Board 11: Instrumentation Division: Student's Participation to Improve Formula SAE Car

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Abstract

Formula Society of Automotive Engineers (FSAE) competition provides opportunity for students to enhance their engineering design and project management skills by applying learned classroom theories in a challenging competition. The engineering design goal for teams is to develop and construct a single-seat race car for the non-professional weekend autocross racer with the best overall package of design, safety, construction, performance and cost. One such improvement has been the implementation of a telemetry and data acquisition system. Data acquisition can be further used to improve the performance of the car on the fly. A telemetry and data acquisition system allows the collection and interpretation of data from sensors, actuators and other relevant critical sub-systems with the car. The collected information enables the team to diagnose and solve issues with the car as well as programming tools, simulation tools, and other procedures used to create the working telemetry and data acquisition system. The system is based on an Arduino Mega microcontroller and its shields, which gathers and transmits data from multiple sensors that measures parameters such as suspension travel, throttle, brake position, steering angle, fuel pressure, lateral/longitude/vertical acceleration, engine coolant temperature and many more sensor values from the Engine Control Module (ECM) via CAN-BUS. Though, many of these devices were not meant to work directly with one another, the use of communication protocols allowed the system to successfully relay data back to the pit via graphical display for assessment by the participating FSAE team. An overview of the construction of the Formula SAE car, telemetry and data acquisition system, equipment and utilized software will be given. Students’ participation and involvement are key factors in the successful completion of the project. The goal of this paper is to explain the concepts and design of the system; components, sensors, actuators, relevant software, calculations, challenges, and the methodologies used to overcome the problems with the system. Students’ involvement and their participation constitutes other parts of the paper.

1.0 Introduction

The Purdue University Northwest (PNW) Formula SAE student organization, has more than 40 members. They are primarily mechanical engineering and engineering technology students, some of whom are known to remain on campus well past 3:30 a.m. in an engineering laboratory, preparing for a competition that already has paid huge dividends for several of them. The PNW students’ car is powered by a lightweight 610 cc motorcycle engine in accordance with Formula SAE Michigan regulations, and it is among the competition’s 120 registered vehicles. But the competition is more than auto racing. Crafted by college students from across the globe, the competing vehicles will be tested for endurance, speed, handling and acceleration. Before any car’s rubber hits the track, each team will compete in static categories based on design, cost and fuel efficiency. Though Purdue Northwest’s College of Engineering and Sciences, College of Technology and a wide range of local sponsors, including faculty and staff members, have been generous in their support and assistance, club members have had to raise more than $25,000 to cover manufacturing and parts costs. Purdue University Northwest competed in its first Formula SAE competition in the past year [1]. The goal of the team has since been to make significant improvements on its systems and designs. One such improvement has been the implementation of a telemetry and data acquisition system. A telemetry and data acquisition system allows for the collection and interpretation of data from sensors on the car, which enables the team to not only diagnose and solve issues with the other systems of the car, but to fine-tune and optimize the geometry of the mechanical systems as well as making suggestions to the driver based on data. A sub-team of the Purdue Northwest Formula SAE team was tasked with the creation of a telemetry and data acquisition system that fits within budgetary constraints. The team required to measure various parameters including, but not limited to: suspension travel of all 4 wheels, throttle and brake position, steering angle, fuel pressure, lateral/longitude/vertical acceleration, engine coolant temperature, and other sensor values from the engine control module (ECM). To accomplish this task, various devices, computer programming tools and software were used. The telemetry system in the car is based largely on an Arduino Mega microcontroller and compatible shields. Some devices used in this project were not necessarily made to be used together, but through the use of communication protocols such as CAN-BUS, I^2C, and SPI, the system was able to produce a reliable flow of data. The data is then transmitted via wireless communications and displayed graphically using LabView. The end result was a reliable and affordable data acquisition system. The goal of this paper is to explain the concepts and design of the system; components, sensors, and software used; the necessary calculations made; the problems that were encountered, the methodologies used to solve the problems; students' participation and safety measures taken during the construction of the system.

