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**DESIGN OF AN AUTOMOTIVE
DATALOGGING SYSTEM**
ACDA6002: ELECTRONIC SYSTEMS DESIGN

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Abstract

This report will evaluate existing commercial-off-the-shelf datalogging systems to inform the design of an automotive datalogging system. A datalogging system can be considered as an electronic sensor array consisting of sensors and a microprocessor, capturing measurable data for the purpose of identifying issues and areas for development [1].

The purpose of this datalogging system being to analyse a vehicles performance characteristic over a 2-hour session on track. Within the datalogging system, the RPM, engine coolant/oil temperature, suspension travel, pitch/roll/yaw and speed will be captured and stored onto a non-volatile storage medium for a later analysis of vehicle performance.

The constraints of the system are that it must be self-powering and not communicate or interact with any of the onboard systems or networks of the host vehicle (i.e., CANBUS), relying solely on the sensors specified in this report for the capture of data.

Literature Review

Existing commercially available datalogging systems for automotive applications vary greatly in their capabilities and therefore in the volume of data captured and stored within the system.

The variance in capability between systems is predominantly due to the intended purpose of the system. For instance, for motorsport applications such as F1, parameters such as Engine Temperature, Coolant Temperature, Oil Temperature/Pressure, AFR, RPM, Suspension Travel, Pitch/Roll/Yaw and Speed will be captured in real-time at high-resolution for constant analysis of both the drivers and vehicles performance [2]. Examples of motorsport-oriented datalogging systems are the Racelogic VBOX and the Race Technology DL1 Pro, which can be custom configurable to the specific requirements and application of the user, with 100s of sensors available.

However, in other applications, such as telematics insurance policies, datalogging systems capture data at a much lower resolution and focus only on parameters such as acceleration/deceleration, speed, and location [3]. Examples of insurance-oriented datalogging systems are the Trakm8 Connect 330 and the Trakm8 Connect 430.

Model.	CAN Integration	Flash Storage	Gyro meter	RPM	GPS	Accelerometer	External Sensor Inputs	Serial (RS232)	Display Module
VBOX	Y	Y	Y	Y	Y	Y	13+4	Y (1)	Y
DL1 Pro	Y	Y	Y	Y	Y	Y	16	Y (2)	Y
Connect 330	N	N	N	N	Y	Y	0	N	N
Connect 430	Y	N	N	N	Y	Y	0	N	N

Figure 1: Comparison of commercially available datalogging systems

Demonstrated by

Figure 1, the motorsport-oriented DAQs are far more capable and are far more flexible than the telematics insurance-oriented DAQs. What is not captured in

Figure 1 is cost, whilst the insurance-oriented DAQs are essentially free to the end-user/customer, the motorsport DAQs are expensive, with the base units for both the VBOX and DL1 costing around £1000 for the base module, not including the cost of the sensors themselves and accessories [4] [5] [6] [7].

Microcontroller

To calculate the required frequency for the microcontroller, the following equation is used:

$$\frac{1}{0.000005/400} * 4 = 32\text{MHz}$$

Equation 1: PIC Clock Speed

Within Equation 1 there 0.00005 is the 50us reading interval of the suspension travel and the 4x multiplier being that a PIC microcontroller can execute a single instruction in 4 clock cycles, and 400 being the number of operations per second that would need to be executed by the PIC [8].

To provision for the sensors and peripherals the microcontroller would have to have 13 usable I/O pins, along with a USB peripheral and an SPI peripheral, for the USB data out and SD card. The microcontroller would also have to have sufficient RAM for the storage of the program variables and for the packets to be constructed for storage on the SD card.

[illegible]

Figure 2: Microchip Advanced Part Selector

A suitable PIC microcontroller which met these requirements could then be identified using the Microchip Advanced Part Selector tool. As seen in Figure 2, three PIC18F microcontrollers were identified, from which the PIC18F24K50 was selected. The datasheet validated that this PIC had 25 I/O Pins, USB support, RS232, an inbuilt Serial peripheral, and an operating frequency of up-to 48MHz [9].

Figure 3: PIC18F24K50 Interrupt Setup

Figure 3 shows the PORTB timer/Interrupt setup, within CCS, used to poll the sensors. Timer 2 is set at 50us overflow for the suspension sensors (20,000Hz); Timer 0 is set 1000ms (1Hz) overflow for the RPM and MPH. For the other sensors, water/oil temperature and pitch/roll/yaw, these interrupts will utilise a counter which when met will read these functions within the interrupt as well. The values for this are shown in Figure 4.

Timer 2	5.00E-05	Timer 1	1
PRW	5.00E-03	Temps	5
Count 0	100.00	Count 1	5

Figure 4: Counter for PRW (Timer 2) and Temperatures (Timer 0)

Figure 5 shows the suspension calculations for the wheel rotation of the vehicle, showing that at the 50us intervals measured – the system will measure the suspension travel every 2.23mm travelled by the vehicle at a maximum speed of 100MPH – a common speed achieved on a racetrack in a modern production vehicle. For instance, the most registered new car of 2024 is the Ford Puma, of which the popular 125ps 1.0T has a top speed of 116MPH [10] [11].

100	mph
44.69	m/s
2.23E-03	m/50us
2.23E-01	cm/50us
2.23E+00	mm/50us

Figure 5: Suspension Measurement Calculation

Figure 6 shows the calculations for the volume of data captured over the 2-hour testing period. Without any form of formatting/data structure, there will be at least 1160657280 bytes of data to be stored on the SD card, which translates to ~1.16GB.

