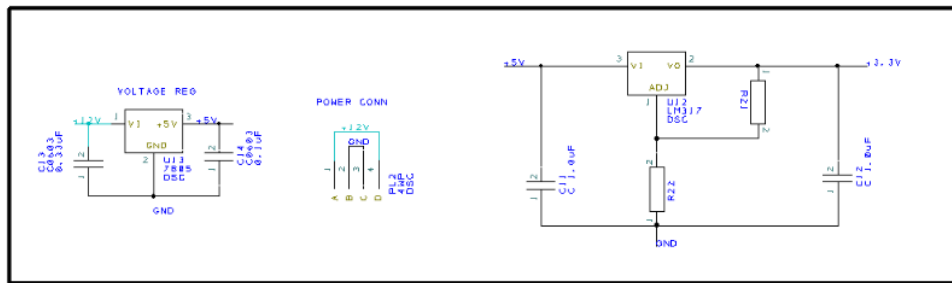


Figure 8: Power Supply, 5V and 3.3V regulators

SD Card & USB Connection

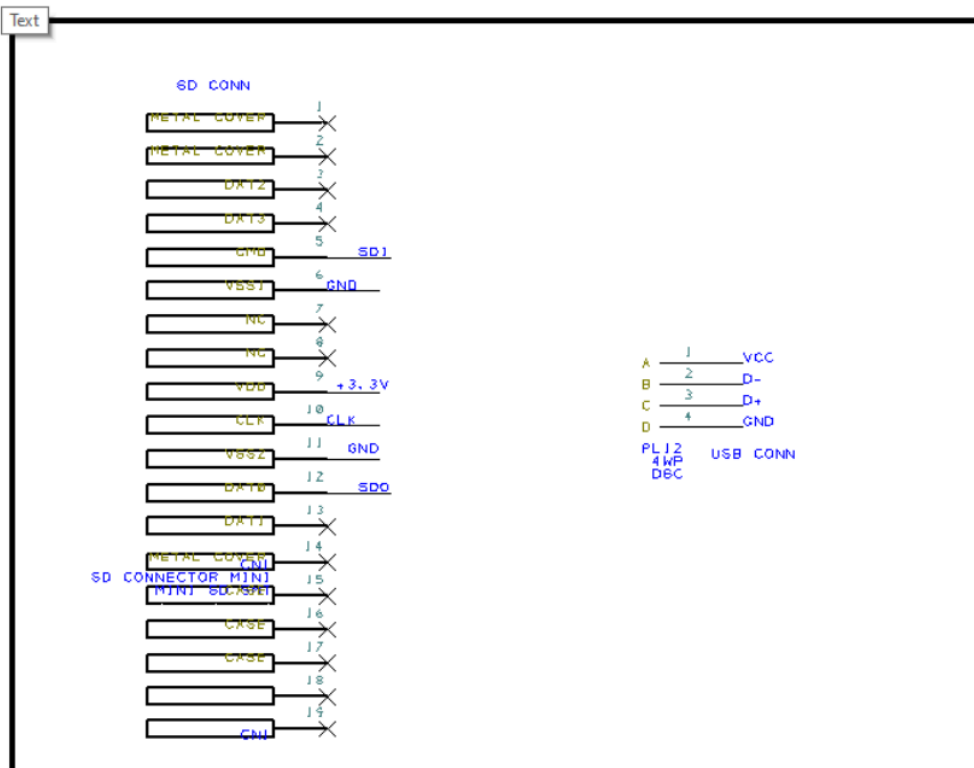


Figure 9: SD & USB connector ports

Tell & Button

