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March 2, 2009

Mr. Patrick Leung
School of Engineering Science
Simon Fraser University
8888 University Drive
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Re: ENSC 440 Design Specification for a Motorcycle Racer Training Device

Dear Mr. Leung:

Monarch Technologies is committed to designing a motorcycle racer training device that will aid in improving racers' skills on the track and act as an informative device off the track. The training mechanism will be a light, robust, and rider friendly device that will detect and display the lean angle of a turn and track the position of the motorcycle which will be transmitted wirelessly to a base PC concurrently. This device will be a small mountable product with a set of LCD and LED displays to show the lean angle of the motorcycle and some keys to power the device and select modes.

The attached document, *Design Specification for a Motorcycle Racer Training Device*, explains how the functional specifications that were provided before will be fulfilled by describing the equipment and devices involved in the system, specifying our reasons for choosing our design and methods, and describing the prototype test in more detail to ensure we met all the functional requirements for the first prototype.

Monarch Technologies is a new engineering firm operating in Vancouver, BC. Our staff has a wide variety of experience ranging from software and hardware programming, and mechanical and electric circuit design. We will complete the duties associated with this project with the same diligence, competence and pride of workmanship as we have displayed on projects we have undertaken previously.

Please do not hesitate to contact us with any questions or comments about the functional specification.

Sincerely,

Ted Meredith *Dan Carter* *Freya Santos* *Helia Sharif*

Ted Meredith	Dan Carter	Freya Santos	Helia Sharif
Chief Executive Officer	Chief Technical Officer	Chief Marketing Officer	Chief Financial Officer

Enclosure: *Design Specification for a Motorcycle Racer Training Device*

Design Specification for a Motorcycle Racer Training Device

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1.8

Executive Summary

As the global population increases, so does the number of cyclists on the road. As a result, the probability of fatalities and accident for riders are at much higher! In order to reduce the probabilities and ensure a safer environment for our motorists in such fast growing society, Monarch Technologies has come up with the ideal solution which is expected to have its first prototype ready by April 2009.

The product, a motorcycle lean indicator module, is designed for racers and beginners, helping them to enhance their riding skills. In particular, the device's main operation is data acquisition which is designed to measure the lean angle during turns along with the location and time of action which will be available for analysis on a stationary PC in real-time. Another mode of operation is a simple lean detector scheme which displays the lean angle visually.

For safety reasons, in order to keep the rider's focus on the road (especially during leaning into turns), the system will display the results on the LCD screen only upon completion of the turn. Also, the LED bars located on the module will provide an estimate of lean angle for the rider to get a better understanding of their limits while riding without having to lose focus of operating the vehicle.

The module is designed to be light, cost effective, and environmentally friendly. Because motorcycles are generally very small, the product is designed to fit on the small dashboard of the bike or mount on the handlebars and not obstruct the rider's view.

The components used are ZX4120 GPS engine board for position tracking, VTI inclinometer for lean detection, AVR Butterfly microcontroller for control of the onboard module, pair of XBee PRO transceivers to wirelessly transmit the packaged GPS and lean angle data, and PC/laptop program that will display the data intuitively. The overall software algorithm of the microcontroller will be to sample GPS data, parse a specific string for longitude, latitude, and UTC time values, then read the inclinometer output for lean angle values, wrap up and forward this data to the RF transmitter to send to the receiver up to 1 mile away LOS. The RF receiver which is connected to a PC or laptop will receive this packet of data. The software program on the computer will display this data intuitively using a GPS or position plot and table of value.

Upon completion of the proof of concept, the product will be ready for the start of its production phase where it can be presented to public and motorcycle enthusiasts. Our innovative solution will significantly increase the safety of all riders, motorists, and pedestrians.

