

Car data logger AP P145780

by Andrew Prescott

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DESIGNING A DATA LOGGER FOR A PROTOTYPE VEHICLE.

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INTRODUCTION

The aim of this report is to design a bespoke data logger for use on a prototype family saloon vehicle, however it should also be adaptable for any type of vehicle. This device must run independently of the vehicle to consistently measure and store information of several variables about the vehicle during a two-hour test run, this means it will also require some independent power source.

1) CURRENTLY ON THE MARKET

Before attempting to design the system a small amount of research must be done in to the systems that are currently available and their main features. Below is a brief overview of four of these products and an evaluation of their main features.

1.1) COSWORTH OMEGA L2 DATA LOGGER [1]

The device pictured on the right in Fig.1 is used in Formula Renault 2.0 and costs £1495. The key features of the system are listed below; this device is also described as rugged and lightweight. Sensors for this device are sold separately or this device can be connected to the vehicle's sensors through the CAN bus to monitor several different variables.

Memory:	128MB for data logging
Digital Inputs:	6 off standard (Applications: 1 x Lap Beacon, 2 x wheel speed)
Analogue Inputs:	16 off. 0 to 5V, 12 bit resolution. (Typical applications: Temperature, Position, Pressure ...)
Data logging	Up to 250 channels at sample rates of up to 1000Hz.
Communications:	2 x CAN, 3 x RS232, 1 x Ethernet (100 MB/s)
Accelerometers:	On board two axis accelerometer.



Figure 1 [1] Cosworth data logger and its features

1.2) AIM EVO 4 CAR RACING DATA LOGGER [2]

This has similar features the Cosworth device and costs £1020, however it has fewer inputs and outputs; with the option for expansion through various other devices also sold by AIM. This device has on board GPS and triaxial accelerometer, the full specifications are shown along with a picture of the device itself in fig.2.

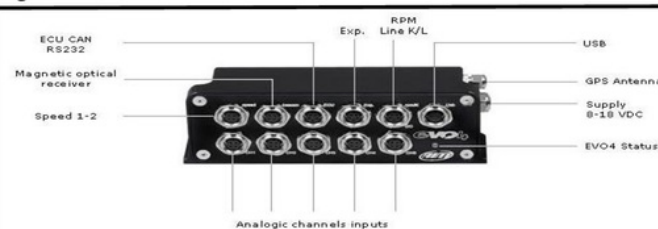


Figure 2 [2] AIM data logger and its features

System dimensions	129x45.5x30 mm
Weight:	240 g
Chassis:	Aluminum
Waterproof:	IP67
Power supply:	9-15 V
Integrated GPS:	Yes
Integrated triaxial accelerometer:	Yes
ECU connection:	(CAN, RS232, K Line) Yes
CAN protocol for external expansion modules	Yes
Analogic channels:	5
RPM channels:	1
Speed channels:	2
Laptimer input:	Yes (optical and magnetic)
Sampling frequency:	(max) 5 KHz
Memory:	16 Mb
USB Data download:	Yes

1.4) MOTEC EDL3 [3]

This device does not have any on board sensors again using the car's electronics to acquire data and focuses on the processing of the logged data to give more information such as range on the current amount of fuel etc. Most of the features can be upgraded as shown in fig.3 these upgrades are internal; however, this company also sells external upgrades such as an increase in logging memory. The base cost of this device is around \$1000.

Logging

- 16 MB standard logging memory (250 MB optional)
- Logging rates up to 1000 samples per second
- Fast Ethernet download

Inputs

- 10 x Analogue voltage inputs (24 optional)
- 4 x Analogue temperature inputs (8 optional)
- 4 x Digital inputs
- 4 x Speed inputs with voltage measuring capability
- 4 x Switched inputs
- Compatible with μ Mod input expanders

Outputs

- 4 x PWM, digital or switched outputs (8 optional)—for devices such as shift lights, warning lights, a gearbox oil pump or a thermo fan

Communications

- 2 x CAN with individually programmable CAN bus speeds
- 1 x RS232

Physical

- Dimensions 194.5 x 98.0 x 14.3 mm excluding connector
- Weight 385 gram
- 1 x 79 pin Autosport connector



The image shows two black, rectangular MOTEC EDL3 data loggers. One is positioned in the foreground, showing its top surface with the 'MoTeC' logo. The other is behind it, showing its side profile with a circular red LED indicator and several screws.

Figure 3 [4] The MOTEC data logger and its features

1.3) STACK MULTI-FUNCTION RECORDER - MFR SYSTEM [4]

This system comes in multiple variants each with similar specifications; there are more expensive versions that have a greater number of input channels these vary from 14 to 45 channels. The specifications that are shared among the devices and what one of the devices looks like is shown below in fig.4. The device costs around £1300 and again, much like the other devices more sensors are sold separately, or it can be connected to the cars electronics through the CAN connector.

- o Bigger recording memory - 32MB as standard.
- o Faster data recorder - up to 200Hz per channel.
- o Better resolution - 10 bit analogue/16 bit digital inputs.
- o More sensor inputs - Up to 45, 24 built-in.
- o Built-in 3-axis $\pm$ 6g g-sensor.
- o Optional driver display & sequential shiftlight.
- o Built-in CAN ECU links and GPS interface options..
- o Built-in real-time telemetry option.
- o Synchronized video-logging and video data overlay option.



The image shows a black, rectangular STACK MFR 800 multi-function recorder. It has a 'STACK' logo on top and 'MFR 800' on the side. The front panel features a circular multi-pin connector and a smaller circular port.

Figure 4[3] The stack data recorder and its specifications

1.5) OBSERVATIONS FROM RESEARCH

These devices come with little to no sensors on board so the easiest way to compare these devices is their logging ability not the data itself (Table 1).

Device	Polling rate	ADC size	Number of channels	Base logging memory	Cost
COSWORTH OMEGA L2 DATA LOGGER	Up to 1000Hz	12 Bit	22	128MB	£1495
AIM EVO 4 CAR RACING DATA LOGGER	Up to 5kHz	12 Bit	8	16MB	£1020
Stack Multi-Function Recorder	200Hz per channel	10 Bit	24	32MB	£1300
MoTeC EDL3	Up to 1000Hz	12 Bit	26	16MB	\$1000

Table 1 Comparison of car data logger features

From these four sampled devices a rough idea of the most effective specifications being used for this purpose. In terms of polling rate, it is difficult to determine which device is the best as they each give a different specification, e.g. per channel etc. however it is assumed that a faster polling rate is better as then a higher amount of information can be logged. The most common size of the ADC used by these devices appears to be 12 bits this should be a minimum when selecting a microcontroller later in the design process. It seems most of these devices are within the £1000-£1500 cost range however the cost factor is not really a focus as this device is being created as a one off.

2) SENSORS

This device needs to monitor several aspects of the cars performance independently from the car consistently for a two-hour test run on a prototype family saloon vehicle; therefore, the sensors must be rugged enough to cope with the strains and temperatures associated with the vehicle. The parameters required in the specification are: engine temperature, RPM, speed, suspension displacement, and pitch roll and yaw. The next few sections go through the selection process for these sensors.

2.1) TEMPERATURE

There are several different technologies for measuring temperature electronically but only a few are appropriate for the specification. Before a specific sensor can be chosen first the technology that will be used must be defined. A comparison of some of the considered technologies is shown in the table below (Table 2). The parameters on which these sensors are compared comes from the design specification, a car has an operating temperature of however cold the weather can get (-20°C) to around 200°C absolute maximum. Response time for the sensor is not hugely important as the temperature changes within the engine do not happen instantly. The main factor to take into consideration when selecting the technology is whether the measurement is contactless as the design brief specifies that the device is not allowed to interfere with the car.

