

Assignment 1 - Car Data Logger

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ACDA6002: Electronic Systems Design

Motor Vehicle Data Logger Design

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1.0 Introduction

Vehicle data acquisition systems are a fundamental component for vehicle performance development. Many manufactures have developed systems that connect to stand alone sensors located on a vehicle, as well as communicating directly with vehicle on board electronics and data from the ECU. This report covers the design of a standalone battery powered data acquisition system, suitable for measuring the following parameters over a 2-hour test period of a family saloon car.

- Vehicle speed
- Engine RPM
- Engine Temperature
- Pitch, Roll and Yaw
- Suspension Travel

The data logging system is based around an 8-bit PIC micro controller, interfaced to sensors and modules to read, and store the measured variables in non-volatile memory.

This report outlines the hardware selection of sensor technology, microcontroller specification, enclosure, and connectors appropriate to the operating environment. This is expected to be at high temperatures, high moisture and dirt levels with excessive vibration and shock.

Schematic diagrams have been created demonstrating proper signal conditioning methods, utilising low pass filtering for anti-aliasing, and over voltage protection circuits.

A PCB design has been developed, as well as a full breakdown of prototype costs and a bill of materials.

2.0 Data Logger Overview

Data loggers range from simple low-cost items, such as the MCC USB-231 general purpose datalogger from Digilent [2], to advanced motorsport specific systems such as the AiM EVO5 [3]. Table 1 displays a selection of some available automotive data loggers. The table has been formatted to capture the critical features of each item.

Some of the Key features of the data loggers featured in table 1 are:

- ingress protection (IP) rating of 65 or greater.
- The shock and vibration resistance of certain units show they can endure large amounts of vibration, at frequencies between 180Hz and 20kHz and shocks up to 40G.
- Casing materials of the automotive units are manufactured from anodised aluminium. Anodised aluminium alloys ensure high strength, low weight, and excellent corrosion resistance with hard anodised coatings.
- MIL Spec high pin density, circular connectors, found within high performance racing vehicles and aerospace applications are utilised.
- multiple analogue and digital input channels per unit
- The sample rates for these channels range from 500Hz per channel, up to 10kHz per channel.
- Many contain an internal gyroscope and accelerometer.

- I/O expansion is possible. Including, GPS, Lambda sensors and dedicated thermocouple input modules.
- Wide range of communication protocols – USB, CAN, RS232, Ethernet, TCP/IP, WIFI.
- Cost is determined by functionality - fast sample speeds, large channel counts, expensive connector hardware and increased communications suited for professional motorsport applications, reflected in their price points.

	Digilent MCC USB 231 [2]	AIM EVO4S [4]	AIM EVO5 [3]	AIM MXS 1.2 [5]	2D LG-L9-000 [6]	Bosch Data Logger and Sensor Interface C 80 [7]
Automotive Specific Power Supply	No USB 5V	Yes, Motorsport 9 - 15V	Yes, Motorsport 9 - 15V	Yes, Motorsport	Yes, Motorsport	Yes, Motorsport 8 - 18V
Analogue Inputs	8 Single ended/4 differential	5	8 fully configurable: 0-5V, 0-12V, K thermocouples.	8 fully configurable	Up to 32, 0 - 5V	6, 0 - 5v
Analogue outputs	2, 16 Bit	No	No	No	No	4 x PWM
ADC Resolution	16 - bit	12 Bit	12 Bit	12 Bit	16 Bit	12 Bit
Digital Inputs	8	2 Speed, Lap trigger, Coil RPM Input	Coil, RPM and 4 speed inputs	4 Speed inputs, lap signal, coil RPM input	4	4
Digital Outputs	8	1	2	2	2	0
Sample Rates	50 kS/s	1000Hz	Max freq 1 KHz each	Max 500 Hz each	1kHz, 10kHz per channel	10kHz per channel, logging rate 800kB/s
Communication	USB	CAN, RS232, K-Line	CAN, RS232, K-Line	CAN, RS232, or K-Line	CAN, USB, RS232, Ethernet TCP/IP	CAN, RS232, Ethernet, USB
Internal Inertial Platform	None installed	internal 3 axis 5G Accelerometer, 3 axis Gyro	Internal 3 axis +-5G accelerometer + 3 axis gyro	No	No	No
Internal Memory	256kB flash, 2kB EEPROM	4GB	4GB, 32GB SD Card	4GB	8GB	Up to 16GB
Connectors	32 screw terminals	13, Binder connectors	Deutsch 37 Pin, and 22 Pin Motorsport Connectors	Deutsch 37 Pin, and 22 Pin Motorsport Connectors	2 x 41 pin Motorsport connectors, ASDD2-12-41 PN, ASDD2 12-41 PA	2 x 41 Pin Motorsport Connectors, ASDD612-41 SN, ASDD612-41 SA
Body Material	Plastic	Anodized aluminium	Anodized aluminium	Anodized aluminium	Aluminium	Aluminium
LED's	No	RGB status LED	RGB status LED	6 configurable RGB LEDs	None Specified	105 x 34.5 x 137.5 mm
Dimensions	93.2 x 86.2 x 23.6 mm	130 x 35 x 46.6 mm	114.4 X 47.2 X 58.8mm	169.4 x 97 x 23 mm	76 x 90 x 26 mm	462g
Weight	105 g	330g	300g	530g	245g	462g
IP Rating	None	IP65	IP65	IP65	IP67	IP67
Operating Temperature Range	0°C- 45°C					0°C- 85°C
Shock Rating/Vibration	Not Specified	Not Specified	Not Specified	Not Specified	Shock: 40G @10ms, Vibration: 12G @1000Hz	200m/s2 @ 180Hz 50.4(m/s2)/Hz @ 20Hz
Wireless Capable	No	No	Yes, Wi-Fi	Yes, Wi-Fi		1 x sensor supply 5 V ± 1 % (250 mA)
Power Output	5V, 150 mA			400mA		10W @ 14V
Power Consumption				Yes, GPS Module Channel Expansion, TC Hub, Lambda Controller, Camera	Yes, Series connection of up to 2 units	
Expandable	No	Yes, Memory, sensor modules (digital, analogue, TC), video recording	Yes, GPS Module, Channel Expansion, Lambda controller			
Cost	£295.64 (£)	£1180 + VAT (££)	£1600 + VAT (££)	£2328 (£££)	(£££)	£5,396.85

Table 1 - Data Logger Specification Comparison Table

3.0 Microcontroller Selection

The microcontroller (MCU), required for this application is from the 8-bit PIC range from Microchip. In order to determine the microcontroller, Microchip's parametric search function has been used to filter devices based upon the functions required.

- **MCU Family:** 8 – Bit PIC MCU.
- **Automotive Compatible:** Yes.
- **ADC Resolution:** 10 – bit minimum.
- **ADC Inputs:** 5 minimum.
- **USB Interface:** Yes, required for data download to PC.
- **Low Power Capable:** Yes, desirable for battery powered applications.
- **Serial Peripherals:** Yes. UART, SPI and I²C. Required for communication between external components such as storage and digital sensors.

Table 2 displays the microcontrollers suggested, listing their functions for comparison.

From table 2, the selected MCU's for comparison include the PIC16F1826 [8], PIC16F1828 [9], PIC16F1829 [10], PIC16F1786 [11], PIC16F19155 [12], PIC16F18877 [13], PIC18F46J50 [14] and the PIC18F45K50 [15].

The PIC18F46J50 in a 44-pin surface mount package has been selected. This device has 13, 10 Bit resolution ADC inputs, which is ample for the application, 2 UART, SPI and I²C interfaces for the connection of external storage modules and digital sensors. The device has a dedicated USB interface. The device has a real time clock feature, suitable for datalogging applications. The PIC18F46J50 has ample program storage memory of 64KB, this will allow for high level code to be compiled for the software application, as well as having headroom to carry out scaling and calculation functions for interfaced sensors.