Table of Contents

List of Figures

List of Tables

Acronyms

ADC	Analog to Digital converter
CEP	Circular Error Probable
DMM	Digital Multi Meter
GPS	Global Positioning System
GUI	Graphical user interface
LCD	Liquid Crystal Display
LED	Light emitting diode
LOS	Line of Sight
MCU	Microcontroller
PC	Personal Computer
RF	Radio Frequency
RX	Receive
RoHS	Restriction of Hazardous Substances
RXD	Received Data
TX	Transmit
UART	Universal Asynchronous Receiver Transmitter
USART	Universal Synchronous Asynchronous Receiver/Transmitter
UTC	Coordinated Universal time

Glossary

NMEA – A combined electrical and data specification for communication between marine electronic devices such as echo sounder, GPS receivers and many other types of instruments. It has been defined by, and is controlled by, the U.S.-based National Marine Electronics Association.

Almanac Data – Information transmitted by each satellite on the orbits and state (health) of every satellite in the GPS constellation. Almanac data allows the GPS receiver to rapidly acquire satellites shortly after it is turned on.

Ephemeris Data – Current satellite position and timing information transmitted as part of the satellite data message. A set of ephemeris data is valid for several hours.

Baud Rate – A measure of how fast data is moving between instruments that use serial communication in baud/sec or pulses/sec.

1.0 Introduction

Monarch Technologies is working to develop a motorcycle racer training device, using lean angle measurements, GPS and wireless data transmission. This unique solution will allow riders to collect data about how they ride, in order for them to fine tune their performance and provide them with a competitive advantage over other teams and riders. Additionally, this system will have a secondary function of providing users with lean information during recreational rides through an on-dash device.

1.1 Scope

This document describes the design specifications of the functional requirements for the first prototype Monarch Technologies is developing, hereafter referred to as the Lean Detector, consisting of one onboard module and one base PC module. The purpose of the document is to describe how each functional requirement will be designed and implemented, describe the first prototype test plan, and environmental considerations in our design and system operation.

A second function of this document will be to highlight design differences that will exist between prototype and final product implementations. Time and resource limitations play less of a role in a final product, so certain design decisions maximizing time and cost savings have less of an impact and we want to make note of this.

Finally, the design requirements list within this document drive the design of the Lean Detector and will be tracked within this document

1.2 Intended Audience

This document is intended to act as a reference for the designers working on the various modules of the Lean Detector. They will be able to use this document to learn what they need to design or implement and at what state any given implementation currently is at.

Management will be able to use this document to assess current development trajectories and timelines, to make certain the features being built into the Lean Detector meet market demands. Marketing will be able to use this document to build promotional material and competitive analyses.

2.0 System Overview

As mentioned, the lean detector system will have 2 modes of operation. It will assist the hobbyist rider by providing lean information after a turn through a LCD and LED visual, or for the race rider, a more sophisticated version of the device will couple GPS tracking capability with lean information and transmit that data to software running on a PC, providing real-time information to a race crew. The crew can analyze this information to make improvements to machine and rider and increase their chances at achieving victory on the circuit.

The lean detector system has 5 main components: GPS, Inclinometer, Microcontroller (MCU), RF transceivers and PC Data Acquisition software. The onboard module consists of the GPS, Inclinometer, MCU, and RF Transmitter. Whereas the base station module contains the RF receiver and PC Software for data processing and display. A detailed block diagram of the onboard module's subcomponents and data direction are shown in Figure 1. Figure 2 is the base PC module components and data direction.