Figure 1 Student members of Purdue University Northwest's Formula SAE organization have spent most of the 2016-17 academic year designing and building a race car to compete May 10-13 in Formula SAE Michigan at the Michigan International Speedway

2.0 System Description and Layout

2.1 Controller

Arduino Mega 2560, a microcontroller board based on ATmega2560, controls the collection of data for the PNW telemetry system through measurements taken by the potentiometers and data logged and transmitted through the shields. The Arduino Mega 2560 is 101.52mm long, 53.3mm wide, and weighs in at 37g. The microcontroller has 54 digital input/output pins (15 provide PWM output), 16 analog input pins, 4 UARTs (hardware serial ports), a 16MHz crystal oscillator, a USB connection, a power jack, an ISCP header, and a reset button. The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts. The DC current per input/output pin is 20mA, while the DC current for the 3.3V pin is 50mA. It has a flash memory of 256KB of which 8KB is used by the bootloader. It has a static random access memory (SRAM) of 8 KB, while its read only memory (EEPROM) size is 4KB. Its clock operates at a speed of 16MHz [2]. Figure 2 shows the controller board layout as well as actual board.

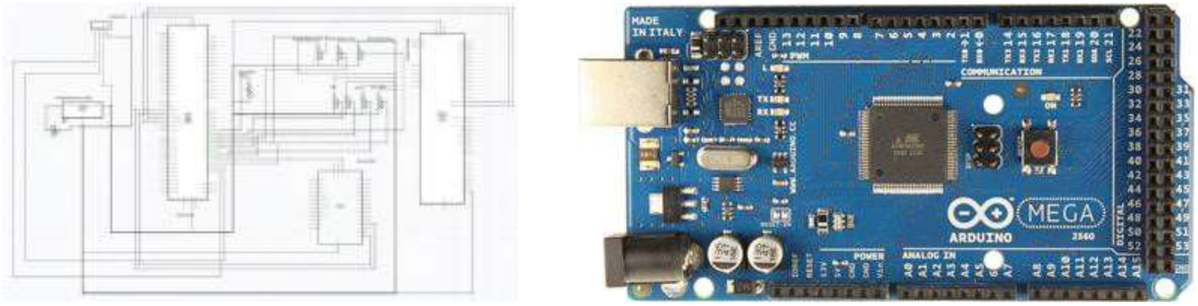

Figure 2 Conroller Layout and Actual Board

2.2 Buck Converter Voltage Regulator

A DROK 090029 regulated Buck Converter power supply, shown in Figure 3, is used to provide power to the critical data collection devices. Steady and constant voltage is very important since variation of supply voltage can cause error in data collection and transmission. This power supply can have an input of 5-32Vdc and maintain a regulated output of 0-30Vdc. It is rated at 30W with the maximum output current of 1.5A. The output voltage preset resolution is 0.1Vdc. The voltage testing accuracy is (± 1%, + 2) digits. The output is set to a constant 5Vdc which should not change as the system load changes drastically [3]**.**

Figure 3 DROK Buck Converter Voltage Regulator

2.3 CAN-BUS

The CAN-BUS shield for Arduino allows for the logging of data from the ECU of the vehicle. This data can then be stored and displayed on a screen. The CAN-BUS shield is 101.6mm long, 6.35mm tall, and 101.6mm wide as shown in Figure 4. The shield features CAN V2.0B up to 1Mb/s. It uses the Microchip MCP2515 CAN controller and the MCP 2551 transceiver. A standard 9-way sub-D, used with an OBD-II cable, enables the CAN connection. The shield has a micro-SD card holder, a serial LCD connector, and a connector for an EM506 GPS module. It has a high speed SPI Interface of 10MHz On the shield, there is a reset button, joystick menu navigation control, and two LED indicators. Power can be supplied to Arduino by the sub-D via a resettable fuse and reverse polarity protection [4].

2.4 Triple-Axis Accelerometer Breakout

The triple-axis accelerometer as shown in Figure 5 is used to determine acceleration forces in longitude, latitude, and vertical directions within the FSAE car. The accelerometer has a supply voltage of 1.95V to 3.6V. Its interface voltage is 1.6V to 3.6V. Its current consumption is 6μA to 165μA. The accelerometer possesses an I²C digital output interface that operates to 2.25MHz with a 4.7kΩ pullup. It is manufactured by Adafruit Part identification number: MMA8451QT [5].