	PIC16F1826	PIC16F1828	PIC16F1829	PIC16F1786	PIC16F19155	PIC16F18877	PIC18F46J50	PIC18F45K50
Family	8-bit MCU	8-bit MCU	8-bit MCU	8-bit MCU	8-bit MCU	8-bit MCU	8-bit MCU	8-bit MCU
CPU Type	8-bit PIC MCU	8-bit PIC MCU	8-bit PIC MCU	8-bit PIC MCU	8-bit PIC MCU	8-bit PIC MCU	8-bit PIC MCU	8-bit PIC MCU
Max CPU Speed (MHz)	32 MHz	32 MHz	32 MHz	32 MHz	32 MHz	32 MHz	48 MHz	48 MHz
FPU								
Operation Voltage	(1.8V-5.5V)	(1.8V-5.5V)	(1.8V-5.5V)	(1.8V-5.5V)	(1.8V-5.5V)	(1.8V-5.5V)	(2V-3.6V)	(1.8V-5.5V)
Temp Range	(-40 to +125)	(-40 to +125)	(-40 to +125)	(-40 to +125)	(-40 to +125)	(-40 to +125)	(-40 to +85)	(-40 to +125)
Pin Count	18	20	20	28	28	40	44	40
Program Memory Size (KB)	3.5	7	14	14	14	56	64	32
SRAM	256 Bytes	256 Bytes	1024 Bytes	1024 Bytes	1024 Bytes	4 KB	3.7109375 KB	2 KB
Data EEPROM/HEF (Bytes)	256	256	256	256	256	256		256
Low Power	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ADC Input	12	12	12	11	20	35	13	25
Max ADC Resolution (Bits)	10	10	10	12	12	10	10	10
DAC Outputs	1	1	1	2				1
Number of Op Amps				2				
Hardware Touch Peripheral					ADC2 with HCVD	ADC2 with HCVD		
UART	1	1	1	1	2	1	2	1
SPI	1	1	2	1	1	2	2	1
I2C	1	1	2	1	1	2	2	1
Number of USB Modules							1	1
USB Interface	None	None	None	None	None	None	FS Device	FS Device
Max 8-Bit Digital Timers	2	4	4	2	2	3	2	2
Max 16-Bit Digital Timers	1	1	1	1	2	4	3	2
Hardware RTCC/RTC					RTCC		RTCC	
Max PWM outputs (including complementary)	4	8	8	21		19		
Number of PWM Time Bases	1	3	3	3		3		
Segmented LCD					96			
Pricing: (USD)	1.43 - 1.77	1.46 - 2.08	1.53 - 2.31	2.05 - 2.61	1.54 - 2.21	1.69 - 2.39	5.02 - 5.06	2.95 - 3.62

Table 2 - PIC MCU Parametric Search Comparison

4.0 Sensor Selection

4.1 Vehicle Suspension Travel

Table 3 displays a selection of appropriate sensor technology for suspension travel measurement.

	SUS-POT-150 [16]	SA-WPxxxxHQ-000 [17]	SA-LP150S-000 [18]	Laser Ride Height Mini FL [19]
Manufacturer	AiM Motorsport	2D	2D	Cosworth
Sensor Type	Linear Potentiometer	Wire Potentiometer	Linear Potentiometer	Laser
Supply Voltage	40VDC (Max) 5V (Typ)	5V	5V	10 - 28V
Output Voltage	0 - 5V	0 - 5V	0 - 5V	0 - 5V
Input Resistance	10kΩ	10kΩ	10kΩ	
Resolution	Infinite	Infinite	<0.01mm	@ 50mm ±0.02mm @350mm ± 0.45mm
Repeatability	≤0.01mm	±0.02 % FS		
Operational Speed	10 m/s		10 m/s	
Mechanical Life	>25 million Cycles	25000 Cycles	>25 million Cycles	
Temperature Range	-40°C to +125°C	-40°C to +125°C	-40°C to +140°C	
Sealing Class	IP65		IP66	
Accuracy		±0.25 % FS		
Linearity	≤±0.5%		0.5% FS	@ 50mm ±0.06mm @ 350mm ± 1.5mm
Cable Type	Raychem 55A 24 AWG		Raychem 3 x 24 AWG	
Material	Aluminium		Aluminium	Aluminium
Connector	Binder 719 Male		Binder 719 Male, Bare wire	Deutsch Autosport (optional)
Price	£225.00	£803.65	£296.72	

Table 3 - Suspension Sensor Comparison Table

From the comparison table, the selected sensor will be the linear potentiometers SUS-POT-150 from AiM motorsport. Its aluminium construction ensures lightness and corrosion resistance. It is low cost compared to alternative methods. It has an IP rating of IP65 making it suitable to the dirty or wet operating environment. It has appropriate electrical characteristics with regards to resolution, input voltage, accuracy, and repeatability. It has excellent mechanical lifetime and provides a convenient mounting method directly to a vehicles shock absorber. The unit can be specified in various lengths, the unit chosen has a displacement of 150mm. Figure 1 displays the selected unit.



Figure 3 - Suspension Potentiometer

4.2 Engine RPM and Wheel Speed

This section overviews the comparison and selection of an appropriate sensor for wheel speed and engine RPM measurement. Table 4 displays a selection of sensors.

	SNG-QPLA-000 [20]	VR-09-B [21]	SD-V01M8-000 [22]
Manufacturer	Honeywell	Texense	2D
Sensor Technology	Hall Effect	Differential Hall Effect	Inductive
Operating Voltage	4.5V to 26V	4V to 25V	12V
Output signal	Square Wave Quadrature Speed	Pulse	Pulse
Switching Frequency	3Hz to 20kHz	max 20kHz	800Hz
Supply Current	12mA	15mA	
Material	PBT	Aluminium	Aluminium
Cable Type	EVA, four conductor, 36 AWG, 28 strand, ø5,2 mm [ø0.20 in] jacket	3 x 26AWG FEP tinned copper braided cable	3 x 0,14 mm2, PVC
IP Rating	IP69K	IP66	
Operating Temperature	-40°C to 150°C	-50°C to 180°C	-50°C to 80°C
EMC immunity	100 V/m		
Cost	£67.67	£164.39 +VAT	

Table 4 - Speed and RPM Sensor Comparison

Engine RPM and wheel speed is typically measure by counting a pulse train from a sensor over a set period of time. The sensor output will be connected to a digital input on the microcontroller.

Comparing the parameters from table 4, the Texense hall effect sensor is appropriate for this application due to its IP66 rating, low operating voltage, operating temperature range, aluminium construction, and sufficient switching frequency. This unit is small, and flange mounted making installation simple on a vehicle. Figure 2 displays the unit.



Figure 4 - Texense Hal Effect Sensor

For wheel speed, the sensor may be mounted in order to pick up bolt heads on a brake rotor, providing the pulse donation. Speed will then be calculated according to pulses per rotation over a fixed time period. Calibration is necessary if pulse count or wheel/rotor diameter changes.

For RPM, the same sensor is utilised, potentially using a flywheel tooth as a pick-up, or a feature of a pulley wheel from the vehicle crankshaft.

4.3 Engine Temperature

Temperature measurement can be derived from various sensing methods such as Thermocouples, resistance thermometers (RTD's), Negative/Positive temperature coefficient thermistors (NTC/PTC) and non-contact infra-red technology. Table 5 displays some selected sensors compared for this application.

	TS M8 Liquid Temperature Sensor [23]	SA-TK01-000 [24]	CE-050-03 Mil-Spec Temperature Sensor [25]	Temperature Sensor NTC M8-HS [26]	SA-NTCM06_5V-000 [27]	NTCALUG85A M6 Series [28]
Manufacturer	Texsense	2D	Reventec	Bosch Motorsport	2D	Vishay
Range	0°C to 150°C	0 - 1000°C	-50°C to 170°C	-55°C to 300°C	0°C - 150°C	0°C - 150°C
Accuracy	2% of Full Scale	± 1%	± 2% Across Temp Range	± 0.3°C @25°C ± 1.3°C @100°C	± 0.5°C @ 40-80°C	± 2%
Sensitivity	22.5mV/°C	0.25°C				
Output	0 - 5V	µV	0-5V, CAN	Resistance Change	Resistance Change	Resistance Change
Response Time	1000ms			<4s		7.5s
Supply Voltage	5V typical	12V for Amplifier	5V	5V typical	5V typical	3.3V
Current	<1mA		<10mA			
Sensing Technology	NTC	K-Type TC	RTD, PT1000, built in signal conditioning	NTC	NTC	NTC 10k @ 25°C
Mounting Type	M8 Male Thread	M5 Male Thread	Thread	M8 Male Thread	M6 SS Male Thread	M6 Ring Terminal
Vibration Resistance	20G pk to pk		10G @ 10Hz-2kHz			
Shock Resistance	500G		50G, half sine			
Operating Temperature	0°C to 150°C		-40°C to 125°C		-25°C to +85°C (Ambient)	
Additional Items Required	No	TC amplifier IN-ATK01_050-000 £170.51	FemaleD38999 connector for harness connection		Female Binder 719 5PM Connector for Harness	24AWG Bare
IP Rating			IP69 (Mating connector)		IP67	
Price	£113.09 +VAT	£200.95	£305			£3.14

Table 5 - Engine Temperature Sensor Comparison Table

From table 5, the sensor selected for engine temperature is the NTCALUG85A M6 Series from Vishay components. This sensor operates using an NTC thermistor embedded into an M6 ring

terminal that can be secured to the vehicles engine block or water pump housing. Using this method is not as preferential as measuring coolant temperature directly, however, this application is required to be portable. Coolant temperature sensors with a defined thread, would require various adapters to be manufactured to accommodate different classes and specifications of vehicle, adding complexity.