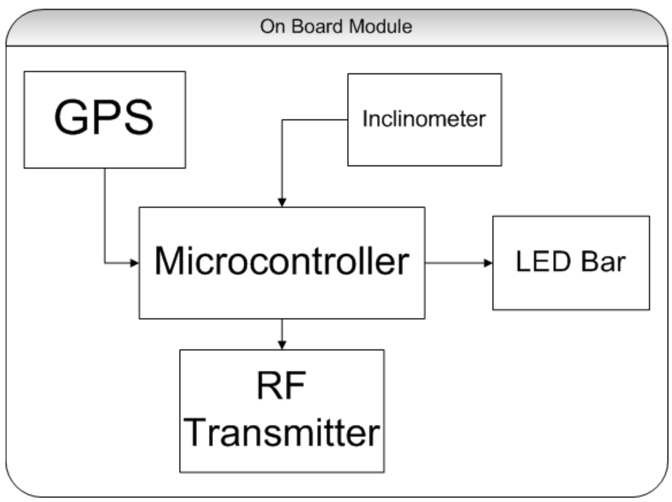


Figure 1: Onboard module

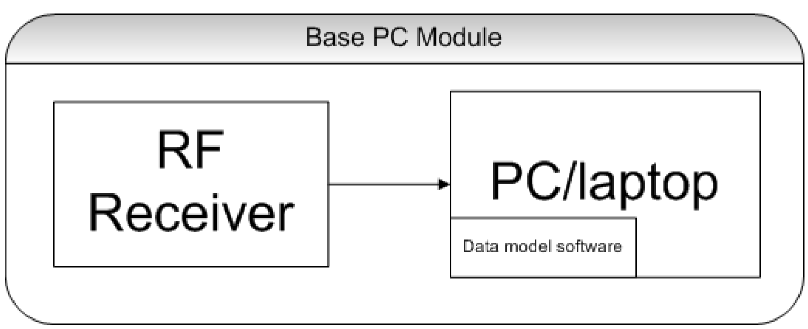


Figure 2: Base PC Module

In order to provide the lean angle of the rider during a turn, a 1D inclinometer is used to measure the incline while turning. The GPS board will track the position of the rider around the track and will be helpful in data modeling and analysis. The microcontroller gathers the lean and GPS data, parses specific data from a GPS string and converts the analog output of the inclinometer into digital output, and then packages and passes this information onto the RF transmitter. The RF transmitter will wirelessly broadcast to the RF receiver which is interfaced to a PC or laptop that contains the data processing and modeling software that will process and display the received data.

2.1 Important factors of the onboard module

We assume the environment is an outdoor race oval track, motorcycle speed will be at least 200 km/h and the onboard module is mounted on the motorcycle's handle bars, and so it is vital that the module is portable, miniature, durable, and non-obstructive to the rider. The accuracy of the GPS, sampling and processing power of the MCU, and transmit time of the RF transmitter are important considerations in providing the real time monitoring experience to users.

We acknowledge that lean detection may be complex because of the motion of the rider during a circular turn. This will be discussed in greater detail in the inclinometer section.

The GPS part must to acquire GPS signal continuously and retain high level of accuracy less than 10 meters as the most of the GPS module can reach with the current GPS technology. In order to reduce the complexity of the system implementation, the number of pins used for the GPS module should be minimized. The GPS module needs to be able to transmit the relevant GPS data such as UTC time, longitude, and latitude to the MCU.

The general performance of the RF transceivers is up to 1 mile (1500 m) which meets our first prototype requirement. This feature is dependent on being outdoors, the transceivers have line of sight, type of antenna used, and perhaps weather conditions [1].

The microcontroller is required to have ADC functionality, enough I/O ports to send data to a LED bar circuit, an LCD display, and at least one USART port to collect information from the GPS and inclinometer, and output necessary information to the RF transmitter and display information to the user via LCD and LED bar. Other considerations are low power consumption MCU and enough processing power to sample and output necessary information in less than 3 seconds.

By considering the factors above, we decided to use the ZX4120 GPS engine board with extendable active antenna, VTI SCA6IT-FAIHIG inclinometer, ATMEL's AVR Butterfly microcontroller and the XBee PRO RF transceivers with wire Antenna as the GPS, inclinometer, MCU and RF chips respectively.

3.0 ZX4120 GPS module

The GPS engine board used is the ZX4120 from Crownhill Associates Ltd. The module communicates via RS232 (TTL level) with NMEA-0183 protocol and has the following main characteristics [2]:

- Average Cold Start is in less than 45 seconds (assuming open sky, stationary)
- Low power consumption
- 16 channels "All-in-View" tracking
- On chip 4Mb flash memory
- TTL level serial ports with one for GPS receiver command message Interface, and one for RTCM-104 DGPS input
- Reacquisition Time: 0.1 seconds

- Support Standard NMEA-0183 and NEMERIX Binary protocol
- External antenna and overload protection
- Size: 25.9mm x 25.9mm x 2.7mm
- Weight: 3.4 grams
- Position accuracy of 7 meters CEP 90%
- Temperature operational range from -40° to +80° Celsius