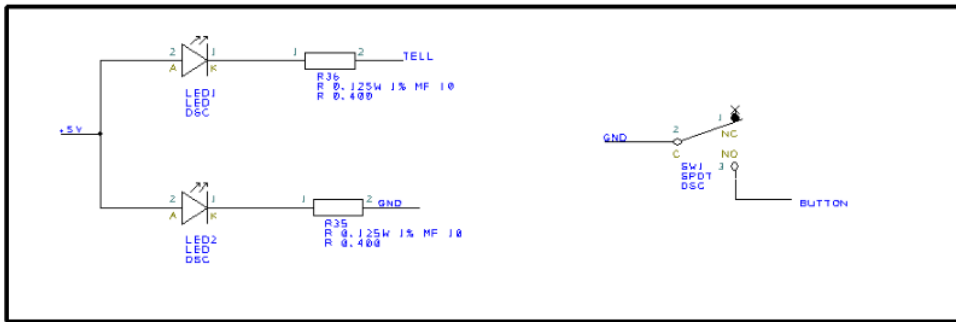


Figure 10: Tell and switch schematic

Software Design & Structure

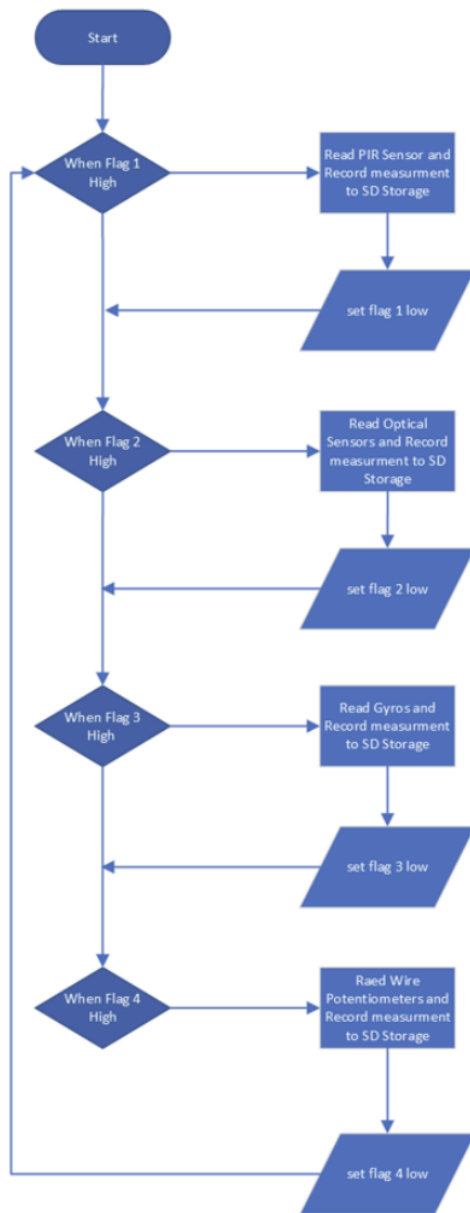


Figure 11: Flowchart showing the main function of the C-code.