The temperature output can be calculated by measuring the voltage at the MCU ADC input using a lookup table provided by the manufacturer. As temperature increases, resistance will decrease. This relationship is not linear, however the manufacturers stated accuracy and temperature range is sufficient for the application.

The selected sensor is extremely low cost, and easily replaceable. It is of low complexity, not requiring additional amplifiers such as those required for thermocouple or RTD measurements. Figure 3 displays the selected sensor.



Figure 5 - Vishay M6 NTC Temperature Sensor

4.4 Pitch, Roll and Yaw Measurement

Measuring pitch, roll and yaw will allow analysis of the vehicle behaviour such as dive under braking, pitch during acceleration, roll during cornering and rate of rotation from steering inputs. Many modern vehicles have on board gyroscope and accelerometers to measure these parameters in a combined inertial measurement unit (IMU). Table 6 displays a group of sensors relevant to this application.

	MPU6050 [29]	IAM-20380 [30]	ASM330LHHXG1 [31]	GYRN3-S [32]
Manufacturer	TDK InvenSense	TDK InvenSense	STMicroElectronics	Texense
Output Signal type	Digital I2C 16 Bit	Digital I2C 16 Bit	I2C, SPI	0-5V analogue per axis
Sensor Type	MEMS IC	MEMS IC	MEMS IC	External device
Range X, Y, Z	$\pm 250, \pm 500, \pm 1000$ ± 2000 °/s (Programmable)	$\pm 250, \pm 500, \pm 1000$ ± 2000 °/s (Programmable)	± 125 °/s to ± 4000 °/s (Programmable)	$\pm 50, \pm 100,$ ± 150 °/s
Operating Current	3.6mA	2.6mA, 1.6mA Low Power Mode	1.3mA	16mA
Operating Voltage	2.375V to 3.46V	1.71V to 3.6V	1.71V to 3.6V	5V
Zero Rate Output		-0.8°/s	± 2 °/s	± 1 °/s
Sensitivity	131 LSB(°/s) @ ± 250 °/s 65.5 LSB(°/s) @ ± 500 °/s 32.8 LSB(°/s) @ ± 1000 °/s 16.4 LSB(°/s) @ ± 2000 °/s	132 LSB(°/s) @ ± 250 °/s 65.5 LSB(°/s) @ ± 500 °/s 32.8 LSB(°/s) @ ± 1000 °/s 16.4 LSB(°/s) @ ± 2000 °/s	4.37 mdps/LSB @ ± 125 °/s 140 mdps/LSB @ ± 4000 °/s	40mV/°/s @ ± 50 °/s 20mV/°/s @ ± 100 °/s 13.3mV/°/s @ ± 150 °/s
Cross Axis Sensitivity	$\pm 2\%$	$\pm 5\%$	$\pm 1\%$	3%
Non-Linearity	0.20%	0.10%	0.01% FS	
Accuracy				2% FS
Shock Rating	10000g	10000g		1000g
Accelerometer Function	Yes	No	Yes	No
Additional Features			AEC-Q100 Automotive Qualified	Motorsport Appropriate
Operating Temperature	-40 to +85°C	-40 to +85°C	-40 to +125°C	-20 to +105°C
Weight				30g
Size	4 x 4 x 0.9mm	3 x 3 x 0.75mm	2.5 x 3.0 x 0.83mm	30 x 21.5 x 11mm
Protection Class	NA	NA	NA	IP66
Price	£7.84	£15.97	£12.31	\$2175

Table 6 - Gyroscope/IMU Comparison

The sensor chosen for this application is the ASM330LHHXG1 MEMS IMU from ST Micro Electronics. The MEMS gyroscope operates using a tuning fork principle, where a resonating mass experiences a Coriolis force when subjected to rotation. The sensing fingers measure a change in capacitance proportional to the angular rate applied [33] and output the result as a digital word [34].

The chosen device is low cost and extremely small so is convenient to integrate directly to the datalogger PCB. Communication via I2C allows for simple integration. Outputs are expressed using 16-bit digital words with a programmable range of ± 125 °/s to ± 4000 °/s, with a sensitivity of 4.37 milli degrees per second (mdps)/LSB @ ± 125 °/s to 140 mdps/LSB @ ± 4000 °/s. This is an extremely sensitive device with small non-linearity, additional accelerometer functionality, low power consumption and automotive qualified. The device also has programmable sampling frequencies, low pass filters and digital filtering  4 the outputs, reducing the need for external components.

5.0 Non-Volatile Memory Requirements

In order to calculate the size of the non-volatile storage required to log each parameter over a 2-hour test period, each measurement is firstly defined with its span and resolution of the desired units. The bytes needed per measurement can then be calculated from the number of bits needed to provide enough discrete steps to cover this measurement range. Table 7 displays the measured parameters, measurement range and resolution of each parameter.

Measured Parameter	Signal Type	Signal Mode	Min Value	Max Value	Unit	Resolution	Value Range	Bits	Bytes
Engine RPM	Digital	Pulse/Frequency	0	8000	RPM	10	800	10	2
Engine Temperature	Analogue	Voltage	0	150	°C	1	150	8	1
Suspension Travel (Front Right)	Analogue	Voltage	0	150	mm	0.5	300	10	2
Suspension Travel (Front Left)	Analogue	Voltage	0	150	mm	0.5	300	10	2
Suspension Travel (Rear Right)	Analogue	Voltage	0	150	mm	0.5	300	10	2
Suspension Travel (Rear Left)	Analogue	Voltage	0	150	mm	0.5	300	10	2
Pitch	Digital (I2C)	Serial	-250	250	°/s	0.00875dps/LSB		16	2
Roll	Digital (I2C)	Serial	-250	250	°/s	0.00875dps/LSB		16	2
Yaw	Digital (I2C)	Serial	-250	250	°/s	0.00875dps/LSB		16	2
Vehicle Road Speed	Digital	Pulse/Frequency	0	255	mph	1	255	8	1

Table 7 - Bit/Bytes required.

From table 7, some variables require 10 bits to cover the measurement range. 2 bytes are needed for these registers, the memory will be right aligned, with the most significant bit to the left to minimise bit shifting operations. Figure 4 displays a 16-bit register containing 2 bytes of data. 6 bits go unused in this configuration and are filled with zero's.

2 Byte								1 Byte							
Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
x	x	x	x	x	Data 10	Data 9	Data 8	Data 7	Data 6	Data 5	Data 4	Data 3	Data 2	Data 1	Data 0
					MSB										LSB

Figure 6 - 10bit register, right aligned data allocation.

The Gyroscope outputs 16 bits of data, 2's complement with the sign bit as the MSb in two sequential 8 bit high and low byte registers per axis. This memory can be allocated in the non-volatile storage over 2 clock cycles.

5.1 Memory Sizing

Memory taken during operation is a function of the sample frequency per channel, total test time, quantity of samples, and bits per sample. A sampling frequency of 1 kHz has been selected for the suspension travel signals to capture rapid changes. A sample frequency of 10Hz has been selected for engine temperature as this is a slow response measurement. The angular rate data output frequency is programmable, this is set in the gyroscope register, G_ODR, at 52Hz. A datalogger sampling frequency of 50Hz has been set for these measurements across x, y and z axis data. A 50Hz sample frequency is set for vehicle road speed and engine RPM. Calculation of memory is as follows:

$$\text{Equation 1} \quad T_{DataLog}(s) = 2 \text{ hrs} = 7200s$$

$$\text{Equation 2} \quad T_{sample}(s) = \frac{1}{f_{sample}(Hz)}$$

$$\text{Equation 3} \quad Samples = \frac{T_{DataLog}(s)}{T_{sample}(s)}$$

$$\text{Equation 4} \quad Memory (Bytes) = Bytes * Samples$$

Table 8 displays the calculated number of bits required to log all parameters at the desired frequency over 2 hours.