Sensor Data	Byte/read	Period/read (s)	Bytes/15s	
MPH	1	1	15	
RPM	1	1	15	
Water Temp	1	5	3	
Oil Temp	1	5	3	
Suspension	8	0.00005	2400000	
PRY	6	0.005	18000	
			2418036	Total/15s
			1160657280	Total/2hrs

Figure 6: Data Capture Calculations

Figure 7 shows the calculations obtained for the average wheel size of a vehicle, which was used to help determine the suspension travel. The wheel size (16") and type profile (55mm) are commonly used on luxury saloons such as the Mercedes C Class and BMW 5 Series.

wheel size (inches)	tyre profile (mm)	total dia (mm)	total circumf (mm)	total circumf (m)
16	55	461.4	1448.80	1.448796
max speed (mph)	mi/min	km/min	metres per second	
100	1.666666667	2.681666667	44.69	
wheel revs/s	wheel RPM			
3.08493704	185.0962224			

Figure 7: Wheel Dimensions and Peak Rotation Speed

Sensor Selection

Sensor Type	Manufacturer	MPN	QTY
Optical Speed Sensor	Compact Instruments	VLS/DA/LSR	2
Spring-return Potentiometer	Unimeasure	HX-PA-20-N20-N46-34K	4
Analog Gyroscope	Analog Devices	ADXL335	1
Thermistor	Vishay	NTCALUG01A103FL	2

Table 1: System Sensor Selection

To measure engine oil and coolant temperature, a 10K Ω thermistor (NTCALUG01A103FL) is used, with a temperature range of -40°C to +150°C [12]. The temperature range of -40°C to +150°C is suitable for both coolant and oil temperature, as an oil temperature of above 150°C is not achievable without catastrophic engine failure – also being true for coolant temperature [13]. A thermistor has been specified due to its simplicity and ease of integration, for instance the coolant sensor may be mounted using Kapton tape to the coolant expansion tank (or even the radiator), with the oil sensor mounted to the oil filter housing or to the sump, again using Kapton tape. Other sensor types, such as infrared, were ruled out due to their added complexity, when compared to thermistors, without a tangible benefit as the sensor is only polled every 5000ms.

A pair of optical sensors have been specified for RPM and vehicle speed. The sensor used for both applications is Compact Instruments VLS/DA/LSR – optical sensors allowing the engine and wheels of the vehicle to rotate without the sensor making physical contact with the moving components, which would otherwise rapidly wear the sensor and lead to premature failure. These optical sensors are digital, with an output voltage range is between 0V to 3V (0V low, 3V high), signal conditioning is required to provide a usable 5V (4.86V) digital input to the PIC, achieved using an Op Amp and Equation 2 [14].

$$3V * \left(1 + \frac{6200}{10000}\right) = 4.86V$$

Equation 2: Op Amp Gain [15]

A 3-axis +/-3.6G analogue gyroscope has been used to measure the pitch, roll, and yaw of the vehicle. The chosen component is an Analog Devices ADXL335. It provides 3 analog (X, Y, Z) signal-conditioned outputs which can be read by the analog pins on the PIC18F, operating on a 3.3V supply [15]. An analog gyroscope was chosen over a digital version as to not rely on hardware interrupts within the microcontroller which could potentially delay or inhibit the capture of other sensor data. This gyroscope can also operate at up to a 500Hz sampling rate, which is above the 200Hz (5ms) required by the system [15].

Finally, an Unimeasure HX-PA-20-N20-N46-34K 10K Ω analog spring-return potentiometer has been used to monitor the suspension travel at each corner of the vehicle. A spring-return type potentiometer allows for a compact and platform-agnostic method of measuring the suspension travel, using a retractable wire with up to 500mm (0.5m) of travel. The use of a spring return potentiometer was specified over other options, such as Ultrasonic measurement or a hall effect sensor, due to the difficulty in mounting a hall effect sensor to the vehicle and the fact an ultrasonic sensor may be unreliable due to the environmental conditions it would be exposed to in a vehicle wheel arch. The potentiometer is also IP68 rated and has a rated life of 500,000 cycles, so will be reliable even when mounted within a vehicle wheel arch where is exposed to water, road debris, and constant wheel movement [16].

Enclosure & External Connectors

When considering the environment the data logging system is operating in, it will be mounted externally to the vehicle and therefore will be exposed to the elements. The enclosure will have to be IP-rated to a suitable level to ensure that the hardware inside is sufficiently protected from dust and moisture, i.e., brake dust, tyre particulates, and rain/spray.

Taking this into account, the enclosure would need to be at least IP64 rated, where the enclosure would be dust-tight and protected against splashing water [17]. To offer greater protection, an IP65 enclosure is specified, to ensure that the enclosure is watertight in all feasible scenarios during the 2-hour track test.



Figure 8: System Enclosure [18]

The chosen enclosure is a Fibex '1912' TA 191209 IP65-rated ABS box, with the dimensions 187.2mm x 122.2mm x 89.9mm; the enclosure housing both the controller PCB (66mm x 69mm x 1.6mm) and battery power supply to the system. The usable internal height of the enclosure is 63.9mm [18]. The controller PCB will be mounted on M3 5mm plastic standoffs, which will then be mounted with plastic adhesive to the base of the enclosure.



Figure 9: IP68 rated external connector [19]

For the external connectivity, the enclosure will use the RS PRO SP17, see Figure 9, line of connectors, which are IP68-rated and have gold-plated contacts. These are a screw-type latch mechanism bulkhead mount connector with solder buckets, so the connectors will be resistant to vibration and may be soldered internally to cabling for to the board via the specified Molex connectors [19]. These connectors will each require 17mm cutout in the side of the enclosure, where a rubber gasket embedded in the connector will maintain a watertight seal with the enclosure. Both 2-pin and 3-pin types of this connector will be used; a 3-pin male version for suspension sensors, RPM, and MPH, and a 2-pin male version for the engine oil and water temperature sensors – with the appropriate female mating connector mounted to the sensor cables.



Figure 10: SPST Switch & Tell LED [20] [21]

Shown in Figure 10 is an IP65 SPST switch and an LED unit. The purpose being to control the start and end of data recording. The SPST switch is an APEM 1415NC BLACK; the switch requires a 16.5mm x 14.3mm cutout in the enclosure [20]. The tell LED component is an Oxley OXL/CLH/80/5/FL30/H/GN, which is an IP67 rated component with an 8mm mounting hole, designed to operate at 5VDC with flying leads [21].

SD Card

As discussed in the Non-volatile data structure section of this report, the SD card required is of a size above 2.304GB. As SD cards follow the binary scheme of sizing, the minimum size of SD card to use is 4GB. As 4GB is also the maximum size of a FAT16 file system/volume, which will most likely be what is used due to its simplicity, it is the ideal capacity for this system [22].

Another consideration is that for the data structure, 320,000bytes/second will need to be written to the SD card, so the write speed of the SD card must exceed 312.5Kb/s.



Figure 11: System SD Card [23]

The chosen SD card is the Delkin Devices S304GSEMC-U3000-3, a 4GB SDHC card with a 90Mb/s max sequential write speed using MLC NAND [23].