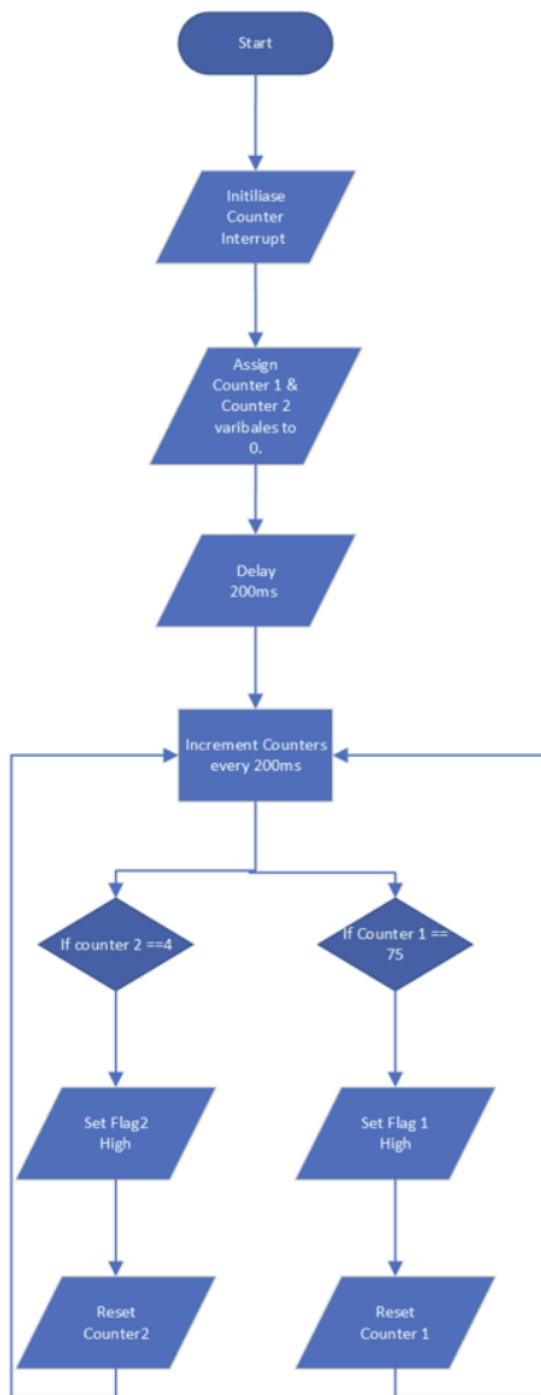


Figure 12: Subroutine which covers the measurement of the temperature, MPH and RPM.

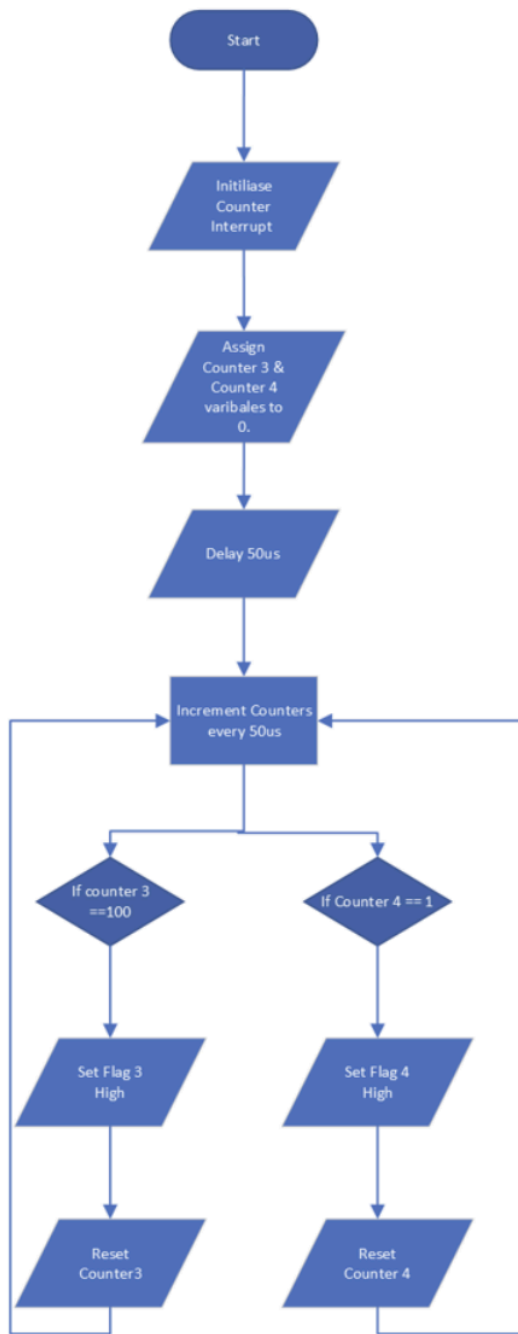


Figure 13: Subroutine to cover the measurements of the gyros and suspension. These routines run off a quicker clock interval as the frequency of measurements is higher.

PCB Design

The figures below show the PCB design for the data logger. The PCB would cost £53.33 from JLCPCB [23] to produce. The PCB consisted of a combination of surface mount and through hole components. The high quantity of components proved difficult to wire so 3 copper layers for +12V, ground and +5V were implemented to take the burden off the wiring complexity. The ideology was to place the connection ports as close to the corresponding signal pin on the microcontroller to simplify the circuitry. Previous attempts place the connectors in co-ordinated rows on one side of the board proved too difficult to implement. Furthermore, the power copper layers were placed in the centre layers rather than on top as the surface mount components provided no through path sometimes, isolating some areas from the rest of the power layer.

The thickness of traces and proximity to other objects was checked with the JLCPCB [23] specification to ensure that this board complied. There were still a couple occasions where pins were isolated and unable to be connected to either ground or power and so a via had to be implemented to solve the problem.