Parameter	Thermistor	Thermocouple	Optical (IR)	RTD
Accuracy/resolution of measurement	All can be high enough for application <1°C			
Contactless	X	X	O	X
Response time	Slow	Fast	Fast	Slow
Temperature range	All can be high enough for application -50 to 200+°C			

Table 2 Comparison of temperature measuring technologies

To best fit the design specification and have an accurate measurement infra-red was selected, this is because it is the only non-contact measurement device in the list. The next step is to select the specific sensor that will be used for the device. Therefore, another set of parameters must be defined to compare and select the specific infra-red sensor (Table 3).

Device Name	Temp. Range	Accuracy	Response time	Output	Supply
Infrared TI-20-r-8 [5]	- 20 to 200°C	± 2.2°C	260ms	CAN 8 Channel	6 to 16V
KIR4 Series Infra-Red Temperature Sensor [6]	0°C to +200°C	<±0.2°C	1ms	0.5V—5V	5-16Vdc (5mA max)
SA-IR200V6-000 [7]	-30°C to +200°C	±2%	10ms	0-5V	5-16V
CTL-SF75-C3 (Page 8-9) [8]	-50°C to 975°C	±1% or ±1°C	120ms	Analogue 0-5V or digital USB, RS232, RS485, CAN, Profibus DP, Ethernet	8 to 36VDC
Memotec IR-temperature sensor [9]	0 - 1000°C	± 1.0%	50ms	5.0 - 16.0 V	Not shown

Table 3 Comparison of IR temperature sensors

As previously mentioned the operating temperature range must be -20 to 200°C the temperature range shown on the table is the measurement range, the operating temperature range for all of these devices is appropriate for the application even if it cannot measure that temperature; however, it would be beneficial to have the capability to measure across the entire range. The selection made was the SA-IR200V6-000 (Fig. 5) due to its capability to measure across the specified range accurately enough for the application and its 0-5V analogue output which makes it compatible with most microcontrollers.



Figure 5 [7] Chosen temperature sensor

2.2) SPEED AND RPM

It is assumed the same sensor can be used for both speed and RPM due to the fact they both are sensing the rate of rotation of an object. This sensor can be selected through the same process as the temperature sensor; first a technology for the sensor must be selected through its applicability to a set of parameters defined by the specification. In this case it was decided that the features that are key is that the sensor has a digital pulse output with a quick response time to ensure the data can be read quickly as this device is required to operate at high speeds. The next important requirement is that the device can make contactless measurements for the same reason the temperature sensor. The comparison of the technologies based on these parameters can be found below in table 4.

Parameter	Magnetic (hall effect or inductive)	Optical (Reflective)	Optical (Beam break)	Switch
Digital	O	O	O	O
Contactless	O/X in some cases uses induction.	O	O/X (Something to break the beam if not already holes in rotor)	X
Response time	Fast	Fast	Fast	Fast (debouncing)

Table 4 Comparison of RPM sensing technologies

After reviewing the information in table 4 it was apparent that an optical sensor using the reflective method would be the best choice as the beam breaking method of optical sensing requires a receiver on one side of the object and the transmitter on the other, this may be hard to implement if only one side of the object is accessible. The magnetic option was not selected to ensure there was no interference to the engine or the electronics of the car due to magnetic noise emitted by the sensor. To select the sensor a few were compared based on the most important features when considering RPM and speed measurements on a car (Table 5).

Device Name	Max RPM	Output	Supply
VLS5/J [10]	250000	NPN pulse	9-12V
VIB 6.631 : Laser trigger / Laser RPM sensor (Page 84) [11]	600000	5V Pulse	5-10V
Turnigy TGY-CPD02 [12]	60000	Not shown	4.0-6.5V
SD-VOP02-000 [13]	78000	Digital	10-30V

Table 5 Comparison of optical RPM sensing technologies

The first factor when deciding which sensor to select is the max RPM detectable. To ensure low speeds can be measured accurately at the sample rate that will need to be defined more specifically later in the design, for now let's assume the speed will be logged every half a second, one revolution per half a second gives a minimum measurable RPM of over 120; this isn't good enough when translated to speed due to gear ratios. Therefore, more than one pulse will be required for one revolution meaning more than one reflective spot on the rotating object; if four markers are placed around the object (one at each quarter rotation) the minimum RPM would then become 30 which is far better for this application. Now the maximum RPM can be calculated given the information that has become apparent from the other calculations, according to the formula 1 racing rules cars must be limited to 15000 RPM [14] which is far greater than any road car; taking this value and multiplying it by four will give the minimum number of pulses that need to be measured to detect this RPM which is 60000 pulses a minute; therefore the sensor will need to be able to detect over 60000 RPM due to gear ratios. Therefore, the VIB 6.631 (Fig. 6) has been chosen as it has the highest RPM capabilities as well as a TTL 5V output with a low supply voltage, and has several casing options. (This factor will help battery life later in development).



Figure 6 [11] Chosen RPM and speed sensor

2.3) SUSPENSION

Applying the same method of selection to this sensor the parameters most important when attempting to measure suspension displacement were listed and different technologies were compared in relation to these parameters this is shown in table 6.

Parameter	Magnetic	LVDT position sensor	Rotary Potentiometer	Linear Potentiometer
Max length	Infinite	Limited	Infinite	limited
Resolution	<0.25°	Technically infinite	<0.25°	Technically infinite
Response time	Instant	Instant	Instant	Instant
Operating temperature	Up to 250°C	Up to 200°C	Up to 125°C	Up to 125°C
Output	Analogue +ve	Analogue +ve to -ve	Analogue resistance change	Analogue resistance change

Table 6 Comparison of suspension sensing technologies

The parameters were chosen due to their importance in measuring the suspension, starting with max length; this parameter was chosen because if the sensor cannot monitor the full range of movement the suspension undergoes then the device will not meet the specification. The sensor must also have the resolution to detect small changes in the system and have the response speed to detect harsh movements at high speeds. The reason operating temperature was considered was down to the fact the area of the car may become warm due to air outlets from the engine or other factors. The information about the technologies has been collected it can be analysed to select the most beneficial sensor for this device. To ensure the data can be logged quickly and efficiently it would be preferable to get the exact position of the suspension at all times without calculation or translation. In a potential divider configuration both the linear potentiometer and the LVDT give a voltage that is proportional to the position of the suspension, however the rotary sensors give a voltage proportional to a rotation which does not give information about the position of the wheel without further calculation. It is for the aforementioned reason that the sensor selected is the linear potentiometer, this was selected over the LVDT due to its simplicity to implement in this application as it does not have an AC output like the LVDT. A comparison of different linear potentiometers can be found in table 7.

Device Name	Body length	Length extended	Supply
Linear PS-C18C [15]	350mm	+250mm	max 40V
LP 150 [16]	282mm	+50mm	Max 130V
LTM-600 [17]	745mm	+676mm	max 42V
Tex 0300 [18]	369mm	+300mm	max 42V

Table 7 Comparison of different linear potentiometers for suspension sensing application

There are few compared properties here as most of them can be adjusted for in external circuitry therefore the sensor that is most applicable sensor would be the one with the most appropriate measurement range, as there is no information provided about any of the dimensions of the suspension system the Tex 300 was selected as it was one of the middle values and the Linear PS-C18C (Fig. 7) has as much lower measurement range for a not much shorter body length meaning the selected sensor has the capability to measure over a greater area without compromising on size as the area it is being fitted in as it may be very confined.