Power Supply

Given that this system must be independent to the vehicle electronics, a battery power source is required. This battery will have to be lightweight and provide an output of >7.5V, or the LM7805 voltage regulator will not be able to supply a consistent +5V [24]. The supply must also maintain >7.5V over the 2-hour period of the test.

Component	Current (A)	Voltage (V)	quantity	Power (W)
wire wound potentiometer	1.00E-04	5	1	5.00E-04
reflector	5.00E-02	5	2	5.00E-01
thermistor 10K	1.50E-02	5	1	7.50E-02
thermistor 10K	1.50E-02	5	1	7.50E-02
gyroscope	3.50E-04	3.3	1	1.16E-03
PIC18F24K50	2.00E-01	5	1	1.00E+00
LED	1.50E-02	5	1	7.50E-02
Totals	2.95E-01			1.73

Table 2: Estimated Power Consumption

Using Table 2, the estimated power consumption of the system components is 1.73W. Therefore, this can be multiplied into Watt-Hours by multiplying by a factor of 2, for 3.46Wh. The power dissipated as heat from the voltage regulators then should be added, see Table 3, where the peak dissipation of the LM7805 is 2.28W, which in Watt-Hours is 4.56Wh, and the peak of the TC1262-3.3V is 0.003255, or 0.006510Wh. When added together, the total battery capacity should exceed 8.07Wh.

LM7805					
Vin (max)	Vout		I(out)	I(in)	Eff (%)
12.6	5		0.3	0.3	39.68254
Vin (min)			P_d(max)	P_d(min)	
9			2.28	1.2	
TC1262-3.3V					
Vin (max)	Vout		I(out)	I(in)	Eff (%)
12.6	3.3		0.00035	0.00035	26.19048
Vin (min)			P_d(max)	P_d(min)	
9			0.003255	0.001995	

Table 3: Voltage Regulator Power Dissipation



Figure 12: System Battery [25]

Figure 12 is a lithium-polymer battery, consisting of 3 cells in series, two of these will be used in a parallel configuration. Each cell is 3.7V for a total of 11.1V. The capacity of the battery is 11.10Wh ($11.1V * 0.5Ah * 2$), far more than the 3.46Wh required. The weight of each battery is also only 58g, keeping the system easily portable. The battery uses an XT30 for discharging, which will require an adapter cable to be made for the Molex Mini-Fit Jr power connector on the PCB. The dimensions of the battery are 53.5mm x 30.5mm x 19mm, meaning it can easily fit within the enclosure [25].

PCB Schematic

Two iterations of the circuit design were completed, an initial version using Proteus Professional 8.4 software, Figure 14, and then a final version in Easy PC V22.0, Figure 13.

As can be seen in the bottom-right of Figure 13, a total of six clamps were used to prevent the input signal/sensor output voltage from the suspension, oil, and water sensors from exceeding 5.1V (the voltage at which the Zener conducts in reverse bias) [26]; the RC component in the clamp circuits blocks are used as a means to de-bounce the sensor outputs [27].

Decoupling capacitors have been added to the PIC and ADXL335 gyroscope components. In both cases, these are 100nF capacitors intended to reduce ripple during transient current load [28]. The decoupling capacitors are placed as close as possible to the component to maximise their effectiveness. Bulk capacitors have been added to the voltage regulators (LM7805, TC1262-3.3) to provide smoothing to the unregulated inputs (+12V) and to the regulated (+3.3V, +5V) outputs.

Regarding the external sensors, these are provisioned for by on-board Molex connectors from the Mini-Fit, Micro-Fit, and Mini-Lock families. These will then connect to another IP-65+ rated connector on the inside of the enclosure, these IP-rated connectors being attached to the sensors, maintaining an environmental seal. The optical sensors (MPH, RPM), require signal conditioning to provide a usable output to the PIC microcontroller, a single supply (+5V) Op Amp (TSU104IQ4T) achieves this, the component containing four isolated Op Amp circuits of which two are used for the RPM and MPH signals [29].

Finally, the gyroscope (ADXL335) has been implemented as a PCB component rather than as an external sensor module – due to the BOM and board space requirements being minimal. Power is supplied by the already-present TC1262-3.3 regulator. The 27nF caps on the X,Y,Z outputs set the operating frequency to 200Hz, or the desired measurement interval of 5ms [15].