Measured Parameter	Bytes	Sample Rate (Hz)	Sample Rate (s)	Test Time (s)	Samples	Bytes
Engine RPM	2	50	0.02	7200	360000	720000
Engine Temperature	1	10	0.1	7200	72000	72000
Suspension Travel (Front Right)	2	1000	0.001	7200	7200000	14400000
Suspension Travel (Front Left)	2	1000	0.001	7200	7200000	14400000
Suspension Travel (Rear Right)	2	1000	0.001	7200	7200000	14400000
Suspension Travel (Rear Left)	2	1000	0.001	7200	7200000	14400000
Pitch	2	50	0.02	7200	360000	720000
Roll	2	50	0.02	7200	360000	720000
Yaw	2	50	0.02	7200	360000	720000
Vehicle Road Speed	1	50	0.02	7200	360000	360000

Table 8 - Memory Size Calculation

From table 8, the total memory required for a 2-hour test run is 60912000 Bytes, or 60.912 MB. For this application, a 128MB SD card, can provide ample storage for the data logger, however sizes into the hundreds of GB are available.

6.0 Connector Specifications

The embedded system for this application will require connectors to interface external sensors from the vehicle to the datalogger, and then wire to board connectors to interface with the PCB. This section outlines the external and PCB Connector specifications.

6.1 PCB Connectors

Interfacing signal wires to the board is achieved using PCB Headers and mating plugs. Table 9 displays a comparison of suitable components.

Manufacturer	JST	JST	Molex
Series	XH [35]	XAD [36]	C-Grid III [37]
Current Rating	3A	3A	3A
Voltage Rating	250V	250V	350V
Temperature Rating	-25°C to +85°C	-25°C to +85°C	-55°C to +125°C
Contact Resistance	10 mΩ	10 mΩ	10 mΩ
Insulation Resistance	1000MΩ	1000MΩ	1000MΩ
Wire Sizes	AWG 30 to 22	AWG 28 to 20	
Orientation	Vertical	Vertical	Vertical
Shrouded	Yes	Yes	Yes
Mounting	PCB Through Hole	PCB Through Hole	PCB Through Hole
Pitch	2.54mm	2.5mm	2.54mm
Mounting Height	9.8mm	10.1mm	10.9mm
Securing Method	Shouldered/locking tag	Secure Locking Device, polarising, mis insertion prevention	Lock to Mating Connector
Cost	£0.079/ pack 1000 pcs	£0.65/ pack of 200	£1.589/ pack of 5

Table 9 - PCB Header Comparison

For this design, the C-Grid III connectors from Molex will be used, in a 3-pole configuration. They have a secure locking feature to the mating part, ensuring connection during high vibration in a vehicle. They have low contact resistance, excellent insulation properties, small footprint and are fully shrouded. Standard PCB through hole mounting vertically provides easy manufacturability. The operating temperature range is suitable for the application intended.



6.2 External Connectors

Each sensor will be interfaced to the datalogger unit via individual connectors. Table 10 displays a selection of connectors that are suited for automotive purposes, with their specifications listed.

Manufacturer	Souriau	TE Connectivity	TE Connectivity	RS PRO
Series	8STA [38]	AS [39]	DT [40]	M12 [41]
Connector Design	Motorsport Circular Connector	Motorsport Circular Connector	Automotive Connector Integral Connector Latch	Industrial Circular Connector
Connector Locking Method	Bayonet Keyed	Bayonet Keyed		Push-Pull
Shell material	Aluminium black Zinc Plated	Aluminium black Zinc Plated	Thermoplastic	Brass, Chrome Plated
Insulating Material	Thermoplastic	Thermoplastic	Thermoplastic	PPS
Seal Type	Silicone	Silicone/Fully Potted	Silicone Rubber	
Number of Contacts	Variable Configurations	Variable Configurations	Variable Configurations	2,3,4 & 5 way panel mount and cable mount
Contact Connection	Crimp	Crimp	Crimp	Solder
Contact Material	Copper Alloy	copper alloy	copper alloy	Brass
Contact Plating	Gold	Gold	Nickel Plated	Gold Plated
Endurance	>500 mating cycles	>500 Mating Cycles	≤ 100 Mating Cycles	>500 mating Cycles
Shock	300g for 3ms			
Vibration	147m/s ² @ 10 - 2000Hz	60g RMS in 3 axes.	20G @ 10 to 2000Hz	
Contact Resistance	2mΩ to 14.6mΩ		8mΩ	
Insulation Resistance	≥5000MΩ		1000MΩ	2000MΩ
Contact Current Rating	5A - 80A across range	3A Max (24AWG)	7.5A to 100A	
Shell Continuity	≤10 mΩ			
Operating Temperature	-55°C to +175°C	-55°C to +170°C	-55°C to +125°C	-40°C to +85°C
IP Rating	IP67	IP67	IP68	IP67
Dimensions	Variable upon package	Variable upon package	Variable upon package	Variable upon package

Table 10 - External Connector Specifications

For this design, the AS series connectors, by Deutsch from TE Connectivity will be used. These are MIL Spec circular connectors, popular in motorsport and high-performance automotive applications. They feature a bayonet key securing method, reducing risk of disconnection. They have a full silicone seal, and terminations can be completely potted using epoxy to ensure its IP67 rating. They exhibit excellent vibration resistance and operating temperature range. They are extremely robust, with a stated life of >500 mating cycles. This will ensure a long service life. The zinc plated aluminium housing ensures corrosion resistance, and excellent EMC shielding. The AS0008 – 98PN, is a flange mounted 3 pin receptacles, these are to be mounted on the datalogger housing. The mating plugs to attach to the sensor leads are AS0608-98SN. The free plug will be sealed using a Raychem 202K121 Heat shrink adhesive boot [42], maintaining IP Rating.



7.0 Enclosure Specification

A suitable enclosure for the application is the AWN16-9-28EBB from Takachi Electric Industrial [43]. This is a dedicated instrument case. It is anodised aluminium, therefore corrosion resistant, strong, lightweight, and finned as a heatsink for cooling. It has an IP rating of IP67 and is EMC shielded. The PCB is mounted via slots on the case interior, with removable end caps making assembly and maintenance simple. This is a standard series of enclosure is reducing cost over proprietary with only minimal machining carried out to accommodate components.

Figure 5 displays the CAD rendering of the instrument case configured with the sensor external connectors and hole cut-outs for push buttons. Figure 6 displays dimensional drawings.



Figure 7 - Instrument Case configured for Data Logger

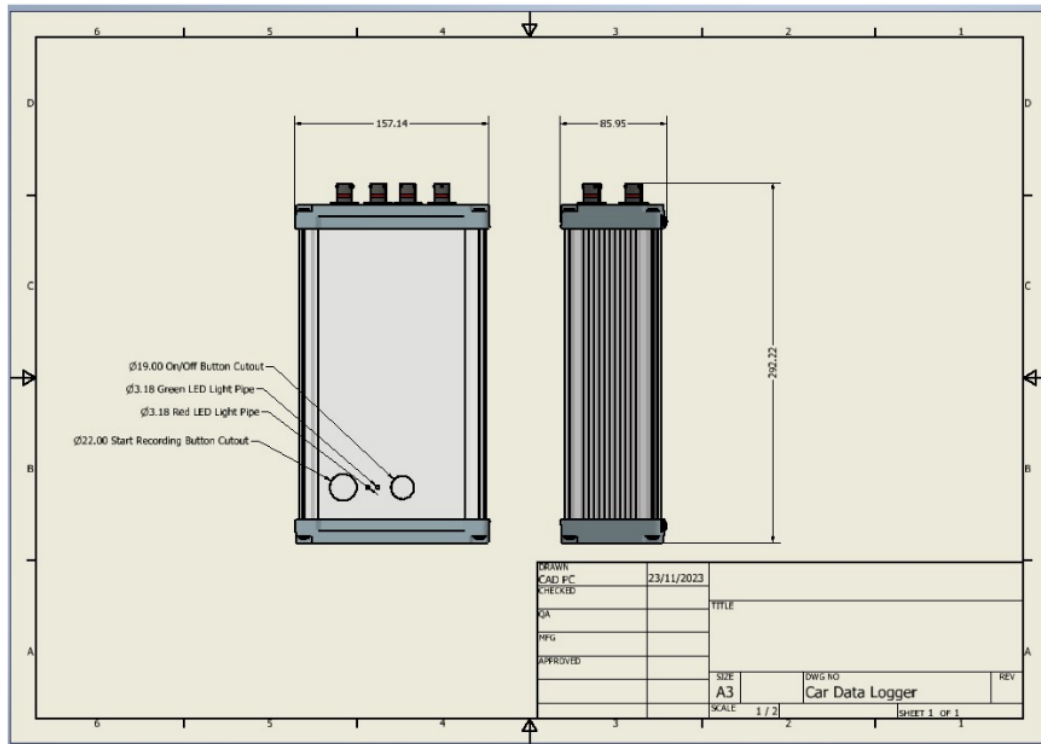


Figure 6 - Instrument Case Dimensions

8.0 Schematic and PCB Design

This section will outline the circuit design for the datalogger, including MCU schematic and interconnecting sensors. From the schematic design, a PCB layout has been created.