Figure 7 [15] Suspension sensor

2.4) PITCH ROLL AND YAW

To measure these parameters there are two main technologies used, these are the gyroscope and the accelerometer, to understand how these devices work how the car moves must be understood. The terms pitch roll and yaw are depicted in figure 8 [19].

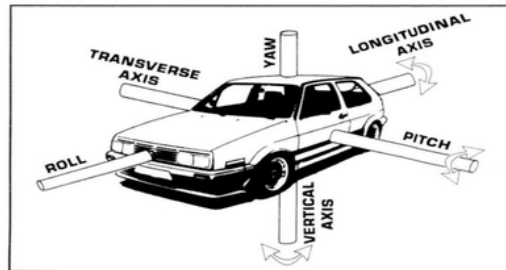


Figure 8 [19] Depiction of PRY acting on a vehicle

This shows there are three axes of movement therefore to detect all three a sensor for each axis is required, so the next step is to decide on the use of an accelerometer or a gyroscope. An accelerometer is used to measure the acceleration in a given direction or it can sense orientation when the object is not accelerating using the acceleration caused by gravity [24]. A gyroscope measures angular velocity around an axis and is more reliable in representing orientation [25]. So therefore, the best option would be to combine the measurement capabilities of both sensors to detect rotation and acceleration. Below in table 8 is a comparison of combined gyroscope and accelerometer sensors based on their key characteristics.

Device Name	Accuracy of gyro	Accuracy of accelerometer	Speed of gyro	Accelerometer max G.	Supply voltage	Output voltage
Variholm acc. and gyro.[20]	+/-2% All 3 axes	XY axes +/-2% FS Z axis +/-1.5% FS	$\pm 150^\circ/\text{sec}$	$\pm 5g$	5 to 16 V	0 - 5 V each axis
BC-3A16 3G300-000 [21]	<1 % all 3 Axes	<1 % all 3 Axis	$\pm 300^\circ/\text{s}$	$\pm 16 G$	8 – 18 VDC	On board ADC for digital output
GYRN3-S [22]	2%	N/A	$\pm 150^\circ/\text{sec}$	NA	5 to 16 V	0-5V
Acceleration Sensor MM5.10 [23]	2 Axes 0.1°	3 Axis 0.1g	$\pm 163^\circ/\text{s}$	$\pm 4.2 g$	7 to 18 V	CAN output

Table 8 Comparison of PRY sensors

The parameters used to compare these sensors were selected to achieve maximum accuracy for the application. To ensure the sensor can measure all movements within the car, the BC-3A16 3G300-000 (Fig.9) was chosen as it's features are far superior than those of the other sensors in accuracy and measurement range, its output also comes in the form of a CAN bus which will remove the need for an ADC for this sensor.



Figure 9 [21] Chosen PRY sensor

3) MICROCONTROLLER SELECTION AND SYSTEM DEVELOPMENT

Now that all the sensors have been defined a microcontroller can be selected using their properties and the specifications needed from the design brief.

3.1) INPUTS AND OUTPUTS

Starting with inputs:

- 4 inputs for suspension (Analogue).
- 1 input for temperature (Analogue).
- 1 input for speed (Digital).
- 1 input for RPM (Digital).
- 2 inputs for PRY sensor CAN bus (Digital).
- 2 inputs for user interaction (Digital).

This gives 10 inputs from our known sensors 5 of which are analogue allowing for redundancy let's assume there are 15 total inputs with the ability for 7 analogue inputs. As decided earlier in the research the ADC used on the analogue inputs must be at least 12-bits in size.

Outputs can be decided by taking information from the design brief:

“Store the collected data to non-volatile memory which can be externally read and cleared when connected to a computer via USB”

This means there must be sufficient output pins to support USB and some form of non-volatile memory, using RS232 will also be beneficial for system monitoring etc. To avoid complications with the FAT-32 interface an SD card has been selected to store the data from the sensors in raw format. Using this information, the number of outputs can be estimated:

- 4 output pins for SD information interface.
- 2 output pins for RS232 use.
- 2 outputs for USB interface.
- 2 outputs for user notification.

In total that gives 10 outputs allowing for redundancy that totals 13 outputs. That totals a minimum of 28 I/O pins for the desired microcontrollers.

3.2) CLOCK SPEED DATA RATE AND STORAGE

Another factor when considering the microcontroller is the clock speed, this can be determined by using information from the sensors. However, to determine the clock speed the rate at which the sensors are read must be determined. Starting with temperature, this value is not likely to change drastically in a short amount of time therefore a sample rate of once every 10 seconds should be more than enough to get valuable information, therefore there will be a 12-bit value read and stored by the microcontroller every 10 seconds. To identify the information as temperature before the reading is stored another 4-bit identifier can be appended making this value 16-bits every 10 seconds.

If the same method is applied for the other analogue channel, suspension, each time the sensor is read a 12-bit value is read and a 16-bit value is stored. As the movement in the suspension is likely to be very rapidly this reading should be done more often than the temperature, let's say every half a millisecond, this information also must be taken from each wheel therefore there are 4 inputs of 12-bits and 4 16-bit values being stored every 0.5ms. To read, convert and store the data would take approximately 200 instruction cycles [26] to be safe 250 will be used per sensor. This will happen 2000 times a second for each sensor totalling 2,000,000 cycles to read and store all the suspension data in one second. The 250 used for the temperature sensor will only average to 25 a second.

The sensors for the RPM and speed will send pulses to the microcontroller that will add it to a count this will take around 5 instruction cycles and this happens 4 times per revolution which totals 20 instruction cycles per sensor per rotation. For RPM the value in that count only needs to be divided by 4 and multiplied (by a number dependent on sample rate) to give RPM, however for speed there are further calculations e.g. the number of revolutions would have to be multiplied by the circumference of the wheel to give distance over time calculation. If the speed and RPM are read every half a second these calculations and storage of the information will need to take place every half a second too, assuming it takes 200 cycles calculate data from the information stored from the pulses, and another 200 to store the 16-bit data, this gives 400 cycles for speed and RPM totalling 800 cycles every half a second plus any cycles taken reading the sensors. Using the 15,000 RPM and 4 pulses per rotation values from earlier at 5 instruction cycles per pulse that gives 300,000 cycles per minute or 5,000 per second for each sensor. This gives a total of 11,600 instruction cycles per second to read and store data from the speed and RPM measurements.

Lastly the pitch roll and yaw measurements, the output of this sensor sends two 8-byte values to denote the three axis values for the accelerometer and gyroscope, this would equal roughly 400 cycles and storing would take another 400. The PRY of the car is likely to change almost as rapidly so it will be measured every millisecond, this means the PRY section will require 40,000 cycles a second.

Below is a table summarising the clock cycle requirements of each part of the system (Table 9).

Sensor	Temperature	Suspension	Speed	RPM	PRY
Polling rate	Read every 10 seconds	Read every half a millisecond	Read every half a second	Read every half a second	Read every millisecond
Clock cycles per second	25	2 million	5,800	5,800	40,000
Bit rate	1.6 bits a second	128,000 bits per second	32 bits per second	32 bits per second	128,000 bits per second
Resolution	0.05°C @ 1.22mV per step	0.07mm@ 1.22mV per step.	Min speed at least ¼ rotation in half a second. Max dependent on wheel size 15,000 RPM	Min speed at least ¼ rotation in half a second. Max 15,000 RPM	0.0045° degrees on gyro. 0.0003G on accelerometer.

Table 9 Number of cycles to read and store information from each sensor and the storage space it takes.