Figure 4 Sparkfun 6479999 Shield CAN-BUS

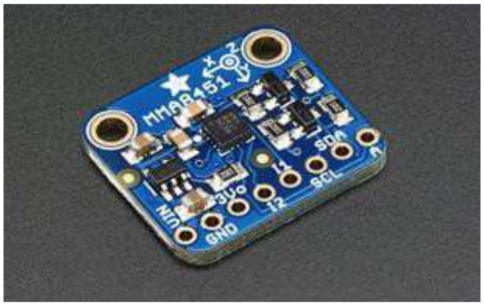

Figure 5 Triple-axis Accelerometer

2.5 UartSBee V4.0 Shield

The UartSBee V4.0 connects the XBee-Pro 900 HP RF module, to the universal serial interface of the computer (USB). The UartSBee V4.0 shield (Figure 6), connected to the XBee-Pro 900 HP RF module (Figure 7), is used to transmit and receive data collected by the Arduino Mega 2560. The data, which is stored on an SD card of the data logging shield, is also transmitted a computer running LabView software which simulates a virtual instrument panel for displaying types of data. The printed circuit board is 3.1cm by 4.1cm. Its microprocessor is FT232RL. The shield's interface is a mini-B USB and a 2.54mm pitch pin header. The communication protocols for this shield are UART, eight bit-bang inputs/outputs, and SPI. Its adapter socket is XBee compatible with a 2.0mm pitch female pin header. The shield is FTDI compatible and has a USB 2.0 compatible Serial Interface. It has 3.3V and 5V inputs/outputs and 3.3V and 5V dual power outputs. The typical and maximum input voltage is 5Vdc, and it has a current consumption of 500mA. Its minimum output voltage is 3.3Vdc, while its maximum output voltage is 5Vdc. Manufacturer: Seeed Studio Part identification number: INT110B2P [6].

Figure 6 UartSBee V4.0

Figure 7 XBee-Pro 900 HP RF module

2.6 XBee-Pro 900 HP RF Module

The XBee-Pro 900 HP RF module allows wireless connectivity to devices. It is connected to the UartSBee v4.0 shield and the RF module will receive and transmit data from the Arduino Mega 2560. The data will be stored on the SD card of the data logging shield and simultaneously transmitted to a computer running LabView software which simulates a virtual instrument panel for displaying types of data. To set up the XBee-Pro 900 HP RF module, XCTU software is used. The specified antenna used is RP-MSA. It has fifteen digital inputs/outputs, four 10-bit ADC inputs, and two PWM outputs. The RF module transmits data at a rate of 10Kbps to 200Kbps. The lower the transmit speed, the longer the range and the slower the transmission and collection of data. The higher the transmit speed, the shorter the range and the faster the transmission and collection of data. The data rate will operate in between those values for the purposes of the PNW Formula SAE vehicle. The frequency range needed is 902-928MHz. The supply voltage is 3.6Vdc. The transmit power is 250mW. Its transmit current is 215mA. Its reception current is 29mA. Its outdoor/line-of-sight range is 10Kbps or up to 9 miles (15.5 km) Manufacturer: Digi International Part identification number: 602-1299-ND [7].

2.7 Transmitting and Receiving Antennas

The transmitting antenna is mounted to the vehicle and handles the transmission of the custom bit string out of the initial processor (Arduino Mega). This 7-inch antenna is a straight whip type that requires panel mount. It has a frequency group of Ultra High Frequency (300 MHz ~ 1 GHz) and a frequency of 900MHz. The gain is 2.1dBi. (Manufacturer: Digi International Part number: 602-1658-ND).

The receiving antenna receives the custom bit string and is mounted to the trailer at the pit. This 6-inch antenna is a tilt whip type that requires a connector mount. It has a frequency group of Ultra High Frequency (300 MHz ~ 1 GHz) and a frequency of 900MHz. Its frequency range is 902MHz ~ 928MHz. The gain is 2.15dBi. These antennas are shown in Figures 8 and 9. (Manufacturer: Digi International Part number: A09-HASM-675-ND) [7].

Figure 8 Transmitting Antenna

Figure 9 Receiver Station Antenna

3.0 Sensors and Actuators

3.1 Linear and Rotary Potentiometer Sensors

The 75mm linear travel potentiometer senses the linear displacement between two points when connected directly to the points of measure. These linear potentiometers can be used for measuring damper compression or extension and steering rotation, which is measured by rack displacement. Each use requires its own specific software management. The linear otentiometers in Purdue Northwest's Formula car is utilized to measure damper compression.