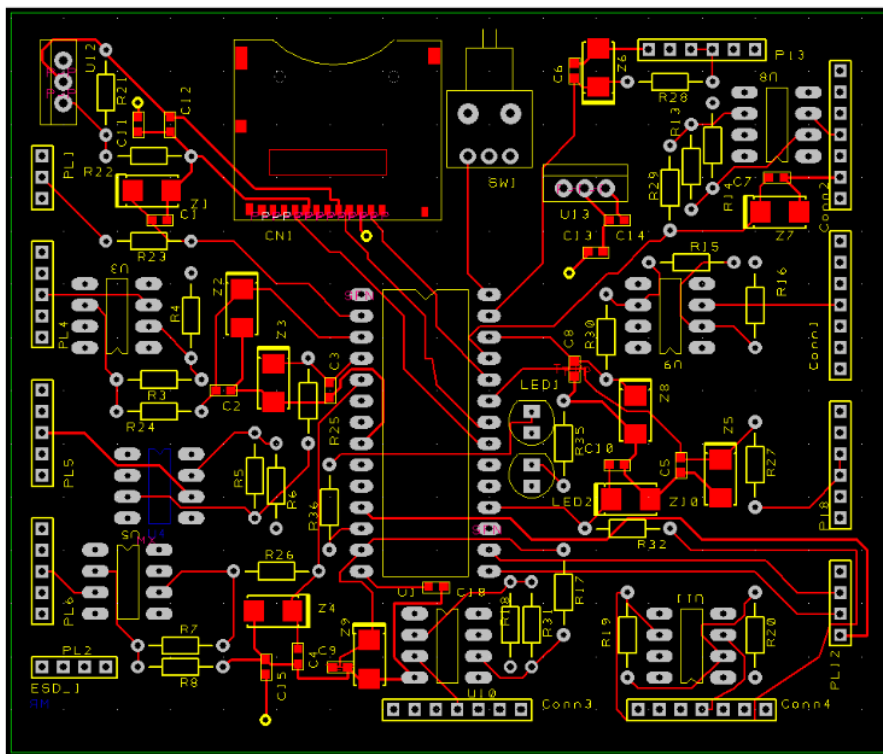


Figure 14: PCB 2D design in Easy-PC [18]

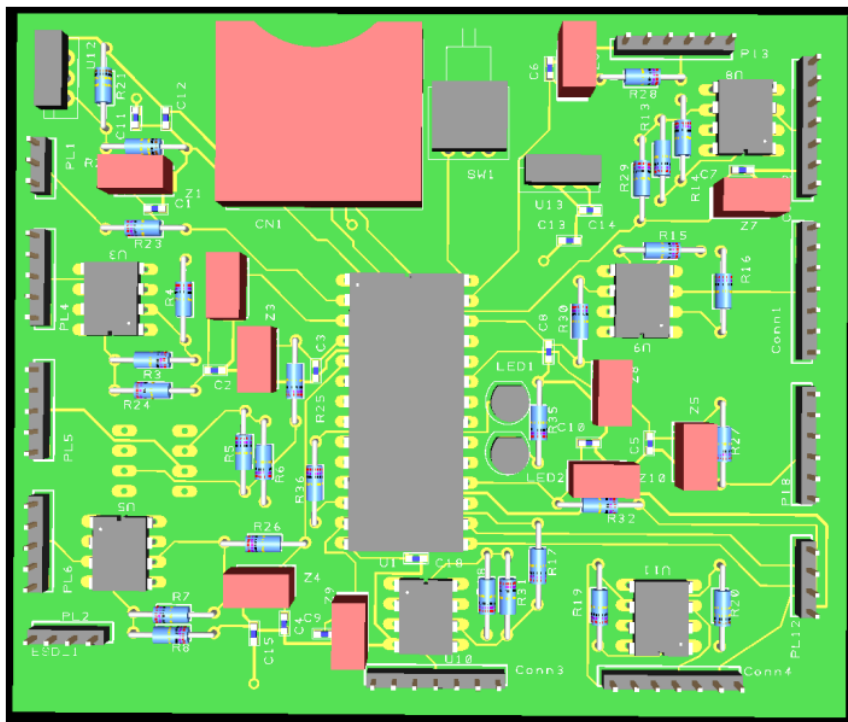


Figure 15: 3D PCB graphic Easy-PC [18]