8.1 Power Supply Circuit

The application is intended to be battery powered. For this design, the power supply will be derived from two 3.4V, 2600mAh, 18650 Lithium-Ion batteries [44] connected in series via a PCB mounted battery holder [45], giving a nominal supply voltage of 7.4V. Power is fed to a 3 pin PCB header, PL12, where a latching On/Off push button [46] connects between the battery and positive supply rail. From the button, a 1A surface mount resettable fuse [47] protects the circuit from overvoltage. A 1N4001 Diode protects the circuit from reverse polarity. Battery voltage feeds an 800mA TO-220 package, Low drop out (LDO) linear voltage regulator, LD1117 – 5.0 [48] providing a 5.0V regulated voltage rail. 10 μ F Tantalum capacitors [49] are placed at the input and output for ripple rejection and decoupling.

The output of the first LDO cascades into a second L1117-3.3, decoupled using 10 μ F Tantalum capacitors providing the 3.3V V_{dd} rail for the circuit. Figure 7 displays the schematic diagram of the power supply rails.

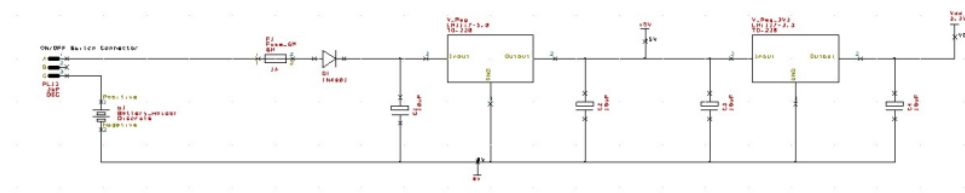


Figure 9 - Linear Power Supply Rail

8.2 Suspension Sensor Interface

Each suspension sensor signal is provided via individual 3 – Pin PCB Headers. 3.3V is fed to each potentiometer, the varying voltage signal is fed back on to pin 2. 100 Ω Current limiting resistors protect the MCU ADC Pin. 3.47V MTZJ3V3B Zener diodes [50] protect the MCU input from overvoltage transients. A sample frequency of 1KHz has been defined for the suspension signals, a low pass filter set at 500Hz is achieved using the 3.3 μ F surface mount capacitors and the 100 Ω resistor. The value for the capacitor is defined using the equation.

$$C = \frac{1}{2\pi f_c R}$$

Where $f_c = 500\text{Hz}$. And $R = 100\Omega$

Figure 8 displays one suspension pot signal interface.

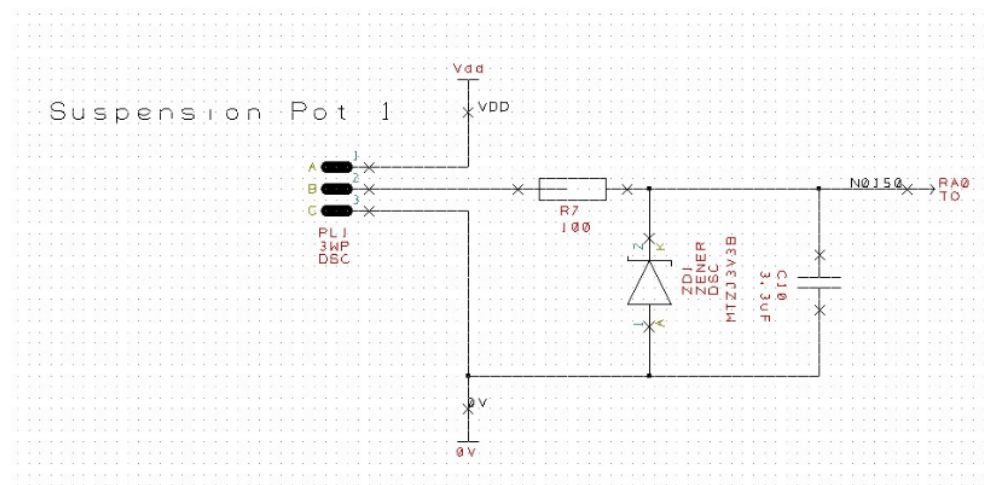


Figure 10 - Suspension Potentiometer interface

8.3 RPM and Speed Sensor Interface

The RPM and Speed sensors are powered from the 5V rail on the PCB, pulses return on pin 2 of the PCB header. The MCU will only tolerate 3.3V inputs, therefore a potential divider circuit has been used to provide a logic level between 0 and 3.3V. Resistor values have been calculated as follows.

$$V_{out} = \frac{R_2 \times V_{in}}{R_1 + R_2}$$

$$R_1 = 4.7k\Omega$$

$$V_{out} = 3.3V$$

$$V_{in} = 5V$$

Rearranging for R2;

$$R_2 = R_1 \times \frac{1}{\left(\left(\frac{V_{in}}{V_{out}}\right) - 1\right)}$$

$$R_2 = 4700 \times \frac{1}{\left(\left(\frac{5}{3.3}\right) - 1\right)}$$

$$R_2 = 9123\Omega$$

Closest equivalent resistor selected as 9.09kΩ.

The 3.47V Zener Diode provides overvoltage protection for the MCU Pin. The pulse inputs are fed into the MCU capture compare pins RD4 and RD5. Figure 9 displays the circuit.

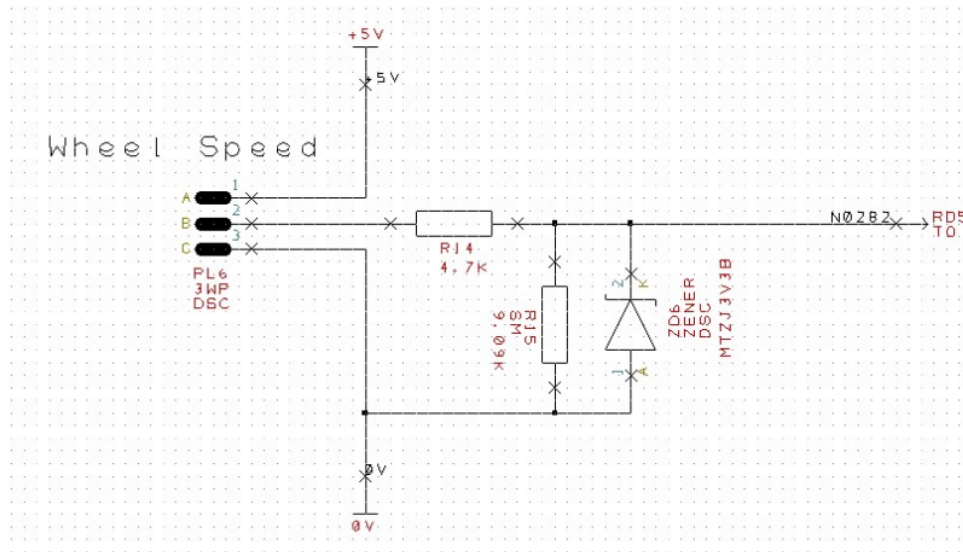


Figure 11 - Wheel speed & RPM Pulse input

8.3 Engine Temperature

Engine temperature is connected on to PL4. 3.3V is fed in to the NTC thermistor. The 10k resistor, R11, forms a potential divider, voltage on net N0285 is then fed to MCU pin RA5 corresponding to temperature change. The 100 μ F capacitor serves as a low pass filter using the impedance of the divider network to form an RC Filter, rejecting high frequency noise. Zener ZD5 serves as over voltage protection. Figure 10 displays the circuit.

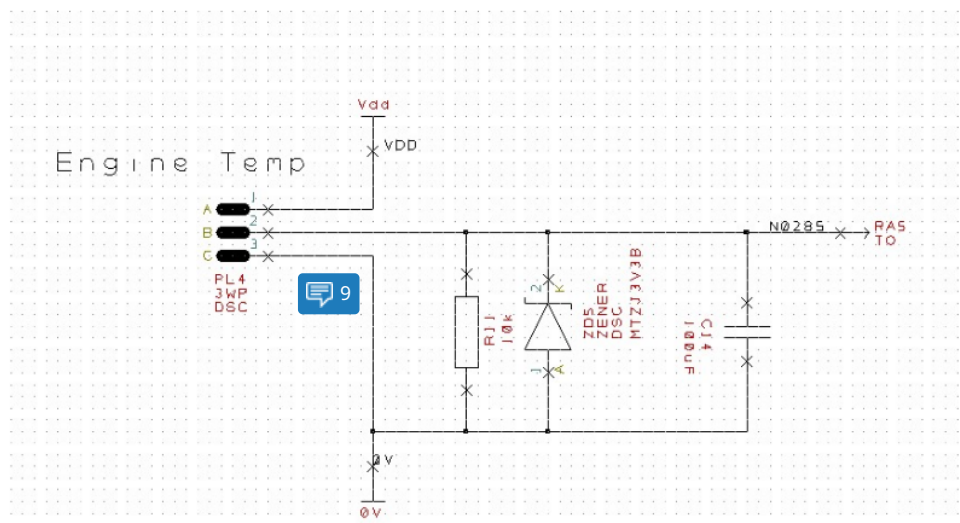


Figure 12 - Engine Temp Circuit

8.4 USB Connection

The USB connection is located on header pins PL7. This is interfaced to an external connector on the datalogger, using a custom USB lead. V_Sense is attached to a 5V tolerant MCU Pin to detect when the USB is connected. The device is wholly battery powered; this flag ensures little current is drawn from the host device. Settings for this command are described in the PIC datasheet, section "22.6 USB Power Modes". Signals D- and D+ connect to the USB input on the MCU pins. Figure 11 displays the circuit.