The linear potentiometer is housed in aluminum casing and has a spherical bearing of Ø5 mm. Its cable is a 450mm Raychem 55A 24 AWG. Its environmental sealing is rated IP65, meaning the component is totally protected against dust ingress and limited ingress of low pressure water jets from any direction. The component best operates at a temperature range of -40˚ to 125˚. It has a mechanical life of greater than 25 million cycles and operates at a maximum speed of 10m/s. Its maximum supply voltage is 40Vdc. The component's resolution is essentially infinite. The repeatability, or retest reliability, of the component is less than or equal to 0.01mm and its independent linearity is less than or equal to ±0.5% (AiM Infotech).

Manufacturer: AiM Sportline Part identification number: X05SNLP075 [8].

The 10G rotary potentiometer kit used in Purdue Northwest's Formula SAE car includes a 10G steering potentiometer, one toothed belt, two toothed pulleys, one Allen key and one bracket kit. The rotary potentiometer, once installed and calibrated, can will measure angular displacement. For the purposes of the Formula SAE competition, the rotary potentiometer measures and collects data on the angular displacement of the steering wheel. The rotary potentiometer has a nominal resistance of 10kΩ, with a tolerance of ±5%. It has a high precision of 0.030%. Mechanically, its displacement is 1080˚per 5 or 10 laps. The component operates at a temperature range of -55˚C to 125 ˚C. At 40˚C, the power of the 10G potentiometer dissipates 2.4W. At 70˚C, it dissipates 1.5W. These potentiometers are shown in Figures 11 & 12. Manufacturer: AiM Sportline Kit identification number: X05SNST10G [9].

Figure 11 Linear Potentiometer-Diameter

Figure 12 Rotary Potentiometer - 10G

3.2 Fuel Pressure Transducer

The pressure transducer in the PNW Formula SAE car is used for the purpose of measuring fuel pressure in pounds per square inch (psi). The device weighs 119.07 grams. Its dimensions are 14.48cm x 11.68cm x 2.54cm. The recommended supply voltage is 5V, and its output voltage is approximately 0.5V – 4.5V. The working pressure range is from 0 - 0.69MPa (0- 100 psi). Its performance guarantee pressure range is from 0-3MPa (0- 435.11 psi). The sensor will burst at a pressure of 5MPa (725.19 psi) and above. Its overall accuracy is 1% full scale, and its long term stability is 0.2% full scale per year. The sensor operates at a temperature range of -40˚C – 125˚C. Manufacturer: Eyourlife Part identification number: LX_QMCQCJPSS100805 [10].

3.3 *Throttle Potentiometer*

The throttle potentiometer as shown in Figure 13, measures the displacement of the throttle. Its nominal resistance is 5kΩ linear. The potentiometer has a tolerance of ±20 % and a linearity of ±2 %. It allows an electrical displacement of up to 106°. Mechanically, the displacement is up to 130°. The sensor fatigues after 10^6 complete cycles. Its cable length is 240 mm. Manufacturer: AiM Sportline Part identification number: X05SNRP972 [11].

Figure 13 Throttle Potentiometer

4.0 Signal Processing

LabView is an electrical simulation and data display software produced by National Instruments. The software utilizes graphical code to ease the process of programming its functions. The LabView Front Panel as shown in Figure 14 is functioning as the graphical user interface for the system. It is displaying the gauges and readings of each data channel being obtained from the vehicle. LabView receives a custom string of bits over a serial COM port and imports the string into this program. There are two main panels for LabView: the Front Panel and the Block Diagram Panel.