From the list above, the important features that will aid in meeting functional requirements are low power consumption, compact size, light weight, memory and 16 channel receivers. The 16 channel receiver feature is an advantage because this shows that the GPS can connect up to 16 satellites thus providing better reading accuracy (to put things in perspective, the current norm is 12 channels) [3]. Although the position accuracy is 7 meters, one must remember that the general speed of a racer will be at least 200 km/h (~56 m/s) and can move a large range of distance in seconds. The accuracy depends on other factors like environmental conditions, signal strength, and horizontal accuracy and vertical accuracy, (in our case, vertical accuracy is expected to be poor because ZX4120's accuracy uses CEP) [4]. The flash memory stores position data, almanac and ephemeris data that will aid the GPS in acquiring satellite fix in the next power up. An image of ZX4120 is seen in Figure 3.

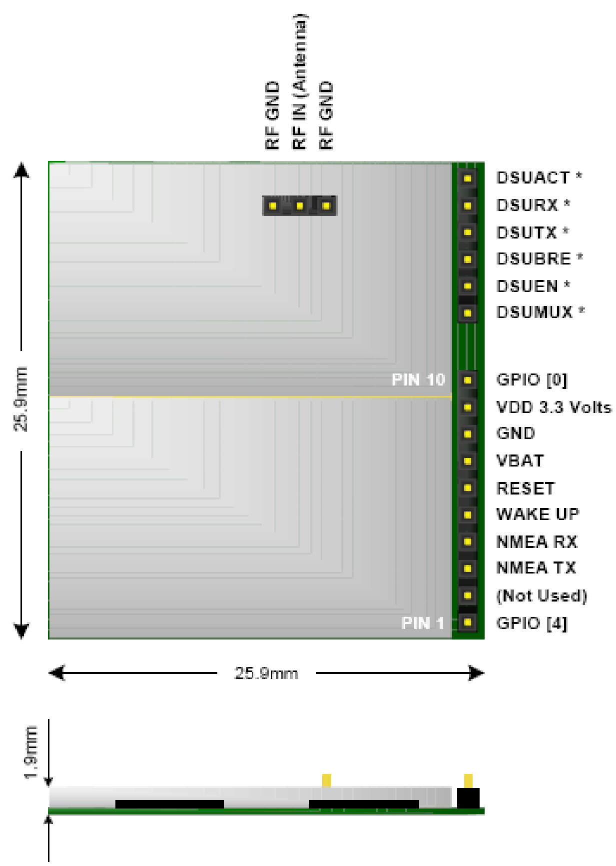


Figure 3: ZX4120 GPS module

To keep the design simple, we will be using the default settings of the GPS and read the GPS output. The neat thing about this is that the GPS in default outputs data every second and stops transmitting only when turned off. Referring to Figure 3, the top right 6 pins (pins 11-16) are used for debugging and will not be applicable to the design, testing and use of the GPS in our project. On the other hand the top 3 pins (pins 17-19) are for antenna connection which will be utilized for stronger signal strength and accuracy. Some of the pins from pins 1 to 10 will be used to read GPS data, to apply the voltage supply and set up the backup battery. A summary of pins 1-19 are outlined in Table 1.

Table 1: Pin List of Serial Interface

Pin number	Name	Description
1	GPIO	Antenna status detect
2	NC	Not connected
3	NMEA TX	NMEA Serial Data output
4	NMEA RX	NMEA Serial Data input
5	Wake up	Input; low active
6	Reset	Input; low active
7	VBat	Backup battery input (1.2 to 2 V)
8	GND	Ground
9	VDD	Power (3 to 3.6 V)
10	GPIO	satellite status indicator
11	DSUMUX	Serial / DSU select
12	DSUEN	DSU enable
13	DSUBRE	DSU break enable
14	DSUTX	DSU transmitter
15	DSURX	DSU receiver
16	DSUACT	DSU active
17	RF GND	RF Ground
18	RF IN	Antenna data input
19	RF GND	RF Ground