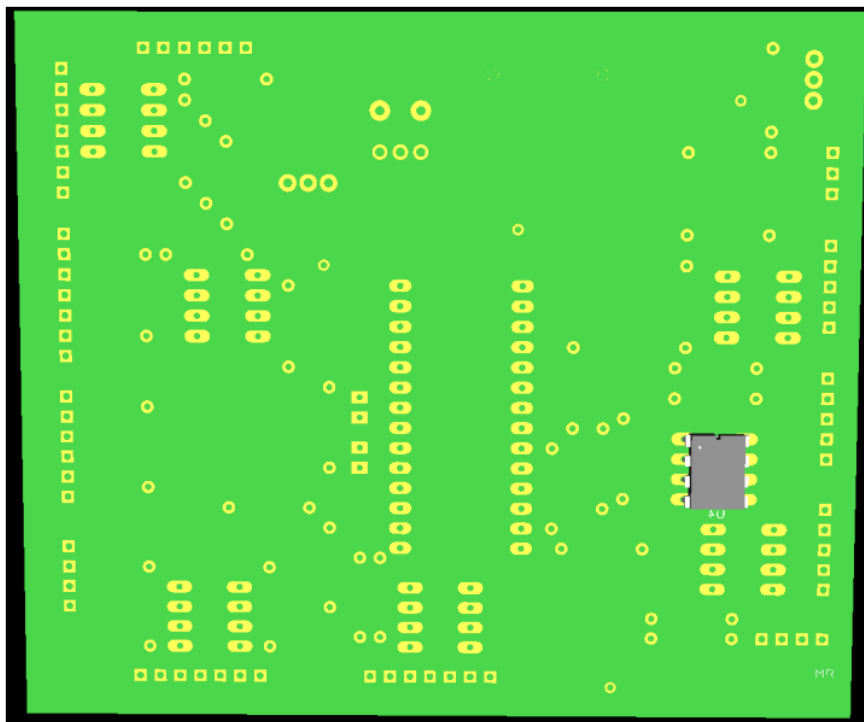


Figure 16: 3D PCB graphic (backside of PCB) in Easy-PC.

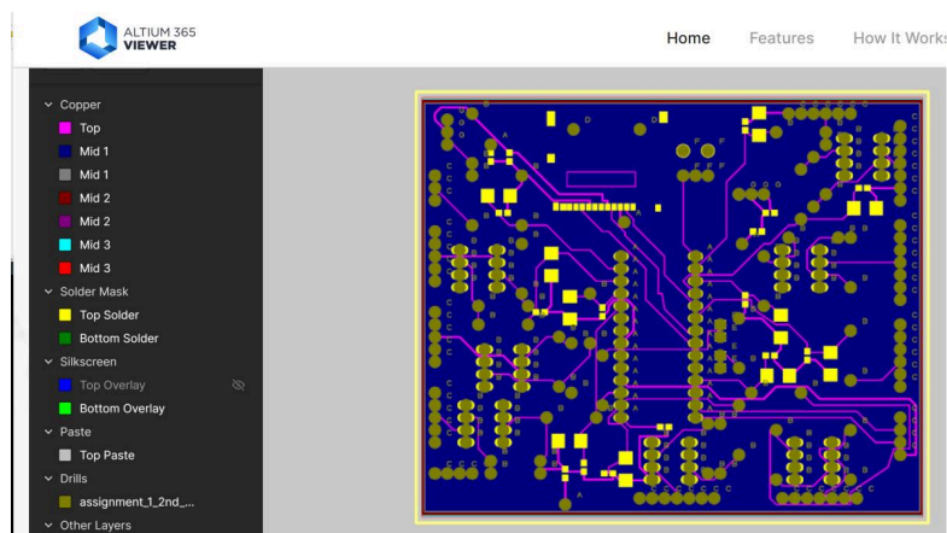


Figure 17: Gerber view in Altium to ensure file is read correctly/ not corrupt.