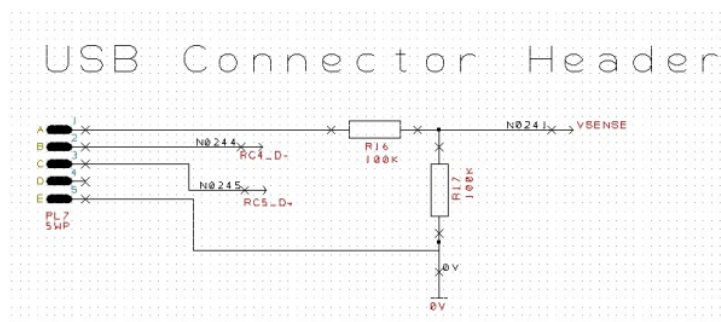


Figure 13 - USB Connection

8.5 SD Card

The SD card is connected using a surface mount holder, found in [51]. Communication is via SPI protocol, DATA0 and CMD transmit and receive data, 20k pull up resistors to Vdd ensure signal is pulled high. CLK is pulled to Vdd providing transmission timing. DATA3 is pulled to ground to enable SPI transfer mode. The holder features a physical card detect switch; this is interfaced to an MCU input pin through a current limiting resistor. The 3.3V supply is decoupled using a 100nF capacitor between Vdd and 0V. Figure 11 displays the SD card holder schematic.

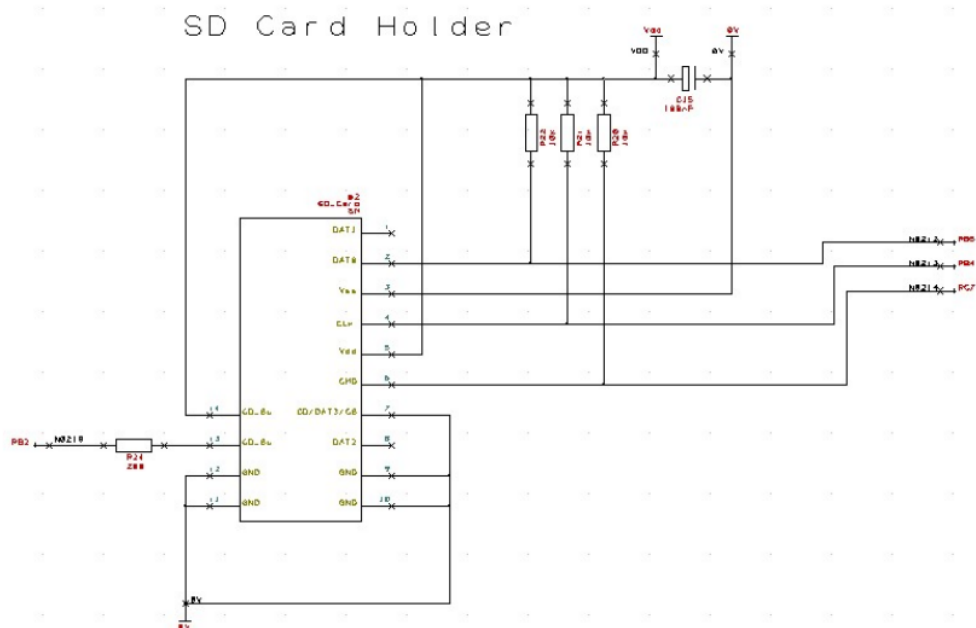


Figure 14 - SD Card Holder Interface

8.6 MCU and Gyro IC

The PIC Microcontroller is configured as per the datasheet. All supply pins are decoupled using 0.1µF 25V X7R surface mount ceramic capacitors close to the MCU pins, such as those found in [52]. The MCLR pins are interfaced through a tactile switch, this function is required a part of the in-circuit programming feature using pins on connector PL9 for program clock and program data. I/O ports are interfaced using TO/FROM ports, with their function annotated next to the Pins.

The Gyroscope module is interfaced using the I2C port on the MCU, the SCL and SDA lines are pulled to Vdd via 4.7KΩ resistors to ensure high logic levels. The IC supply is decoupled using ceramic capacitors to minimise noise. The function of the gyroscope can be found in section 4.4.

The red and green LED's are 3mm through hole mounted items [53] [54] driven directly off the MCU pins. 47Ω resistors serve as current limiting to avoid damage, calculated as follows:

- Forward voltage of red LED = 2V at a current of 30mA and
- Forward voltage of green LED = 2.2V at a current of 25mA

$$R_{LED} = \frac{(V_s - V_{LED})}{I_{LED}}$$

R red = 43.3 Ω closest size = 47 Ω .

R Green = 44 Ω closest size = 47 Ω .

Figure 13 displays the MCU circuit.

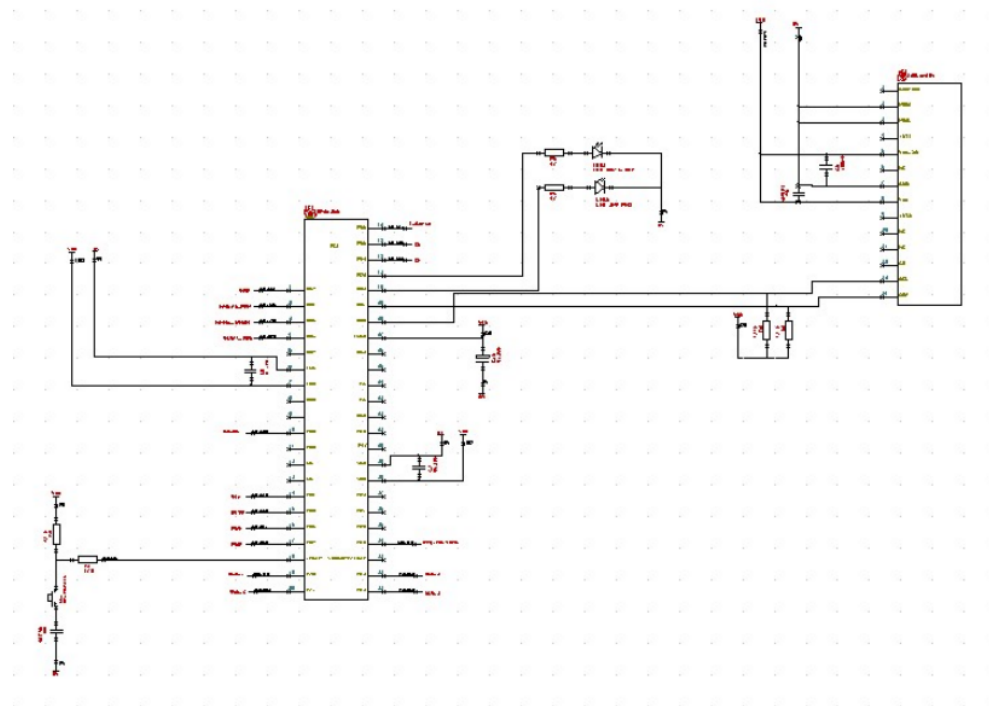


Figure 15 - MCU and Gyro Circuit

8.7 PCB Design

From the schematic, the design has been translated to a PCB layout. General considerations when completing the PCB design and component placement have been taken.

- Header pins mounted near the perimeter of the board.
- Decoupling capacitors mounted as close as reasonably practical to Vdd and GND pins of micro and related IC's and voltage regulators.
- ICSP pins placed in close proximity to the MCU with no pull up resistors or diodes, as suggested by the datasheet.
- Linear voltage regulators placed away from components that may be affected by heat as they dissipate energy.
- Gyro IC placed near the centre of the PCB for axis orientation during operation.
- Signal conditioning components placed close to their relative input header pins for fault finding on individual circuits.
- SD card holder placed at board edge for easy card removal.
- Power planes configured for Vdd and GND using copper pours on inner layers. GND copper pour used for noise immunity and heat dissipation.
- Vias used to connect nets between layers.
- PCB board sized to slide into carrier rails in the enclosure.