Total cycles a second 2.5 million with a small amount of redundancy this means to just read sensors with the predicted number of cycles per operation the clock speed needs to be over 2MHz so 16MHz should be more than adequate.

For storage size there is a total of 256,065.6 bits a second or roughly 32010 bytes a second. In a two-hour test run with this data rate there would be 230,472,000 (230.5MB) bytes of information to add redundancy a class 4 or above SD card sized 1GB or above would be suitable for the data rate and storage capabilities [27].

3.3) MICROCONTROLLER SELECTION

Using the parametric search tool on the microchip website in conjunction with the information obtained in the previous segment a specific microcontroller can be selected. The parameters for the microcontroller selection are shown in table 10. The value for RAM using the data from the sensors that is around 32010 bytes a second not all of which needs to be stored at the same time, allowing for headroom a minimum of 3.5KB of RAM is needed. The program memory allowing for the most redundancy would be about 1KB.

Clock speed	RAM	Program memory	ADC size	I/O pins	RS232, SPI and USB compatible
16MHz	3.5KB	1KB	12-Bits	28 (7 Analogue)	Yes

Table 10 Minimum requirements for the microcontroller

Using this information in the search tool brought up several options, the microcontroller selected was the PIC18F45K80 [28] as it met the requirements with ample headroom to compensate for errors or misjudgements in the estimation of the requirements. This microcontroller has the following key features (Table 11):

Clock speed	RAM	Program memory	ADC size	I/O pins	RS232, SPI, CAN and USB compatible
16MHz internal oscillator	3.6KB	32KB	12-Bits	35 (11 can be Analogue)	Not USB can use FT32 chip

Table 11 Features of the selected microcontroller

Use of the FT232RL, this chip is a surface mount IC and will allow the conversion of the RS-232 ports to use for a USB interface, using CCS a software UART can be configured on any pin using one of the specified circuit configurations. This chip was chosen as there are no microcontrollers within the 8-bit architecture range with a CAN bus and USB compatibility, this chip counteracts this incompatibility [29].

3.4) BATTERY

The important factors when selecting a battery are capacity and output to get an idea of these values the current draw and supply voltage for each part of the system must be considered (Table 12).

Temperature	Suspension	Speed	RPM	PRY	Microcontroller	Peripherals and other components
5V	5V	5V	5V	8V	5V	5V
1mA typical 2mA overestimate	Sensor has 12k assuming there is a larger resistance in series around 3mA overestimated	Class 2 laser 1mW @ 5.8V = .18mA overestimated to 1mA	Class 2 laser 1mW @ 5.8V = .18mA overestimated to 1mA	40mA at 12V	4uA at 1.8V Overestimate to 50mA at full operation	20mA

Table 12 Power requirements of each sub-system

This totals 116mA total from estimations, allowing for errors in these estimations that value should be increased to around 250mA meaning a minimum value of a 500mA hour battery should be selected for a two-hour battery life. The maximum voltage required by the battery is 8V so a 12V battery with voltage regulators should be adequate, however this also increases current draw, so 1A hour should be the new minimum.

Due to the design requirements this device needs to be portable, one of the smallest rechargeable 12V batteries with a high capacity was the LC-R123R4PG by Panasonic shown in fig.10 [30]. This has a capacity of 3.4Ah and dimensions of 67mm x 134mm which should be sufficient for the application.



Figure 10 [28] Battery selection

3.5) BLOCK DIAGRAM

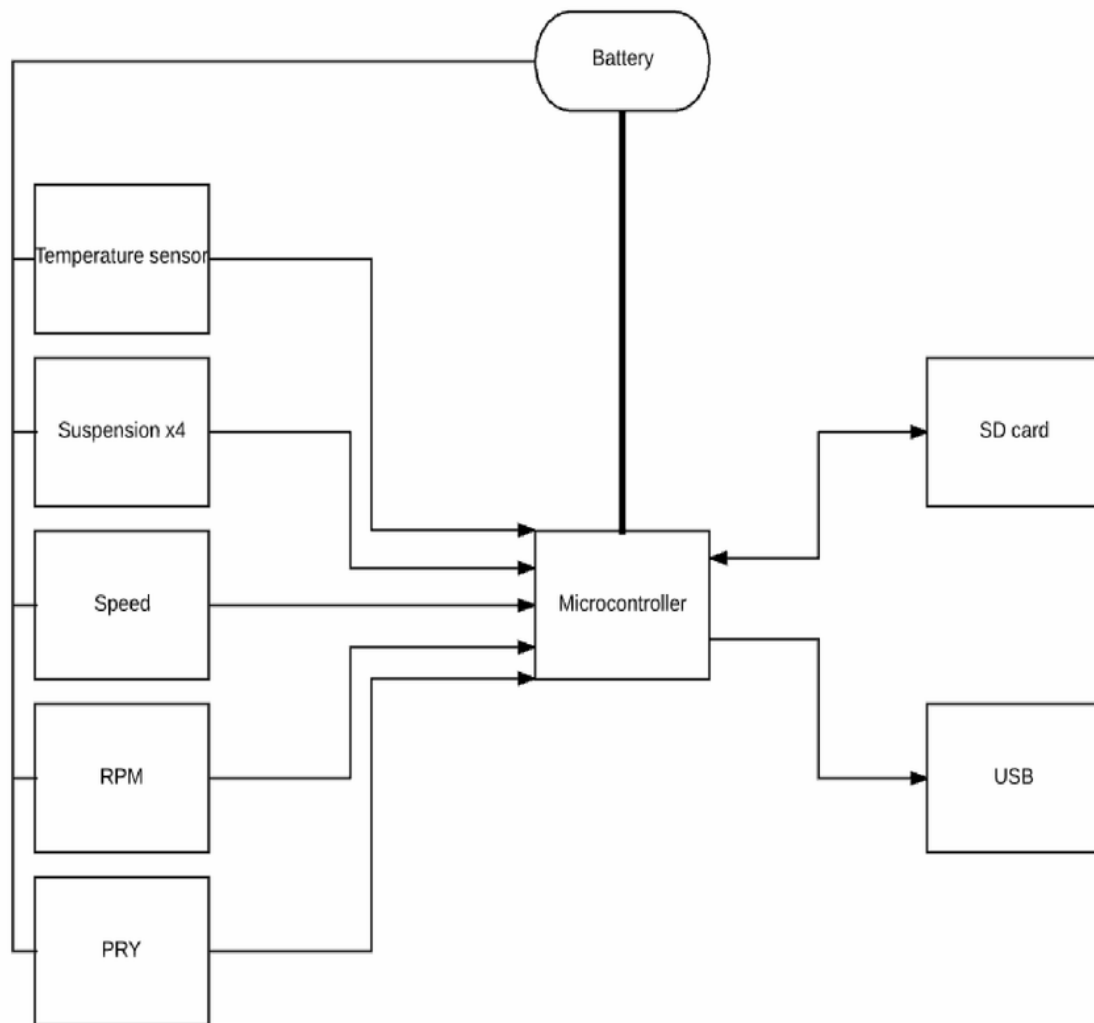


Figure 11 System Block diagram

3.6) CODING STRUCTURE

The rates that the sensors are being read has already been determined in section 3.2, this means the synthesis of the structure diagram can be done.

Temperature	Suspension	Speed	RPM	PRY
Read every 10 seconds	Read every half a millisecond	Read every half a second	Read every half a second	Read every millisecond

Table 13 Table showing the polling rate of each sensor

Below in table 14 is a structure diagram showing how the sensors are read and at what times. Each block represents the sensor being read and the information that is read being stored on the SD card.