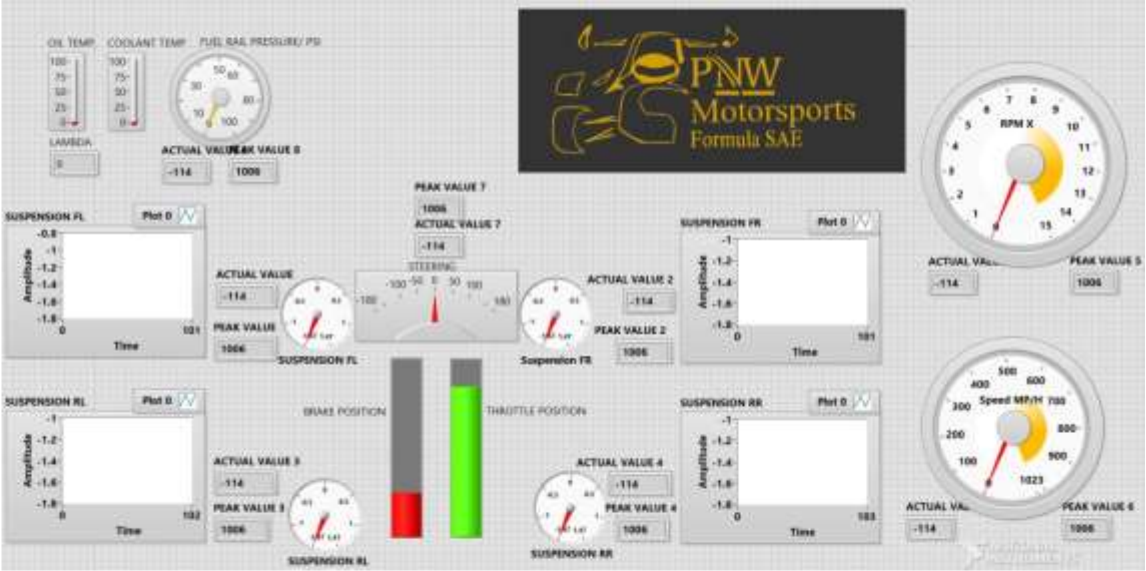

Figure 14 LabView Front Panel for Formula SAE Car

This section of the Block Diagram Panel, depicted in Figure 15, it handles all the COM port configuration and communication work. The COM port number or address is defined through this section of the graphical code, as well as the number of bits in the custom string and baud ate.

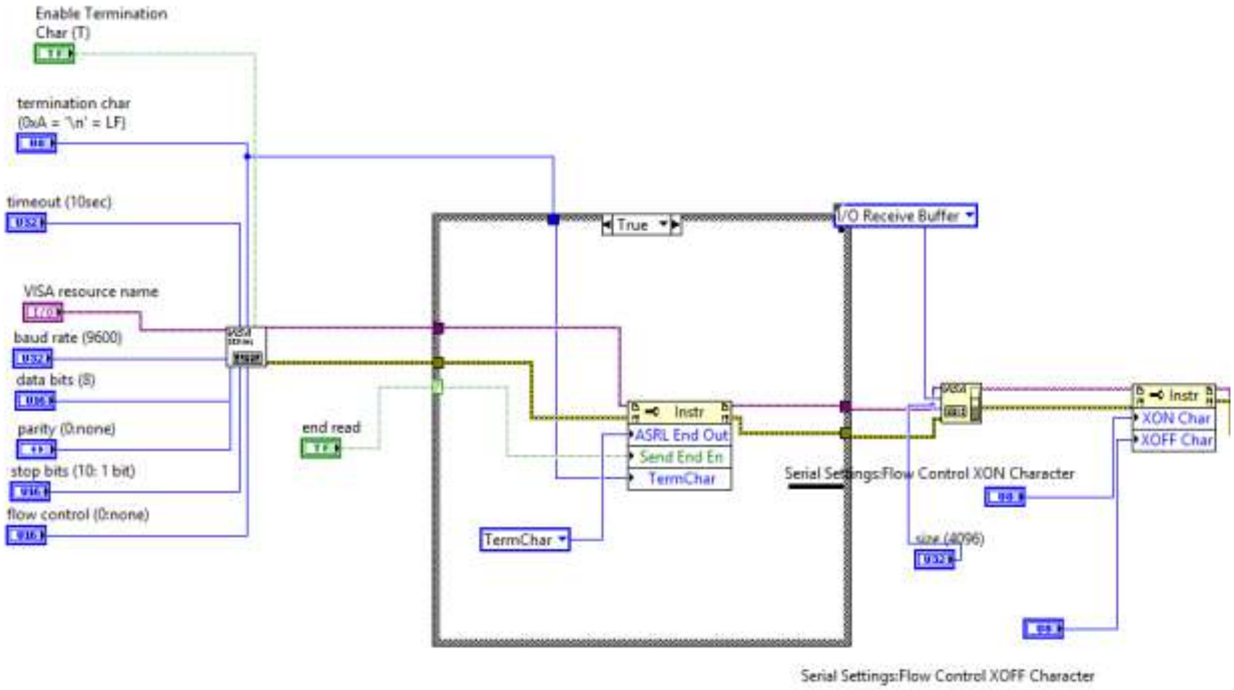

Figure 15 The Block Diagram (VISA function)

After the string is obtained through the designated COM port and the VISA function, it is later sent to be processed and dissected into its intended custom sections. Each section starts at an offset value and extends to a designated length. The offset determines how many bits from the beginning of the string shall be skipped, and the length determines the bit count of usable data for a specific channel. The string section is then processed and then sent to be displayed.

