DAQ-T: Columbia Formula SAE vehicle data acquisition and telemetry system

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Description:
This project is motivated by the Society of Automotive Engineers (SAE) student design competition. The premise of the event is to design, fabricate, and test a formula racecar for national competition. For the 2004 vehicle it is desired to develop a real-time data acquisition and telemetry system for use with the car. The telemetry system will be used to monitor various parameters related to the engine and chassis performance. The data will be sampled using sensors and other hardware on board the car while the car is in motion. It will be processed by an embedded microcontroller and wirelessly transmitted to a base-station in real-time where it can be further processed in software and viewed by engineers. These data can serve as testing data for the engineering team and as a performance indicator. This information can also be used to make adjustments to the car (such as to the fuel control) to alter its performance.

About the vehicle:
The vehicle is a formula style racecar built with a *space-frame* chassis powered by a 600cc motorcycle engine. For a summary of how the engine works you can consult howstuffworks.com here. The engine is controlled by an embedded electronic fuel injection (EFI) controller. The EFI controller uses various sensor data (see below) to determine how much fuel to put into the engine's combustion chamber on every cycle of the engine. On every cycle of the engine, the fuel controller processes the sensor data and uses some user specified information (namely a *base fuel map/load table*) to generate 12V pulses used to control a bank of fuel injectors. The pulse width determines the duration an injector stays open. The longer an injector stays open, the more fuel goes into the engine for combustion. For every engine speed value (aka *load site*) there is an ideal *Volumetric Efficiency* (VE) that allows the engine to achieve maximum performance. The larger the VE is, the greater the load on the engine. Maximum engine torque occurs at the highest VE load site. It is desired to maximize torque through all load sites, but there are mechanical constraints that make this difficult to do. However, the ideal can be approached through tuning the engine

Channels to be viewed:
1. Engine speed (RPM)
2. Manifold Air Pressure (MAP)
3. Manifold Air Temperature (MAT)
4. Engine Temperature
5. Air/Fuel Mixture (AF)
6. Fuel Consumption
7. Lateral G force accelerometer (multiple channels)
8. Forward Acceleration

Motivation for the data:
Items 1-5 are important parameters related to engine performance. These are the main parameters that the EFI controller uses to calculate pulse widths.

Fuel consumption is important to know for making vehicle range calculations. It is very difficult to implement mechanically, but is simple to do electronically.
Fuel Consumption = Σ (pulse width x injector flow rate x 2). The additional factor of two is needed since the engine is a *batch fire* system. Fuel consumption should be reset either by the user on demand, or upon power up of the system.

Lateral G force and acceleration is an important measure of the chassis performance. Ideally, this car should be able to sustain lateral 'g' force between 1 and 2 times the earth's gravitational attraction. G-force can be measured using IC accelerometers.

Sensor implementation on the vehicle:
1. Engine RPM is measured on the vehicle using a magnetic reluctance sensor. A steel timing wheel is attached to the crankshaft of the engine. It has pattern of 12 teeth, with one tooth missing, at a fixed spacing. As the crankshaft rotates, the teeth pass under a magnetic reluctance sensor, which causes a sinusoidal (differential) voltage signal to develop. The RPM is a function to the instantaneous frequency of this signal.

2. The MAP sensor produces a linear 0-5 V signal which is proportional to the absolute air pressure inside the air intake manifold.

3. The MAT sensor is a thermistor. The temperature is directly proportional to the conductance across the leads of the sensor.

4. The Engine Temperature sensor is a thermistor.

5. The AF sensor produces a linear 0-5V signal proportional to the air fuel mixture extrapolated from the proportion of oxygen in the exhaust header. This is a measure of the *stoichiometric efficiency* of the engine.

6. Fuel Consumption will be calculated by measuring pulse widths of the outputs to the fuel injectors from the fuel controller.

7, 8. Lateral and forward acceleration can be calculated from accelerometers mounted to the car such as the ADXL chip from Analog Devices.

Hardware implementation:
Wireless transmission will be implemented using a radio modem link from Maxstream. The radio modem interfaces to the data bus using the RS-232 protocol at a maximum data rate of 19.2 kbps and transmits data to the receiver using the 900 MHz unlicensed band.

Embedded controller option 1:
One option for hardware implementation is to use a PIC microcontroller from Microchip Technologies. One suitable chip is the PIC16C63A. The PIC16 chip is an 8-bit controller with a built in 8 channel x 8 bit Analog-to-Digital converter (ADC) and timer circuitry. This seems to be the most cost-effective, simple, and flexible hardware implementation. We would have to print our own custom board, but this will allow us to incorporate any additional analog interfacing circuitry (differential to single ended converters, buffers, etc.) on the same board.

Embedded controller option 2:
Another option is to use PC/104 components. We would need a main processor board, an analog interface board, and a serial driver board. This may not be as cost effective, but eliminates board design.

For either option, a sturdy enclosure will be needed to house the hardware. This will be machined in-house using sheet aluminum.

Software implementation:
On the receiver side, data will be processed, stored in memory, and displayed on screen either graphically or textually using software.

Glossary

- Batch fire – ignition system where two (or more) pistons are fired at the same time during one cycle. This is opposed to sequential ignition where only one piston in the engine is fired per cycle.
- Base fuel map/load table – a lookup table of user specified values that the EFI computer uses to calculate pulse widths. The user specifies how much fuel s/he would like the computer to put in under general loading conditions and the computer adjusts the value based on secondary lookup tables and sensor data. It is usually set by tuning the engine on a dynamometer.
- Soichiometric efficiency – the actual air/fuel ratio that was present in the engine during the combustion stroke.
- Volumetric efficiency (VE) – ratio of the amount of stuff in a cylinder/actual volume of cylinder. This is a measure of how much fuel the engine should burn effectively.
- Load site – the theoretical VE for a given engine speed range (usually at intervals of 50 RPM)