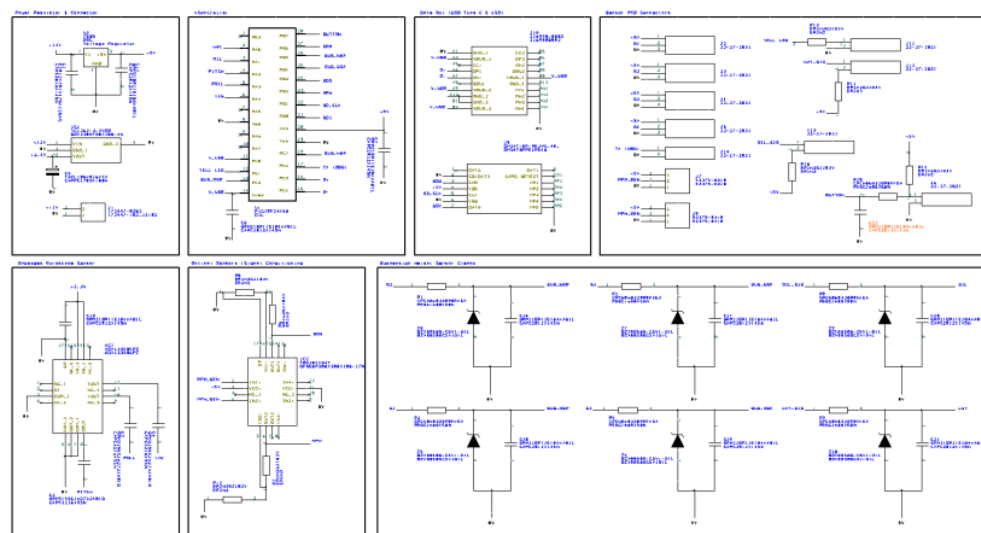


Figure 13: Easy PC PCB Circuit Schematic

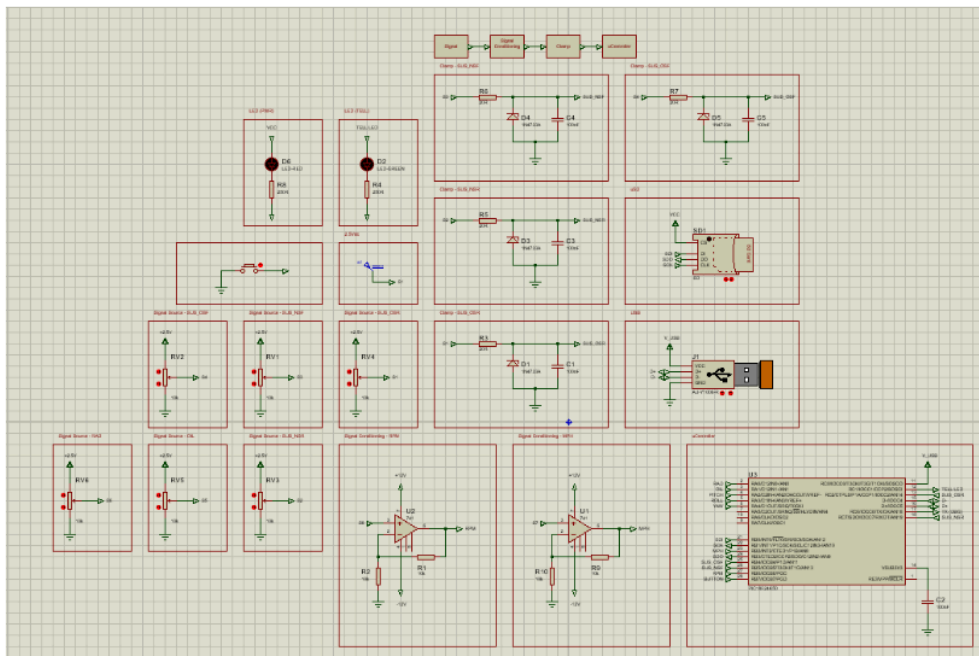


Figure 14: Proteus Circuit Schematic

PCB Design

As seen in Figure 15, the PCB design is a 4-layer PCB, comprising of: Signalling (TOP), +5V (INTERNAL 1), GND (INTERNAL 2) and Signalling (BOTTOM). The physical dimensions of the PCB are 66mm x 69mm x 1.6mm. The track width used for signalling traces was set at 0.3mm, with 0.4mm used where possible/necessary for the power traces – much of the power transfer in the design is through the internal +5V power plane. Barring the connectors, the LM7805 regulator, the PIC and the USB-C port, all components on the PCB design are surface-mounted – the aim being to reduce the PCB size and therefore allow for a smaller enclosure and reduce PCB cost [30].

The board has four M3 mounting holes, which are at each corner of the board and are at a square 58mm spacing from each other. The connectors have been placed at, or close to, the board edges to facilitate easier assembly into the system. A micro-SD connector has been specified, rather than a full-size SD connector, as most SD-type cards sold are now of the cheaper micro-SD type and to reduce overall board size and therefore PCB cost [31] [30].

Figure 16 shows a 3D view of the PCB design to give an impression of what a real implementation of the board would look like. As can be seen, several components have a 'red box' 3D model, where the 3D model of the component could not be properly displayed by Easy-PC.

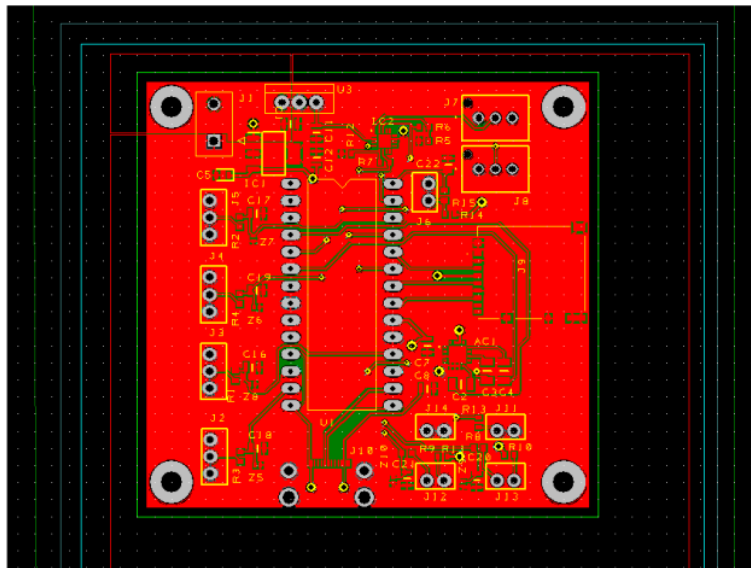


Figure 15: PCB Design (2D view)

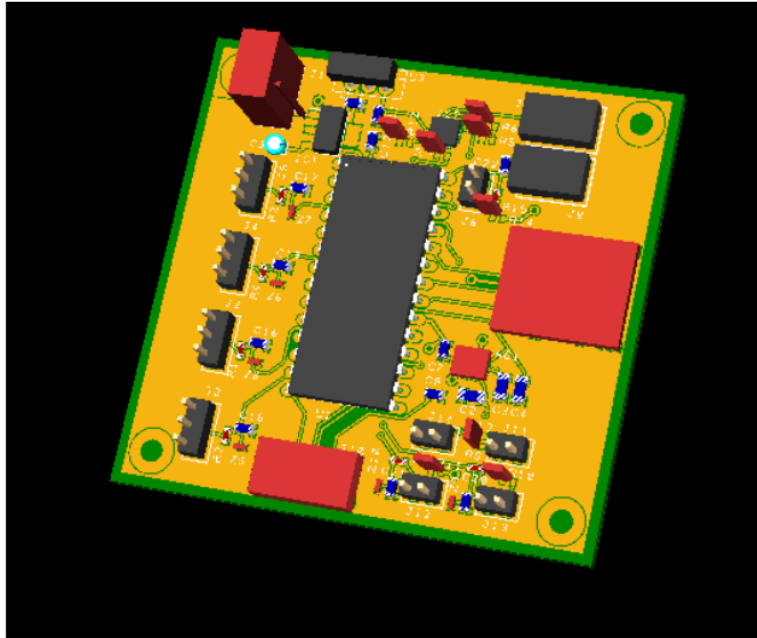


Figure 16: PCB Design (3D view)

PCB Design Testing

With a PCB design now finalised, the Design Rules Check (DRC) could be carried out to identify errors and anomalies within the design which could then be rectified prior to exporting the PCB as a Gerber file; a DRC check is important as it ensures that the design meets the constraints for the technology and methods by which the PCB will be manufactured by the fabricator [32].