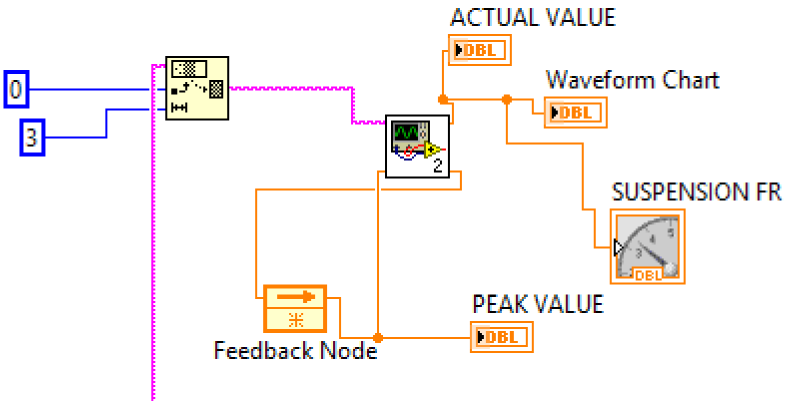

Figure 16 Diagrams for VI

Prior to displaying the string of bits, it has been mentioned that it shall be processed. The processing is carried out through the sub.VI function shown in the center of the diagram in Figure 16. The detailed explanation of a sub.VI is shown in Figure 17 below.

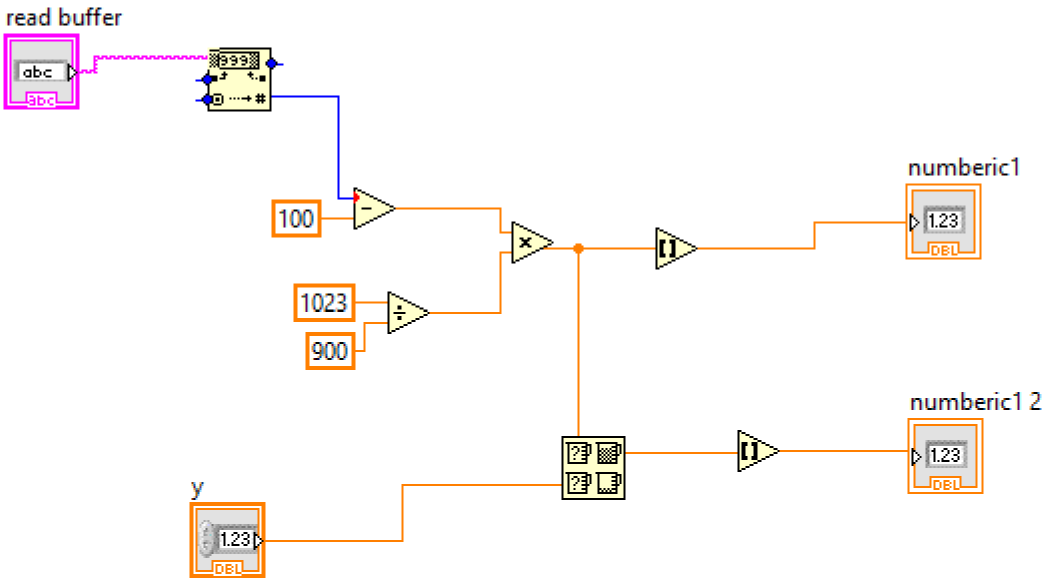

Figure 17 Detailed sub VI

5.0 Effect of Sub-Systems on overall system performance

5.1 Suspension

The design relies heavily on dynamics simulations performed on specific software. Data acquired from these simulations are then saved to be used as a reference for future designs. However, with the introduction of a data acquisition system incorporated into the FSAE car, real time data can be analyzed and collected to improve the handling of the car. Sensors such as the shock LVDTs and accelerometer display what roll gradient the car experiences when driving around sharp corners and can be adjusted for quicker or slower damper response. Based on data collected, different suspension setups can be prepared ahead of time for each dynamic event at the FSAE Michigan event. The addition of a data acquisition system can aid in verifying computer simulation designs and provide data to improve immediate handling as well as future suspension designs.

5.2 Drive Train

The data acquisition system not only helps fine-tune and adjust the mechanical systems of the vehicle, it will also allow the FSAE team to diagnose any faults that may occur especially the ones that may lead to catastrophic failures. For instance, detecting abnormally high engine temperature readings or low oil pressure readings at the right time can help avert a major engine failure.