0 seconds	Temp.	RPM	Speed	SFL	SFR	SBL	SBR	PRY
0.5ms	SFL	SFR	SBL	SBR				
1ms	SFL	SFR	SBL	SBR	PRY			
1.5ms	SFL	SFR	SBL	SBR				
2ms	SFL	SFR	SBL	SBR	PRY			
Repeat until 500ms								
500ms	RPM	Speed	SFL	SFR	SBL	SBR	PRY	
500.5ms	SFL	SFR	SBL	SBR				
501ms	SFL	SFR	SBL	SBR	PRY			
Repeat until 1 second								
1 second	RPM	Speed	SFL	SFR	SBL	SBR	PRY	
1000.5ms	SFL	SFR	SBL	SBR				
1001ms	SFL	SFR	SBL	SBR	PRY			
Repeat until 10 seconds								
10 seconds	Temp.	RPM	Speed	SFL	SFR	SBL	SBR	PRY
Repeat for 2-hour cycle								

Table 14 Structure diagram of sensor reading (SFL=susp. front left, SFR=susp. front right etc. PRY=pitch, roll, yaw)

3.7) SYSTEM CAPABILITIES

Below is a table summarising the specifications of the system (Table 15).

Clock speed	RAM	Program memory	ADC size	I/O pins	RS232, SPI and USB compatible
16MHz internal oscillator	3.6KB	1KB	12-Bits	40/44 (11 can be Analogue)	Yes
Sensor Selected device	Temperature SA-IR200V6-000	Suspension Linear PS-C18C	Speed VIB 6.63	RPM VIB 6.63	PRY BC-3A16 3G300-000
Resolution	0.05°C @ 1.22mV per step	0.07mm@ 1.22mV per step.	Min speed at least ¼ rotation in half a second. Max dependent on wheel size 15,000 RPM	Min speed at least ¼ rotation in half a second. Max 15,000 RPM	0.0045° degrees on gyro. 0.0003G on accelerometer.
Measurement range	-30°C to +200°C	0-300mm	0-1500RPM	0-15,000 RPM	0-16G Accelerometer 0-300°/s Gyro.

Table 15 Full system specification

4) DESIGN OF ENCLOSURE, CONNECTORS, AND PCB

The case cannot be created until the PCB size is known, the case size and PCB size cannot be determined until the connectors being used have been specified.

4.1) CONNECTORS

First the connectors needed must be defined from the inputs and outputs of the system.

- 4 connectors for suspension (one for each wheel) 3 pins each (Supply voltage, ground and output)
- 1 connector for temperature 3 pins (Supply voltage, ground and output)
- 1 connector for speed 3 pins (Supply voltage, ground and output)
- 1 connector for RPM 3 pins (Supply voltage, ground and output)
- 1 connector for PRY 5 pins (CAN bus output binder 719PF from 2D technology) if connector was removed possibility for 4 pins.
- 1 connector for power 2 pins (Ground and Supply Voltage 12V)
- A standard USB output and SD card holder will also be required.

Starting with the simplest selection, which is the PRY connector which is already attached and can be easily fitted to the female port also sold by 2D technology. The pin out for the male (Binder 719,5PM) and female (Binder 719,5PF) connectors can be found in figure 12. After contacting the company it was found the IP ratings for this type of connector is IP40 and IP67 after being filled with silicone although this information is not available through the datasheet[31].

COM-line Binder 719, 5pin	Pin	Name	Description	Color
	1	TxD	Serial Bus Transmit	white
	2	RxD	Serial Bus Receive	green
	3	GND	Ground	black
	4	n.c.	Not connected	-
	5	Vext	Power	red

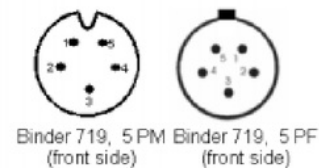


Figure 12 [32] PRY sensor connector pin out

To connect the suspension sensors to the device a connector with at least three pins is required, this connector must also be weather resistance and gold plated for maximum data transfer. After some research the DT06-3S-E008 male and DT04-3P-E004 male connectors were found they are both IP67 rated and gold plated, which makes them both sufficient for the purpose. To ensure these connectors are not placed in the wrong place each wheel will be colour coded and the other receptacles will not match the input. To ensure the connectors are not placed in the wrong polarity there is a clip on one side of the connector which is visible in figure 13 [33], [34].



Figure 13 [33], [34] Male and female connectors used for suspension sensors

The connector for temperature must also have a minimum of three pins and have the same ruggedness capabilities as the suspension connectors, an appropriate 3 pin connector and socket was found to be the 3 pin version from 8STA range from Esterline (Fig. 14) [35]. This connector socket pair has gold plating and IP67 rating with reverse polarity prevention.



Figure 14 [35] 8STA connector for temperature

The same connector can be used for both speed and RPM and they can be colour coded, if these are plugged in to the wrong port the data logged will be wrong but the inputs and supply voltage are the same so there will be no damage to any of the circuitry. These connectors also need to be rugged, have three pins, and be gold plated. The S-type connector from Lemo has the possibility of 2-22 connections the variant with 4 is most suited to this application as it means the connection cannot be placed in the wrong orientation they are also IP67 rated [36]. These fittings can be seen in figure 15.

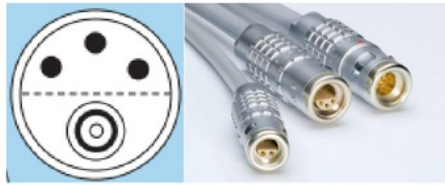


Figure 15 [36] Lemo S-type connectors for speed and RPM sensors

The battery will need to be connected to the main PCB, this does not need to be as rugged as the other connectors as it will be inside the case, however it will be removable to enable it to be recharged. The socket and the connector are for this application are both very basic and most would be compatible as long as it was the correct voltage and current rating. The plug and socket selected are from RS online and can be seen in figure 10 they are rated at 12V and 5A (Fig. 16) [37], [38]. This also allows for a switch to be placed in series with the cable to act as a power switch (ON/OFF).



Figure 16 [37], [38] Power connector and port

The SD card holder and USB port were also found at RS online, for the SD card holder the only requirement was gold plated pins to ensure the data rate was supported, there were no real requirements of the USB as the data rate for the transfer to PC is not defined. The components selected are pictured below in figure 17 [39], [40].

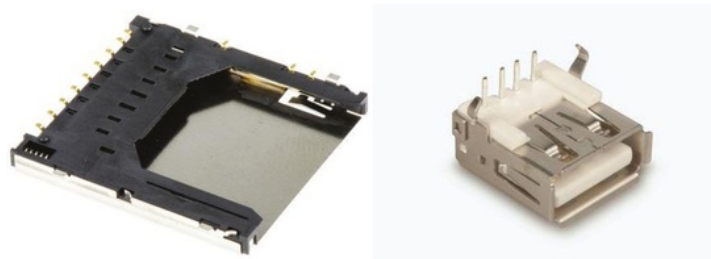


Figure 17 [39], [40] The SD card holder and USB offload port

The cabling to connect the sensors to the system must be rugged and have enough cores, the same cable can be used for all, each require 3 core cabling apart from the PRY sensor, however this sensor comes with appropriate cabling. The cable that was chosen is the EAS range from electra-cables, these were chosen as they come in multiple colours (this will help sensor identification), multiple AWG sizes (this will help fit to different connectors) and can withstand the temperatures and data transfer rates of this application [41]. The cable can be cut to whatever length is required.