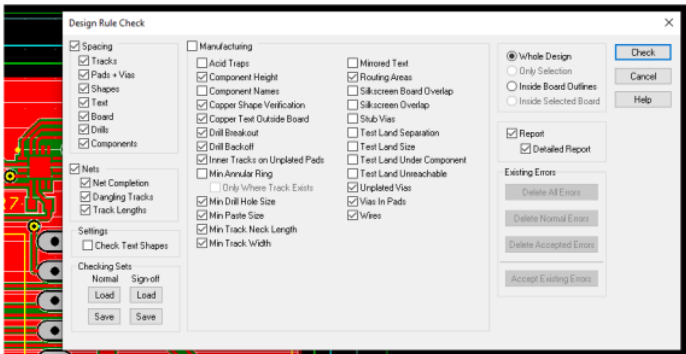


Figure 17: PCB DRC Configuration

Figure 17 shows the DRC window in Easy-PC. Within this, the options shown are selected, with a report generated by the DRC checks, with the aim being to have no errors within the design. Using this tool, several errors relating to dangling tracks and minor adjustments to track and component placement could be made, until there were no remaining errors. Figure 18, shows the result.

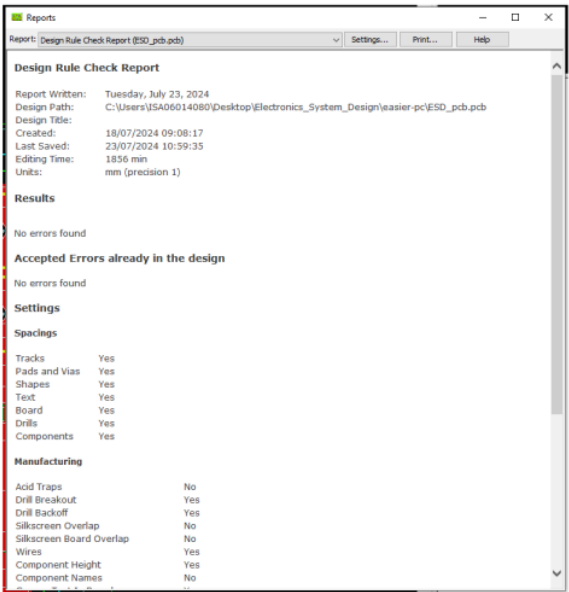


Figure 18: PCB Design DRC Result

Software Implementation

Software Structure

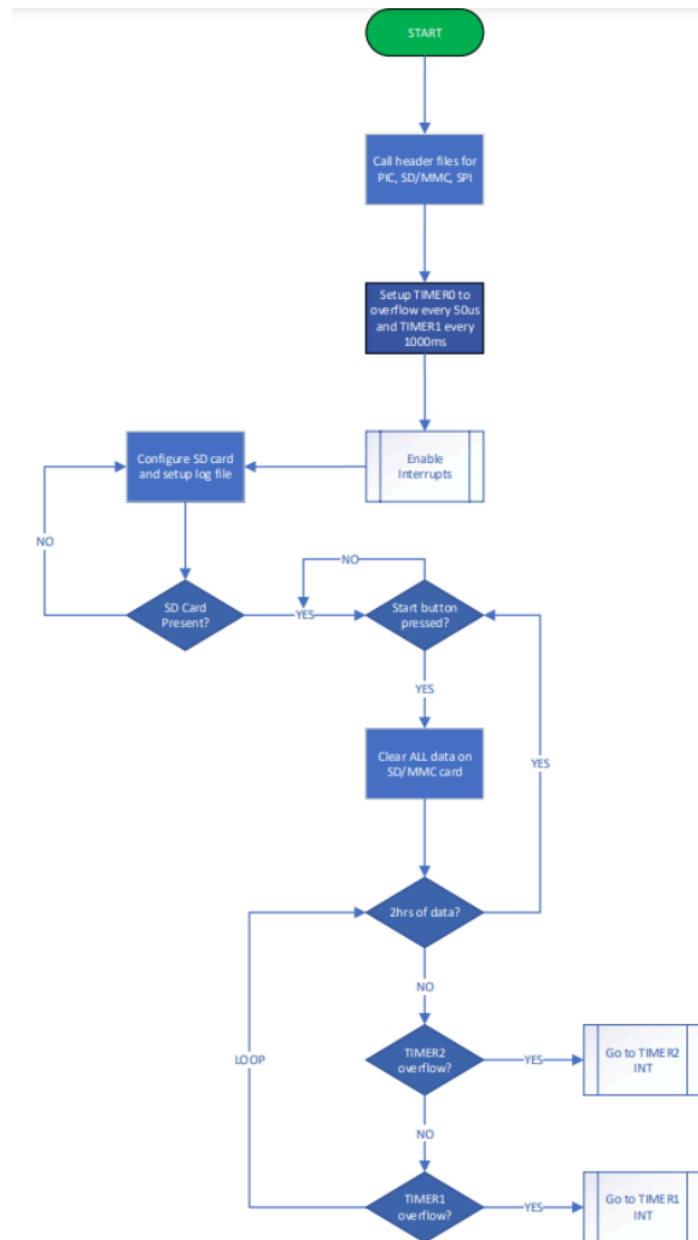


Figure 19: Software Flowchart

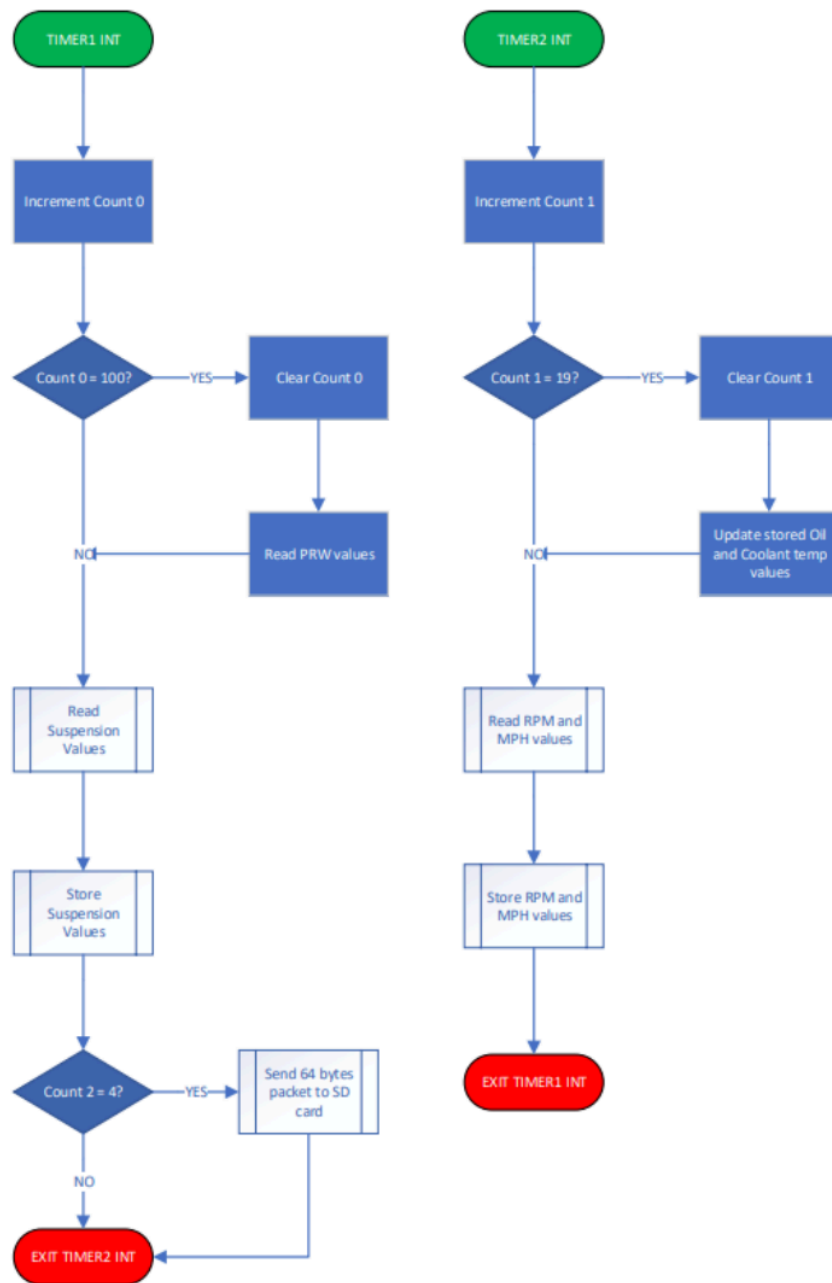


Figure 20: Software Interrupt Routines

Data Packet Structure

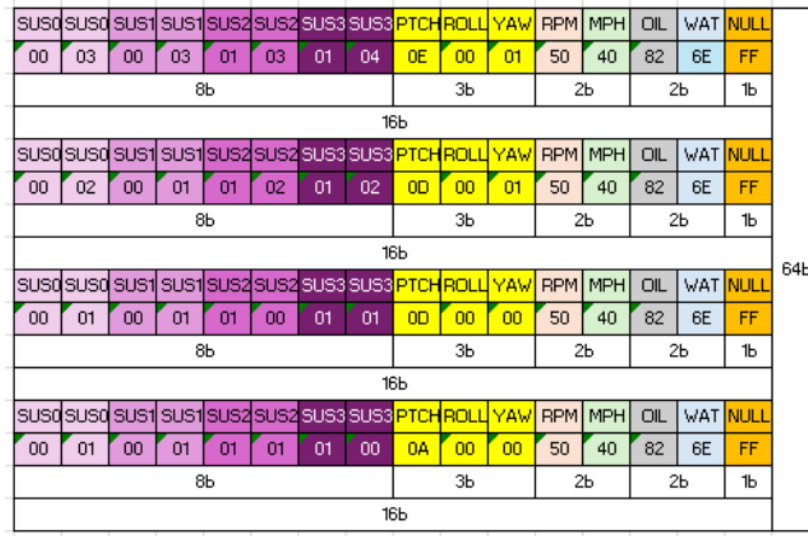


Figure 21: Data Packet Structure

Figure 21 is the data packet structure used for all writes to the non-volatile memory (SD card). All bytes are in hexadecimal, to allow a greater range of values to be represented. Each packet consists of 64 bytes, with 4*16byte splits constructed at the 50us intervals, each packet is sent every 200us. As the data adds to 15 bytes, an 'FF' terminating character is added to form the 16 bytes split [33] and delimitate the data in the RAW filesystem.

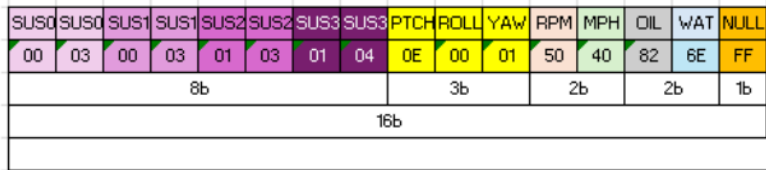


Figure 22: Data Packet Structure Example

Figure 22 is sample packet, the first 8 bytes are the suspension travel is taken as: (0x0003) 3mm for SUS0, (0x0003) 3mm for SUS1, (0x0103) 19mm for SUS2 and (0x0020) 20mm for SUS3. For 2nd 8 bytes, the pitch is measured as 14° (0x0E), roll is 0° (0x00), and the yaw is 1° (0x01). The RPM is 3200 (0x50 = 32, x10) and the speed is 64 MPH (0x40), the oil temperature is 130°C (0x82) and the water temperature is 110°C (0x6E).

Non-Volatile Data Structure

ADDRESS OFFSET	HEXADECIMAL																ASCII															
0x00000000	01	FF	44	41	54	41	FF	53	54	41	52	54	FF	0D	0A	02	SCH	.	D	A	T	A	.	S	T	A	R	T	.	CR	LF	STX
0x00000010	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000020	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000030	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000040	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000050	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000060	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000070	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000080	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000090	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x000000A0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x000000B0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x000000C0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x000000D0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x000000E0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x000000F0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000100	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000110	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000120	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000130	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000140	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000150	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000160	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000170	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x00000180	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x89543FD0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x89543FE0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x89543FF0	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x89544000	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF	SUS0	SUS0	SUS1	SUS1	SUS2	SUS2	SUS3	SUS3	PTCH	ROLL	YAW	RPM	MPH	OIL	WAT	FF
0x89544010	03	26	FF	45	4E	44	FF	4F	46	FF	46	45	4C	45	FF	26	03	26	FF	45	4E	44	FF	4F	46	FF	46	45	4C	45	FF	26
																	03 26 FF 45 4E 44 FF 4F 46 FF 46 45 4C 45 FF 26 03 26 FF 45 4E 44 FF 4F 46 FF 46 45 4C 45 FF 26															

Figure 23: Non-volatile Memory Structure

Figure 23 is the memory structure found on the SD card, starting from the base address at offset 0x00000000h. ASCII has been used, to allow for legibility as a log file when the data is analysed. The 'STX' notation in the header means "start of text", with the 'ETX' notation meaning "end of text" [33].