6.0 Students Participation

The PNW student organization Formula SAE, has more than 40 members. They are primarily mechanical and technology engineering students, some of whom are known to remain on campus well past 3:30 a.m. in the laboratory, preparing for a competition that already has paid huge dividends for several of them. Despite carrying full course loads, club president and other Formula SAE members frequently spend 60+-hour per week working to turn their dream into a reality. That is when the car they have designed and assembled competes in Formula SAE at the Michigan International Speedway outside Detroit. The PNW students' car is powered by a lightweight 610 cc motorcycle engine in accordance with Formula SAE Michigan regulations, and it is among the competition's 120 registered vehicles. But the competition is more than auto racing. Crafted by college students from across the globe, the competing vehicles are tested for endurance, speed, handling and acceleration. Before any car's rubber hits the track, each team competes in static categories based on design, cost and fuel efficiency. Though, Purdue Northwest's College of Engineering and Sciences, College of Technology and a wide range of local sponsors, including faculty and staff members, have been generous in their support and assistance, club members have had to raise more than $25,000 to cover manufacturing and parts costs. But no matter how the Purdue Northwest team fares, six of its graduating team members already have become winners by accepting job offers—two with Chrysler, one with General Motors and three in non-automotive engineering capacities—in part due to their participation in the Formula SAE venture. A 22-year-old junior who has secured a summer internship with the Ford stamping plant in Chicago Heights, said. "Every time we go to a job fair and say we're part of our school's Formula SAE team, the employer tells us, 'We know all about SAE.' Additionally, 15 PNW team members are applying what they have learned from their race car-building experience to complete their senior design projects. These projects focus on such automotive topics as aerodynamics, telemetry, suspension, power train, chassis and electrical systems. These students are highly-motivated, well-organized, self-sufficient, self-organized and willing to sacrifice their time and leisure activities for this project; actually, this project has become their leisure activity.

7.0 Summary and Conclusion

In summary, the time, labor, and funds that contributed to the construction of the telemetry and data acquisition system resulted in a functional system that returns reliable data. This system allowed for the monitoring of multiple parameters of the vehicle. From the data gathered, Purdue Northwest Motorsports could make necessary adjustments to the suspension and the drive train systems as well as detect and predict mechanical failures before they occur. This system allows the team to make suggestions to the driver to improve the performance. The overall cost of this system was $1553.84. Though, slightly over budget, the creation of this system proves that a functional telemetry system can be made in-house at an affordable price with outstanding functionality. Each part and process has an average price that is used for creating the standardized cost value. Additionally, 15 PNW senior team members also are applying what they have learned from their race car-building experience to produce degree-required, PNW design projects. Their senior design projects focus on such automotive topics as aerodynamics, telemetry, suspension, power train, chassis and electrical-related issues. These students are highly-motivated, well and self-organized, self-sufficient, and willing to sacrifice their time and leisure activities for this project; actually, this project has become their leisure activity. Furthermore, the students assisted in raising over $25000 funding for the club and projects expenses.

In order to design, assemble and guarantee the functionality of the system, it needed to resolve several issues. The followings are a brief list of the challenges:

1. Devices from different manufacturers used in this project were not necessarily made to work with other vendors' products. By use of communication protocols such as CAN-BUS, I^2C, and SPI, the devices were able to communicate together and produce a reliable flow of data.
2. The RF module transmits data at a rate of 10Kbps to 200Kbps. The lower the transmit speed, the longer the range and the slower the transmission and collection of data. The higher the transmit speed, the shorter the range and the faster the transmission and collection of data. The lower data rate was used for the PNW Formula SAE vehicle. The lower rate of data transmission resulted very reliable communication link.
3. Linear and rotary potentiometers, sensors and actuators were not completely linear and the output signal was not changing linearly with the device setting for all points. A modified equation for each device needed to be found and applied.

The cost of this system is substantially lower than commercially available telemetry systems for the FSAE cars. The telemetry system worked very well and produced reliable data transmission from the car to the pit. PNW students competed in its first Formula SAE competition in the past year. The students worked hard and showed involvements for all aspects of the work, however, groups from other schools put up very good effort as well and received award for the best overall car performance, and the Formula SAE members from PNW received award for telemetry and innovation at the completion. Students are working now to improve the car performance with integrated telemetry data acquisition for this year competition.

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