4.2) SCHEMATIC

Below in figure 18 is an example of one of the four suspension sensors, RV1 is the sensor itself and R2, D1 and C1 are acting as a 5V voltage clamp to give a 0-5V analogue output to the microcontroller.

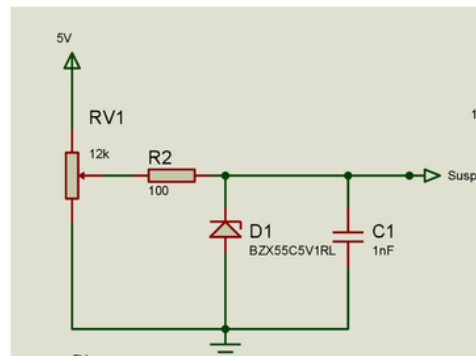


Figure 18 Suspension sensor block

Below in figure 19 is the temperature sensor RV3 is the sensor itself and R7, D4 and C4 are acting as a 5V voltage clamp to give a 0-5V analogue output to the microcontroller.

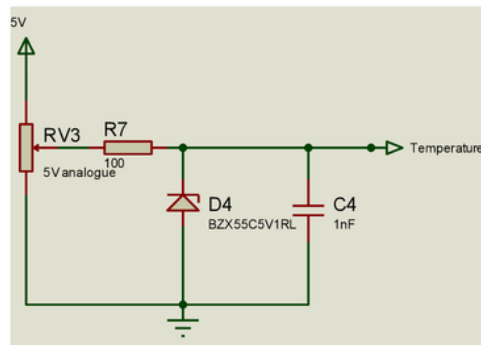


Figure 19 Temperature sensor block

Below in figure 20 is the sensor used for RPM and speed, the optical sensor sends a 5V pulse R5 is a pull-down resistor, again there is a 5V voltage clamp to ensure the pulse does not surpass 5V.

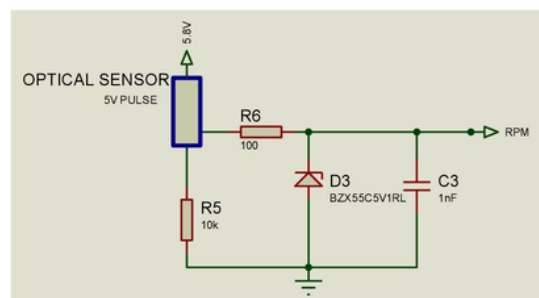


Figure 20 Optical RPM and speed sensor

Below in figure 21 is the voltage regulators used to gain the necessary voltages from the battery.

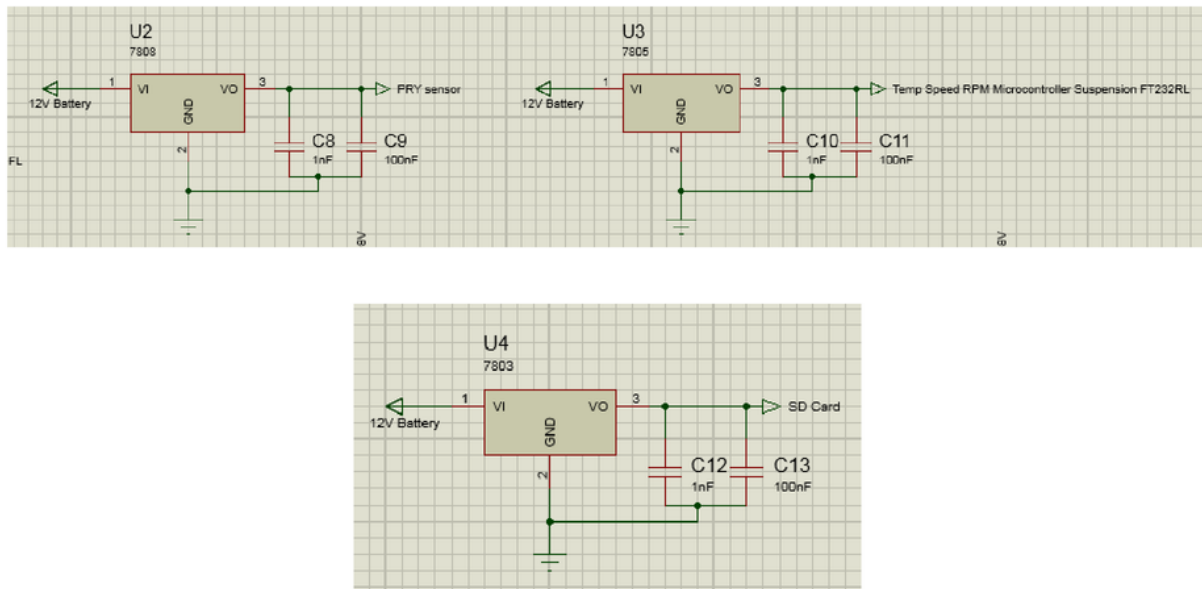


Figure 21 Voltage regulators

Below in figure 22 is the pitch roll yaw sensor.

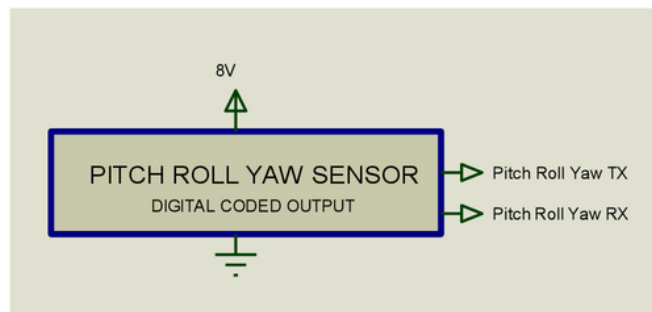
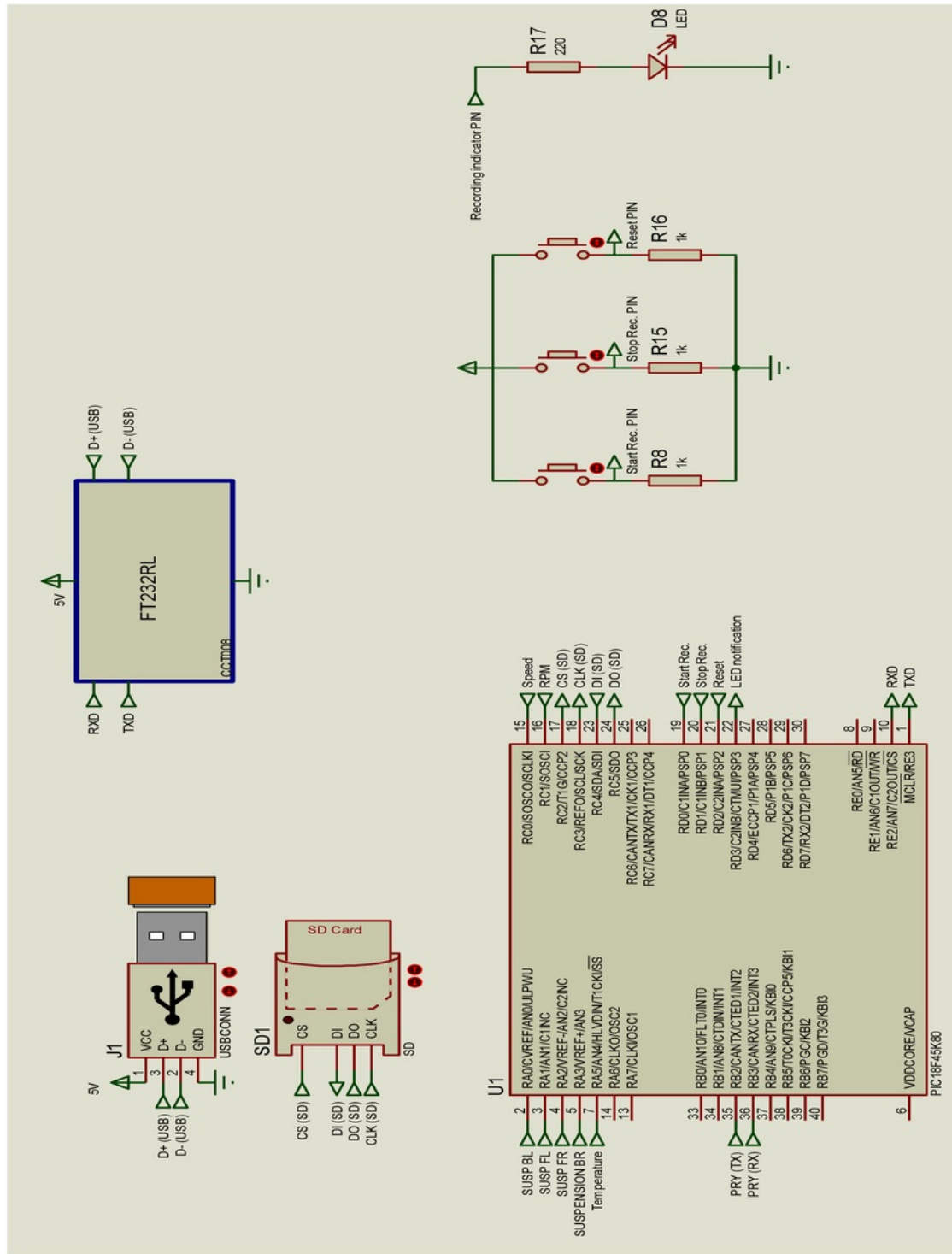