Of these 19 pins, we will use the following:

- Pin 3 to read the GPS data output
- Pin 6 when set to low will reset the device; ZX4120 always requires a reset at power-up or it will not start properly.
- Pin 7 to provide a backup battery input of 1.5 V; this ensures the GPS memory is powered and stabilized
- Pins 8, 17 and 19 are ground
- Pin 9 provides 3.3 V to power the GPS
- Pin 18 to collect antenna information

3.1 Interface to Antenna

The active antenna used with the ZX4120 has an operating temperature between ranges of -30 to +80°C and is built into a waterproof housing. These characteristics make the antenna suitable for outdoor testing. The antenna assists in tracking satellite fixes and increasing the signal strength. The GPS is connected to the antenna through an adapter to a BNC connector and power terminals.

3.2 Interface to PC and Microcontroller

For testing and design purposes, we need the GPS to interface to a PC so we can capture and analyze the output GPS data. In order to interface the GPS to a PC, a serial converter was required such as the Max232 [5]. The circuit diagram we followed is shown in Figure 4. Note that since we are only concerned about the output of the GPS (NMEA TX), the NMEA RX connection to the serial converter was not included in our actual circuit. Fittingly, we were able to directly connect the serial converter output to the UART RX pin of the AVR butterfly to send the data to the MCU; more detailed information on the microcontroller and GPS interface is in section 6.1.

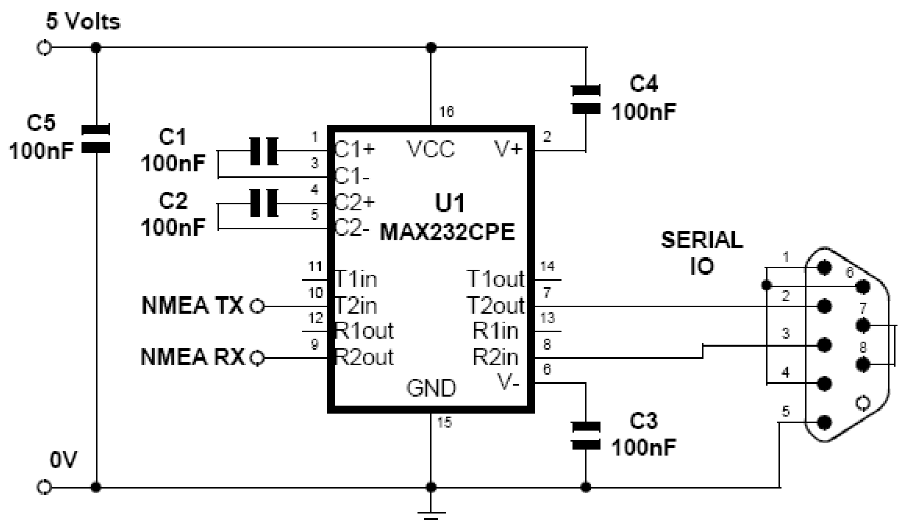


Figure 4: GPS interface to a PC using serial converter [5]

Using HyperTerminal on a PC and specifying the following serial communication default settings of the GPS, we were able to capture GPS data. Similarly, in order for the MCU to receive the GPS data, during USART initialization the serial communication had to be initialized to the default settings of the GPS. The default serial communication settings of the GPS are outlined in Table 2.

Table 2: Default serial communication settings of GPS [2]

Baud Rate	9600
Stop bit	1
Start bit	1
Parity	None
Data bits	8
Hardware flow control	none

3.3 NMEA Serial Data Output

The ZX4120 GPS NMEA protocol is capable of supporting the 8 NMEA formats, which are summarized in Table 3 [2]. ZX4120 is capable of supporting many other NMEA extensions that allows one to control the receiver while in NMEA protocol mode. As mentioned before, we intend to use the default settings of the GPS and so will not use the other NMEA extensions.