Figure 14 displays the PCB top Silk and figure 15 displays a 3D image of the complete board.

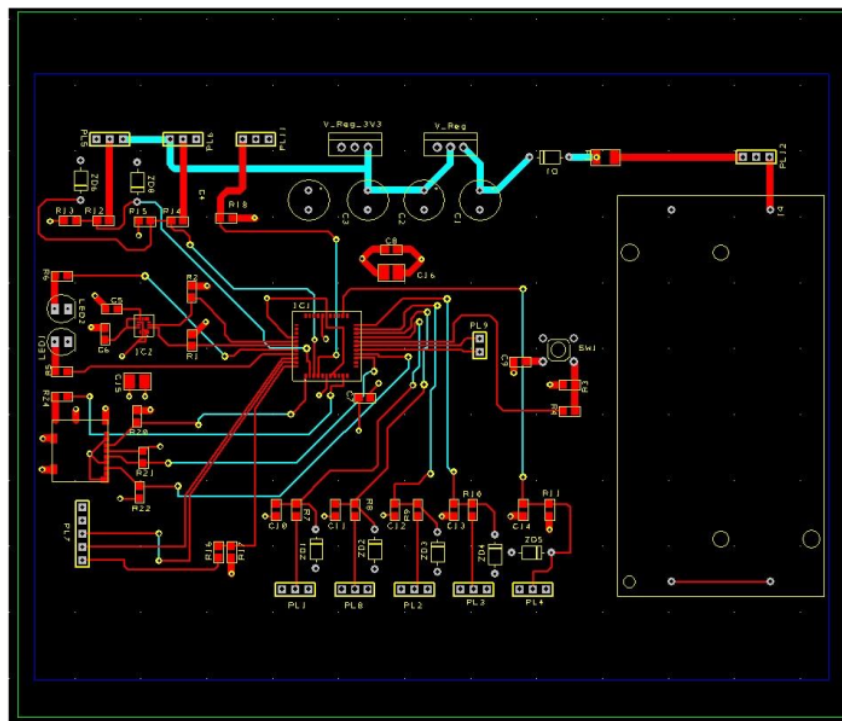


Figure 16 - PCB Top Silk

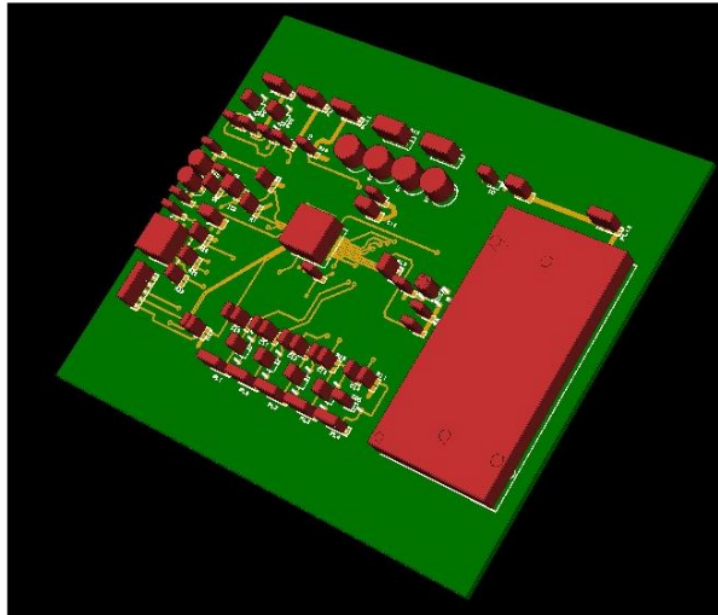


Figure 17 - 3D PCB Render

9.0 Software Design

For this application, software flow charts have been created outlining the basic logic functionality of the system. 3 charts are displayed in figures 16, 17 and 18 displaying the main mode, data acquisition mode and data download modes.