Figure 22 PRY sensor

On the next page is the microcontroller and its connections to the storage, USB (FT232 interface) and user interface (Fig. 23).



4.3) PCB LAYOUT AND DESIGN

Once the schematic has been developed the PCB can be designed; below are images of the final PCB with all design and integrity checks passed. The first image shows the layout and top layer connections of the components on the PCB (Fig 24).

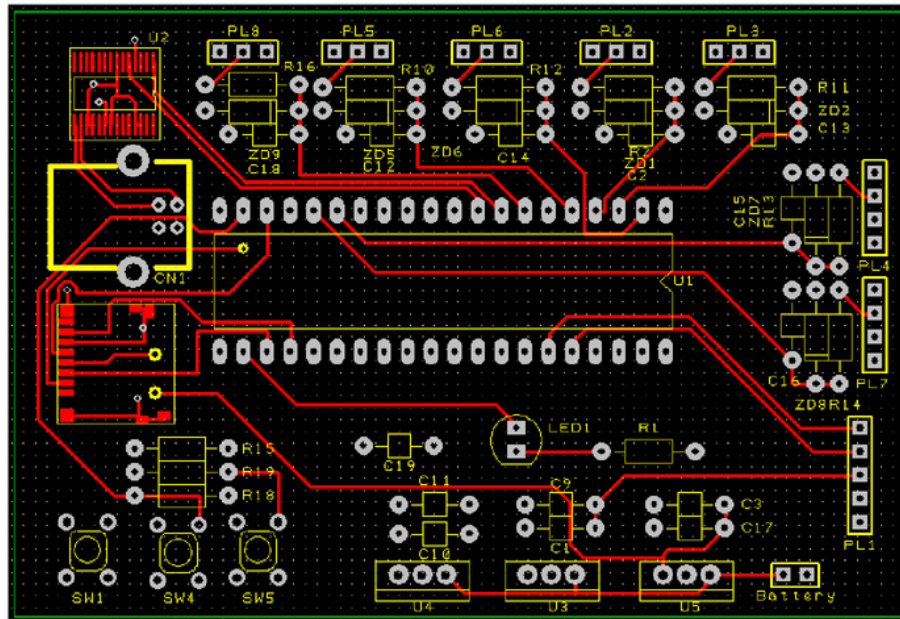


Figure 24 PCB layout top layer

Figure 25 shows the bottom copper layer, the 5V and 0V copper pours as well as some tracks that were not feasible on the top layer.

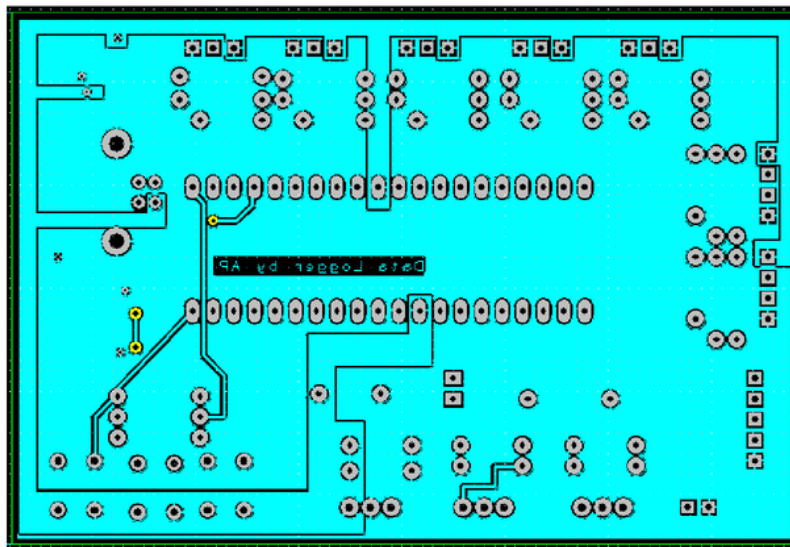


Figure 25 PCB bottom copper

Figure 26 shows bottom and top layers combined.

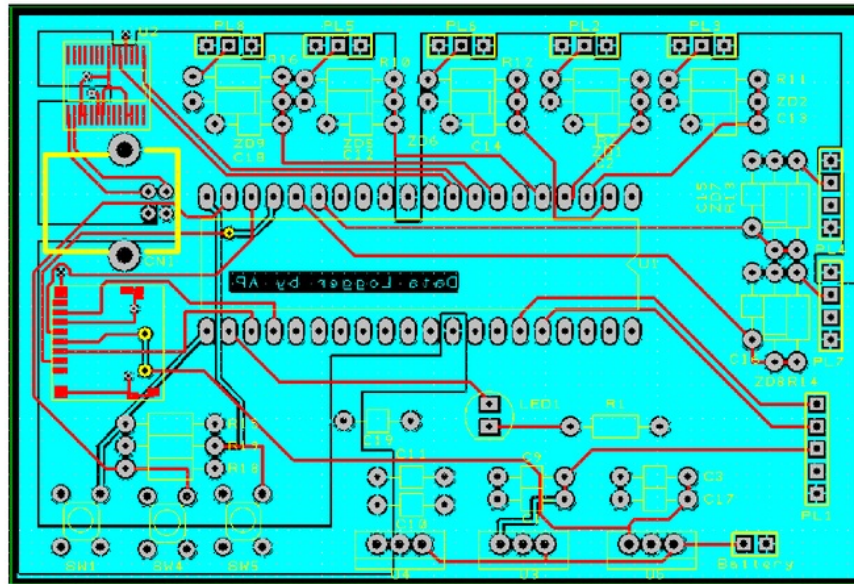


Figure 26 Bottom and top layer PCB

Figure 27 shows the 3D view of the final PCB the red blocks are components without 3D models (SD card slot, USB and switches).