The total size of the memory map is 2.304GB, meaning that a minimum size of 4GB for an SD card is required. At offset 0x89544000h there is an ASCII End-of-File character line, which denotes that the SD card is full of logged data and should be removed and read by a PC.

Physical Implementation

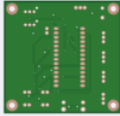
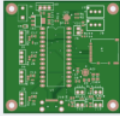
Component Bill of Materials

Component	Part No.	Manufacturer	Unit Cost	Qty
47uF Capacitor	C2012X7R1V475K125AC	TDK	0.23	1
27nF Capacitor	GRM3195C1H273JA01D	Murata	0.15	3
100nF Capacitor	GRM21BR11E104KA01L	Murata	0.26	7
1uF Capacitor	TACL105K016XTA	Kyocera AVX	1.52	1
5V1 Zener Diode	BZX8850S-C5V1-QYL	Nexperia	0.30	4
20Ω Resistor	CRCW060320R0FKEA	Vishay	0.02	4
6K2Ω Resistor	ERJ3EKF6201V	Panasonic	0.22	2
10KΩ Resistor	ERJH3GJ103V	Panasonic	0.03	2
3V3 LDO Voltage Regulator	TC1262-3.3VDB	Microchip	0.64	1
5V Voltage Regulator	LM7805CT/NOPB	TI	1.63	1
Single-Supply Op Amp	TSU104IQ4T	ST Micro	1.43	1
3-axis 3G Gyroscope	ADXL335BCPZ-RL	Analog Devices	6.60	1
Optical Speed Sensor	VLS/DA/LSR	C. Instruments	295.00	2
Spring Return Potentiometer	HX-PA-20-N20-N46-34K	Unimeasure	260.13	4
10KΩ Thermistor	NTCALUG01A103FL	Vishay	3.54	2
2-Pin TH Female Header	172447-0202	Molex	0.98	1
3-Pin TH Male Header	22-27-2031	Molex	0.30	4
2-Pin TH Male Header	22-27-2021	Molex	0.25	5
3-Pin TH Female Header	53375-0310	Molex	0.20	2
2-Pin Mating Connector	39-01-6026	Molex	0.46	1
Mating Connector Pins	39-00-0074	Molex	0.59	2
3-Pin Mating Connector	22-01-3037	Molex	0.29	4
2-Pin Mating Connector	22-01-3027	Molex	0.23	5
Mating Connector Pins	08-50-0032	Molex	0.15	22
3-Pin Mating Connector	51103-0300	Molex	0.21	2
Mating Connector Pins	50752-8200	Molex	0.13	6
PIC18F Microcontroller	PIC18F24K50-I/SP	Microchip	2.69	1
Micro-SD Card Connector	DM3AT-SF-PEJM5(40)	Hirose	3.12	1
USB Type C Connector	216990-0002	Molex	0.71	1
External LED Green IP67 8mm	OXL/CLH/80/5/FL30/H/GN	Oxley	9.8	1
2-Pin Male Circular IP68 Bulkhead connector	144-4172	RS PRO	12.4	2
3-Pin Male Circular IP68 Bulkhead connector	144-4173	RS PRO	9.84	6
Momentary Switch IP65	1415NC BLACK	APEM	3.36	1
M3 Standoff 5mm Length	AS-305	Hirosugi	0.34	4
ABS Enclosure 187.2mm x 122.2mm x 89.9mm IP65	TA 191209 ENCLOSURE	Fibox	14.60	1
500mAh 3S1P 11.1V Lipo Battery Pack	Nano-Tech Plus 500mAh 3S 70C Lipo Pack	Turnigy	5.65	1
Lipo AC/DC Battery Charger	P403 (US Plug*)	Turnigy	15.25	1
3-pin BS1363 (UK) Plug	490-015	RS PRO	1.97	1
4GB Micro-SD card	S304GSEMC-U3000-3	Delkin Devices	13.50	1
2-Pin Female Circular IP68 Cable Mount Connector	144-4179	RS PRO	17.29	2
3-Pin Female Circular IP68 Cable Mount Connector	144-4180	RS PRO	18.17	6
M3 Bolt 4mm Length	MT3-4	Takachi Electric	1.75	4
100m 16AWG Black Wire (Internal)	180-5946	RS PRO	57.62	1
50m 2-core 18AWG Grey Wire (External)	827-4243	RS PRO	41.75	1
25m 3-core 18AWG Black Wire (External)	210-1250	RS PRO	45.49	1
PCB Fabrication and Postage	N/A	JLCPCB	37.85	
Total Cost			2155.14	

Table 4: System Bill of Materials (BOM)

PCB Fabrication

Figure 24 and Figure 25 are both online quotes for the fabrication of the PCB design. Figure 24 is a quote from a China-based manufacturer, JLCPCB; Figure 25 is a quote from a UK-based manufacturer, Newbury Electronics. For the quote from JLCPCB, the surface finish has been specified as Leadfree HASL.



o Upload File

Detected 6 layer board of 66.04x68.58mm(2.6x2.7 inches)