9.1 Main Configuration Mode

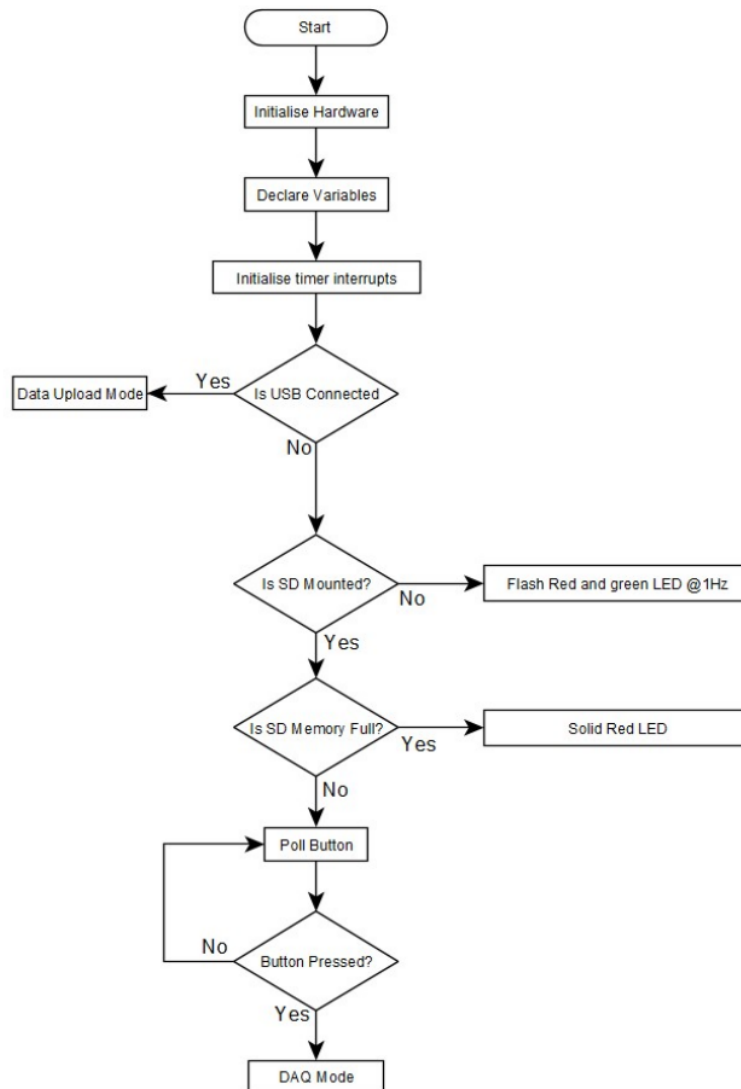


Figure 18 - Main Program Mode

9.2 Data Acquisition Mode

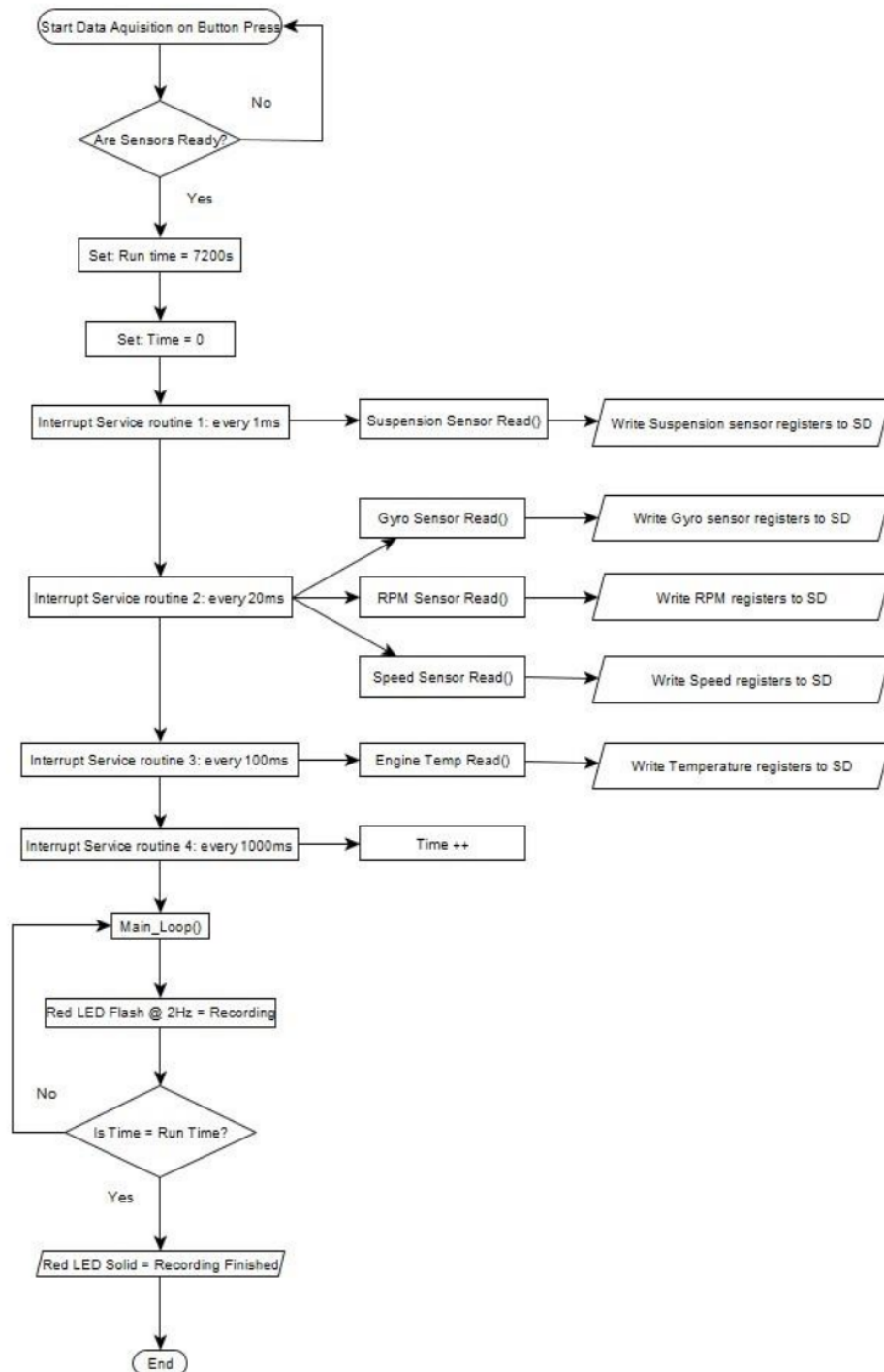


Figure 19 - Data Acquisition Mode Flow Chart

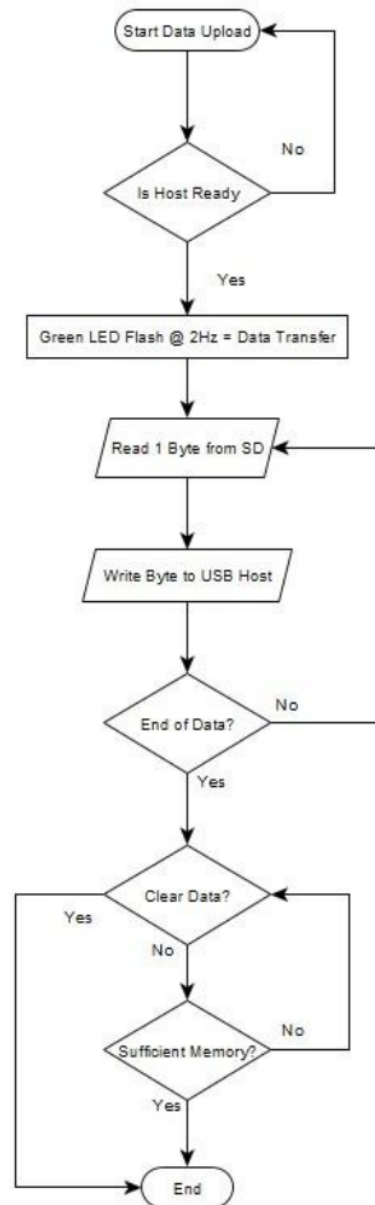


Figure 20 - Data Upload Mode

10. Bill of Materials and Prototype Cost

Table 11 displays the bill of materials and costing,

Item	Quantity	Supplier	Stock/Part Number	Cost Each	Total
MCU	1	Mouser	579-PIC18F46J50-I/PT	£ 3.90	£ 3.90
Gyro	1	Mouser	ASM330LHHXG1TR	£ 12.31	£ 12.31
Speed & RPM	2	Texense	VR-09-B	£ 197.27	£ 394.54
Temperature	1	Mouser	NTCALUG85A M6 Series	£ 2.62	£ 2.62
Suspension	4	AIM	SUS-POT-150-RJ	£ 225.00	£ 900.00
Enclosure	1	RS	906-0398	£ 151.22	£ 151.22
Logger Connectors	8	TE Connectivity	AS0008-98PN	£ 43.43	£ 347.44
Sensor Connectors	8	TE Connectivity	AS0608-98SN	£ 43.43	£ 347.44
Green LED	1	RS	228-5944	£ 0.17	£ 0.17
Red LED	1	RS	228-5916	£ 0.17	£ 0.17
Vishay 10µF Tantalum Capacitor	4	RS	250-9035	£ 1.24	£ 4.94
PCB Headers	11	RS	360-6689	£ 1.59	£ 17.48
Wire Housings	11	RS	360-6140	£ 0.55	£ 6.09
Battery	2	RS	788-7261	£ 14.98	£ 29.96
Battery Holder	1	Farnell	2533468	£ 6.66	£ 6.66
Fuse	1	Farnell	9350314	£ 0.29	£ 0.29
LM1117-3.3 V reg	1	Farnell	3122029	£ 1.31	£ 1.31
LM1117-5.0 V reg	1	Farnell		£ 1.31	£ 1.31
SD Card	1	RS	896-7560	£ 2.16	£ 2.16
PCB	1	JLCPCB		£ 5.12	£ 5.12
Resistors	22			£ 0.02	£ 0.33
Zener Diodes	7	Farnell	1N5221B	£ 2.05	£ 14.35
Push Button	1	RS	811-8480	£ 14.32	£ 14.32
Push Button (Latching)	1	RS	811-8575	£ 17.72	£ 17.72
Tactile Switch	1	Farnell	9471715	£ 0.11	£ 0.11
				£	2,281.97

Table 11 - Bill of Materials

From table 11, the approximate prototype build cost comes to £2281.97. This is comparable to units currently available, including the sensors.



11.0 Conclusion and Future Improvements

This report has covered the design of a car data acquisition system suitable for automotive testing. A schematic diagram, enclosure, connector, and PCB design have been created utilising items that can withstand harsh environments such as moisture, vibration high temperatures and dirt. The solution presented shall work in its intended environment. From section 2, some additional features that may be added to the system for future iterations are suggested below.

- Wireless connectivity – Enables users to download data, allocate sample times and view live data without a physical connection.
- Expansion connector for additional I/O. This may be connected to an I2C bus or physical analogue and digital channels to monitor features such as throttle position sensors, brake switch, intake air temperature, brake pressure.
- Dedicated thermocouple channel for measurement of exhaust temperature.
- On board battery charging. This design has not been equipped with in circuit charging, however the capacity of the specified batteries is sufficient for extended periods.
- Controller Area Network (CAN) connectivity. CAN is a rugged protocol particularly suited to automotive applications where multiple nodes are interconnected throughout a vehicle [1]. On Board GPS Module.
- Provision for PWM output to drive display instruments.



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Assignment 1 - Car Data Logger

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

72/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5



Comment 1

Excellent range of existing systems researched.

PAGE 6

PAGE 7

PAGE 8



Comment 2

Good justifications

PAGE 9



Comment 3

Good justifications

PAGE 10



Comment 4

Excellent



Comment 5

This is about the minimum speed you could sample at. At 70mph a car would cover 31.3mm in 1ms.

This would have been better if it were sampled a bit quicker



Comment 6

Good justifications



Comment 7

Excellent, thoughts given to environmental protection.



Comment 8

Excellent - thought given to enclosure layout



Comment 9

Does the thermistor need a ground connection?

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29



Comment 10

You cannot compare your build costs to other system's build costs. You only know what they retail for.

PAGE 30



Comment 11

Good suggestions

PAGE 31

PAGE 32

PAGE 33

GRADING FORM: SMU GENERIC_SMOSEY

NIALL REES

71.75

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



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

7

KNOWLEDGE & UNDERSTANDING

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



Good hardware design, although more thought is required on how the user connects to the battery for charging. Currently they have to open the box. Software structure is ok
Good clear diagrams

17

COGNITIVE & INTELLECTUAL

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



Excellent justifications given for component and connector selections, and memory sizing.
Excellent product packaging

26.25

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Very detailed costings. Excellent suggestions for next version.

14

TRANSFERABLE SKILLS

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



Can communicate professionally and, confidently in a suitable format.

Work is coherent, very fluent and is presented professionally.

7.5