Build Cost

Part	Name	Quantity	Cost(£)	Info
MPH-sensor	SD-VOP02-000	1	£254	
RPM-sensor	SD-VOP02-000	1	£254	
Temp - sensor	Calex PC21MT-0	1	207	
PRY - sensor	Baumer Sensor, 5-Pin	3	576	
Suspension -sensor	SP1-12-3	4	1381.36	384.34 each
battery	RS PRO 14.8V Lithium-Ion Rechargeable Battery Pack, 2.6Ah	1	39.38	
voltage reg	LM 7805	1	0.68	
Op-Amp	Lm741	7	28.91	4.13 each
resistor	misc	20+	3	est
Zener Diode	5.1V	20+	2.58	
Microprocessor	PIC18F24K50	1	2.95	
USB (female)	RS PRO, Through Hole, Socket Type A USB Connector	1	2.98	
SD card port (female)	Development Kit Pmod MicroSD Card Slot for use with Store and Access On Sy	1	8.35	
LED	RS PRO1.6 → 2.4V Red LED 3 mm Through Hole	2	2.11	
Casing	1200 PROTECTOR TOOL CASE	1	69.77	
SD-card	32 GB SD	1	8.3	
4 Pin sensor conn F	Binder Connector 4 Pin	2	15	7.5 each
4 Pin sensor conn M/F	RS PRO Circular Connector 4 Pin SY13	4	39.76	9.94 each
5 Pin sensor conn M/F	RS PRO Circular Connector 4 Pin SY13	3	66.45	22.5 each
2 Pin sensor conn M/F	RS PRO Circular Connector 4 Pin SY13	2	19.88	9.94 each
Pin conn F 7 pin	Molex F 7 pin	4	21.16	5.29 each
Pin conn F 5 pin	Molex F 5 pin	3	16.89	5.63 each
Pin conn F 6 pin	Molex F 6 pin	2	10.76	5.38 each
Pin conn F 3 pin	Molex F 3 pin	1	2.24	
PCB		1	53.33	
Total			£3,087	

List of Potential Improvements:

- Greater fidelity on ADC. Other models had up to a 24-bit ADC, compared to 10-bit.
- The DEWESoft signal conditioning is also far superior and can achieve 130dB signal-to-noise (SNR) and an ability to minimise aliasing using DualCoreADC technology [3].
- DEWESoft products have in-built synchronisation so no matter the sampling rate of the different sensors they will always be synchronised including video synchronisation. This could aid troubleshooting if anomalies in the data is found [3].
- DEWESoft also offers GPS/GNSS positioning.
- DEWESoft also offer a free data acquisition software 'DeweSoftX' [24] which is heavily used across many markets. It could be something to make the system compatible within future for simple signal processing.
- DEWESoft DAQs are also expandable making it easy to extend channel count by various methods including USB and an EtherCat slave port to connect addition DAQs [3].
- Shock and Vibration proof. No measured protection against this on this design and so would be a very important aspect to consider in future to make the system more robust and versatile i.e. if this DAQ was fitted to an automobile being tested off-road instead of a track.

References

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FINAL GRADE

GENERAL COMMENTS

68/100

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GRADING FORM: SMU GENERIC_GJ

MATT RUSSELL

68.35

RESEARCH-INFORMED LITERATURE



Good literature review of available systems with a good comparison table of relevant information but would have been better with some images.68%

6.8

KNOWLEDGE AND UNDERSTANDING



Your schematic diagram is good but there are a couple of issues. There are no voltage regulators shown in the circuit diagram. You are showing -12V being applied to the amplifiers but there is no mention of a -12v supply on the Proteus schematic diagram but on your easy-pc schematic you are showing a 741 amplifier being used with a single sided supply, are you sure it works correctly like this. . Your PCB although good does have a single component on the back side, unnecessarily. A good attempt 65%

16.25

ANALYSIS



Good selection of microcontroller, and of the enclosure. Reasonable selection of sensors with some images and short spec. A 100nf cap should be placed between the power lines as close to the microcontroller as possible. Your connectors are good. 70%

24.5

PRACTICAL APPLICATION AND DEP.



your costings are nicely tabulated and carry manufacturer and part numbers. Reasonable attempt at future enhancements but all appear to be connected to Dewsoft.. 68%

13.6

SKILLS FOR PROFESSIONAL PRAC.



The report is well presented with a good number of images. Good selection of references. 72%

7.2