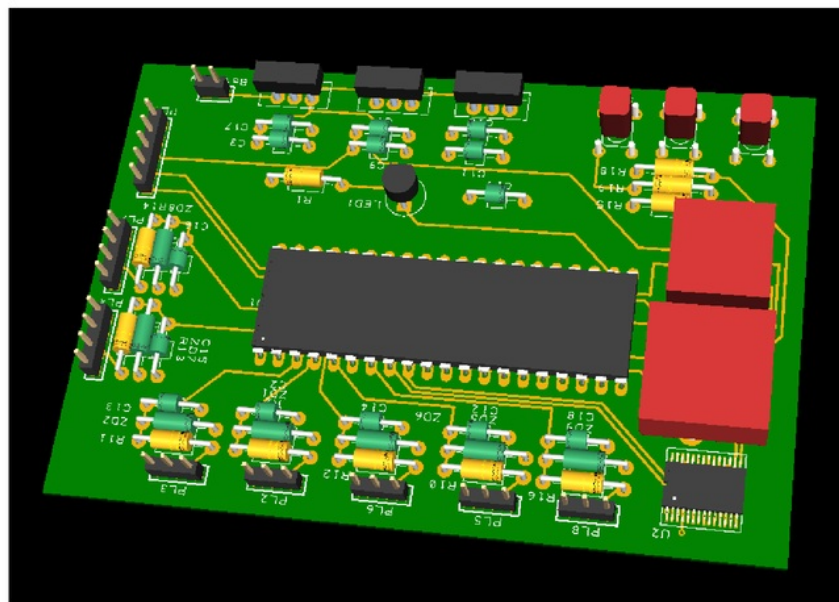


Figure 27 3D PCB view top

Below in figure 28 is the bottom of the PCB in 3D view.

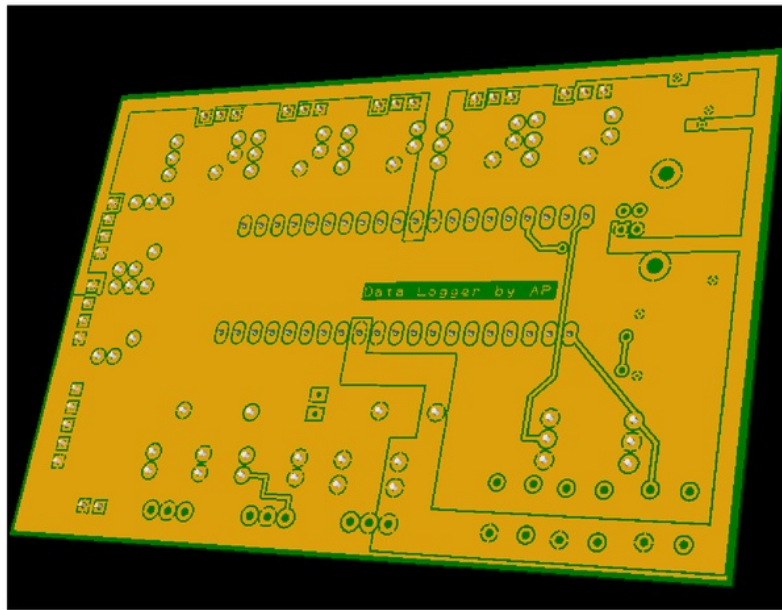


Figure 28 Back of PCB 3D view

4.4) CASE DIMENSIONS AND MATERIALS

The case for this device must house the battery and PCB, this case must also be rugged and portable, and now that the size of the PCB and battery are known the case can be designed. The size of the battery is, Height: 60mm Width: 67mm Depth: 134mm, the PCB dimensions after development are Width: 98mm Length: 67mm, allowing for room around these components for caballing and connectors the case should be at least 150mm x 100mm x 80mm as shown in figure 29.

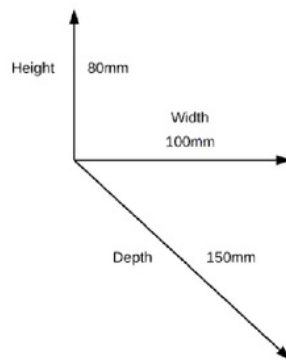


Figure 29 Minimum case dimensions

The Klippon K51 (Fig. 30) [42] was selected as it has sufficient space, IP68 rating, and is shock resistant. The case weighs about 1.3kg, this weight along with the battery and other components will make the device weigh around 3kg which is relatively light and will make the device portable, making it suitable for the specification. This case has a lid which is attached via 4 screws which can be easily removed to charge the battery, remove the SD card or offload the data. Holes can be made in the sides of the case to allow for the connectors to be attached also its dimensions are 120mm x 220mm x 81mm.



Figure 30 Case selection Klippon K51

4.5) TOTAL DEVICE COST

To estimate the cost of the device the cost of each component was evaluated, if the cost was not apparent the company was contacted, most sellers replied however some did not, for these parts the prices are estimated (table. Each part was rounded to the nearest sensible cost e.g. £2.50 = £3.

DEVICE	COST
PIC18F45K80	£3
TEMPERATURE SENSOR	£40
SPEED AND RPM SENSOR	£120
SUSPENSION SENSOR X4	£360
PRY SENSOR	£150
CONNECTORS AND CABLING	£300
BATTERY	£35
CASE	£90
PCB AND COMPONENTS	£300

Table 16 Cost of data logger breakdown

This totals £1398, overestimating slightly further this device could cost £1450 to construct.

5) FUTURE IMPROVEMENTS

For the next iteration of this device several improvements could be made. The first factor is the data, the polling rate could be increased to allow more information to be taken in, more accurate sensors could be used to increase the accuracy of the readings. The other factor is usability, there are several things that could improve this factor, the first is the data being stored, this is currently stored in raw binary format; this could be improved by either changing the format the data is stored or perhaps making some form of computer software that makes the data easier to read and maybe enable some form system diagnostics/updates. Another change that may improve usability would be to add an interactive display to the device, this could be used to display information about the device, change settings within the device and much more. Currently to change the SD card, offload data or charge the battery, the case must be opened, if these devices were placed so they were accessible from the exterior of the case and there was some form of recharging port this problem could be counteracted. Making this device more power efficient could help reduce the size of the battery, and more PCB development may reduce the size and weight of the overall package.

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Car data logger AP P145780

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: SMU GENERIC_GJ

ANDREW PRESCOTT

67.30

RESEARCH-INFORMED LITERATURE



Good literature review of available systems with a good comparison table of relevant information which could have been improved with a thumbnail image of the device in the table.68%

6.8

KNOWLEDGE AND UNDERSTANDING



Good overall schematic design but a few problems can be seen. The voltage regulator output capacitors should be 100nF and 1uF. The 3V3 and clk pins are reversed on the sdcard connector. The pull down resistors on the switches should be 4k7.65%

16.25

ANALYSIS



Good selection of microcontroller. Good selection of sensors showing calcs for each one with a nicely laid out table showing a limited number of sensors to be chosen from but an image or illustration of each would have been beneficial. Reasonable case selection but there is no discussion or reflection of other cases. Good selection of connectors. 65%

22.75

PRACTICAL APPLICATION AND DEP.



Costings nicely put forward as a table with price but without supplier of component and lacking detail with a very hopeful total. Reasonable attempt at future enhancements.65%

13

SKILLS FOR PROFESSIONAL PRAC.



The report is well presented with very well presented tabled data and diagrams. A good selection of references. 85%

8.5