Gerber Viewer

Material

FR-4

Flex

Aluminum

Copper Core

Rogers

PTFE Teflon

1234567891011121314151617181920

High Precision PCB

66.58 * 66.04

5

Industrial/Consumer electronics

Aerospace

Medical

Via Covering

£ 12.47

Surface Finish

£ 3.80

Build Time

PCB: 3-4 days

£ 0.00

3 days

PCBA Only

£ 0.00

2-3 days

£ 48.82

Calculated Price

£ 21.71

Additional charges may apply for special cases

SAVE TO CART

Shipping Estimate

£ 16.14

DHL Express Worldwide

2-4 business days

Weight

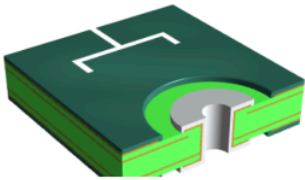
0.20kg

Coupons

Save \$20 >

Figure 24: PCB Fabrication Online Quote #1

Your order details



4 layer FR4 (150 deg C) middle Tg 1.6mm IS Green White

Product Family

4 layer

Service

Standard

Copper Weight

35

Material

FR4 (150 deg C) middle Tg

Thickness

1.6 mm

Finish

IS

Circuit Size X

69 mm

Circuit Size Y

66 mm

Quantity

5

Update / Reset Price

Supply in panels

No

Show Lot Price

Show Unit Price

W/Days	2	3	4	5
3	£ 262.24	£ 281.61	£ 300.96	£ 320.35
4	£ 208.36	£ 224.94	£ 241.56	£ 258.15
5	£ 144.46	£ 158.28	£ 172.12	£ 185.95
7	£ 132.90	£ 145.62	£ 158.36	£ 171.10
10	£ 115.56	£ 126.63	£ 137.72	£ 148.75
15	£ 86.68	£ 94.98	£ 103.28	£ 111.60

Back

Next

Figure 25: PCB Fabrication Online Quote #2

Component Datasheets

Microcontroller:

https://ww1.microchip.com/downloads/aemDocuments/documents/OTH/ProductDocuments/DataSheets/PIC18F2X_45K50-30000684B.pdf

SD Card:

<https://4donline.ihs.com/images/VipMasterIC/IC/DLKN/DLKN-S-A0018450086/DLKN-S-A0018450086-1.pdf?hkey=6D3A4C79FDBF58556ACFDE234799DDF0>

Op Amp:

<https://www.st.com/content/ccc/resource/technical/document/datasheet/96/1c/8a/ee/73/94/4f/70/DM00078536.pdf/files/DM00078536.pdf/jcr:content/translations/en.DM00078536.pdf>

Optical Speed Sensor:

<https://compactinstruments.co.uk/wp-content/uploads/2019/10/VLS-DA-LSR-Optical-Speed-Sensor-Laser-7.5-15vdc-3v-Output-instruction-manual.pdf>

Spring Return Potentiometer:

<https://unimeasure.com/wp-content/uploads/2023/01/hx-pa.pdf>

10K Ω Thermistor:

<https://www.farnell.com/datasheets/3007263.pdf>

3.3V LDO Regulator:

<https://ww1.microchip.com/downloads/aemDocuments/documents/APID/ProductDocuments/DataSheets/TC1014-1015-1185-50-mA-100-mA-and-150-mA-CMOS-LDOs-with-Shutdown-and-Reference-Bypass-Data-Sheet-DS20001335.pdf>

5.0V Linear Regulator:

<https://www.sparkfun.com/datasheets/Components/LM7805.pdf>

3-axis Gyroscope:

<https://www.analog.com/media/en/technical-documentation/data-sheets/adxl335.pdf>

Future Development

The total cost of the system, referring to the BOM (Table 4) was £2155.14 – not including time cost, or the cost of an IDE and software development. Improvements could be made to the system to either lower the overall cost, or to add further functionality and utility to the system.

A low-hanging-fruit improvement would be adding an external UART Debug connector, an external USB C, and external charging connector to the outside of the enclosure. This would allow data to be read from the system, the system to be re-charged, and debugging to be carried out without the system enclosure needing to be opened.

Another method to reduce cost would be to replace the through-hole PIC18F24K50 with the QFN-packaged version (PIC18F24K50-I/ML), which would have the effect of reducing overall board size and thus system cost [34]. Related to the PIC, a 4-pin 2.54mm header could be added to allow for the use of an ICSP, allowing the software of the PIC to be updated even after the system has been deployed [35].

TC1262-3.3V (5V Supply)					
V _{in} (new)			P _d		Eff (%)
5			0.000595		66
R-78E5.0-1.0					
V _{in} (max)	V _{out}		I _(out)	I _(in)	~Eff (%)
12.6	5		0.3	0.3	85
V _{in} (min)			P _d		
9			0.667059		

Table 5: T1262-3.3V +5V supply

Finally, the LM7805 Linear-regulator could be replaced with a TO-220 compatible drop-in replacement, such as the Recom R-78E5.0-1.0 which is a switching regulator offering a 5V 1A output. The benefit of this being that it is typically over 80% efficient [36], rather than the 39.7% of the LM7805, see Table 3. Finally, the TC1262-3.3V could draw from the +5V supply, which would reduce power dissipation from 3.255e-3W to 5.95e-4W, see Table 3 and Table 5. Overall, this would reduce the required battery capacity to 4.84Wh, removing the requirement for 2 battery packs.

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RPH_2110763_ESD_Assignment

GRADEMARK REPORT

FINAL GRADE

68/100

GENERAL COMMENTS

A specification is given to you as a blueprint for what your customer requires, it is not given to you so that you can change the design. Changes should be incorporated into the Future Development section.

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GRADING FORM: SMU GENERIC_GJ

RHYS HIGGINS

67.75

RESEARCH-INFORMED LITERATURE



Good literature review of available systems with a fairly good comparison table of relevant information but would have been better with some images.62%

6.2

KNOWLEDGE AND UNDERSTANDING



Your schematic diagram is good but there are a couple of issues. The 7805 regulators need a tank capacitor of about 100µF in addition to the 100nF caps you have. Your PCB has been routed but there are many errors, you need to use the PCB checking tools. You have also connected analog inputs to pins that are not meant for analog inputs. Your input for RPM is correctly taken to an interrupt input. A good attempt 70%

17.5

ANALYSIS



Good selection of microcontroller, questionable selection of the enclosure as there does not appear to be any protected place for the bulkhead connectors. Reasonable selection of sensors but no reasons for the decision. A 100nF cap should be placed between the power lines as close to the microcontroller as possible. Your connectors are reasonable. 65%

22.75

PRACTICAL APPLICATION AND DEP.



Your costings are nicely tabulated and carry manufacturer and part numbers. Reasonable attempt at future enhancements. 68%

13.6

SKILLS FOR PROFESSIONAL PRACT.



The report is well presented with some good explanations of choices and images. Very good

7.7

explanation of the data storage structure.
Excellent selection of references. 77%