Table 3: ZX4120 NMEA Protocol [2], [6]

NMEA Message prefix	Format	Description
$GPGGA	GPS fix data	Time, position and fix type data
$GPGLL	Geographic position Latitude / Longitude	Latitude, longitude, UTC time of position fix and status
$GPGSA	GNSS DOP and actives satellites	GPS receiver operating mode, satellites used in the position solution and DOP values
$GPGSV	Satellites in view	The number of GPS satellites in view satellite ID numbers, elevation, azimuth, and SNR values
$GPRMC	Recommended minimum specific GNSS data	Signal-to-noise ratio, signal strength, frequency, and bit rate from a radio-beacon receiver
$GPVTG	Velocity and track over ground	Time, date, position, course and speed data
$GPZDA	Date and time	Course and speed information relative to the ground

The general NMEA format contains an ASCII string that starts with a '$' character and ends with a <CR><LF> sequence; NMEA standard messages start with 'GP' then a 3-letter message identifier [2]. The specific NMEA message string we're interested in is $GPGGA. This string provides the geographic position, UTC time and other additional information. Table 4 shows an example $GPGGA message string and what each field means.

Table 4: $GPGGA example and data format [2], [6]

$GPGGA,161229.487,3723.2475,N,12158.3416,W,1,07,1.0,9.0,M, ,,,0000*18			
Name	Example	Units	Description
Message ID	$GPGGA		GGA protocol header
UTC Time	161229.487		Fix time to 1ms accuracy
Latitude	3723.2475		Degrees * 100 + minutes.
N/S Indicator	N		N=north or S=south
Longitude	12158.3416		Degree * 100 + minutes.
E/W Indicator	W		E=east or W=west
Position Fix Indicator	1		0: Fix not available or invalid. 1: GPS SPS mode. Fix available.
Satellites Used	07		Number of satellites (range 0 to 16)
HDOP	1.0		Horizontal Dilution of Precision
MSL Altitude	9.0	meters	Altitude above mean seal level
Units	M	meters	
Geoid Separation	meters	meters	Separation from Geoid, can be blank.
Units	M	meters	
Age of Diff. Corr.		second	Null fields when DGPS is not used
Diff. Ref. Station ID	0000		

Checksum	*18		
<CR> <LF>			End of message termination

4.0 VTI Inclinometer

The lean sensor used in the lean detector system is a VTI SCA61T-FA1H1G 1-D angle sensor. This 8-pin chip has both digital and analog output. This chip was chosen for its high tolerance to vibration, highly accurate angle measurement and simple system integration. Given the limited number of inputs on the Butterfly board, we will use the analog output of the VTI chip.

We are following the application schematic provided by VTI in the SCA61T-FA1H1G datasheet, shown in Figure 5. Vout, the voltage created from the sensor as it measures lean angle, is connected to the ADC pin of the microcontroller.

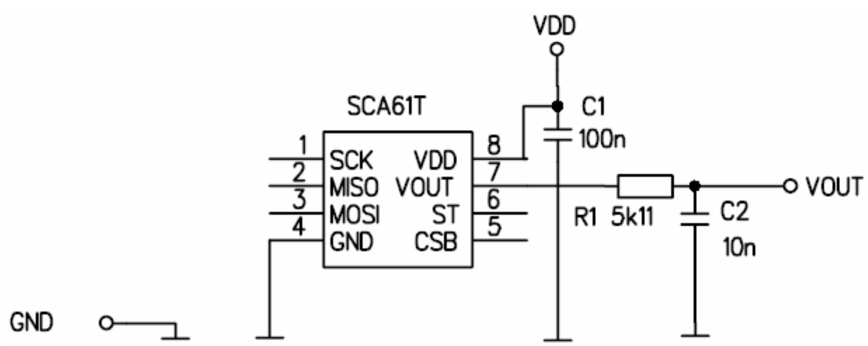


Figure 5: Analog connection and layout

Output from the lean sensor ranges from 0V to 5V, as the sensor transitions from -90° to 90°, as shown in Figure 6. The ADC port of the Butterfly board supports this entire voltage range. In reality, a motorcycle will not typically exceed 70° except in catastrophic situations (i.e. an accident), so we will typically be receiving voltages from roughly 0.75V to 4.25V, with 2.5V as the median.

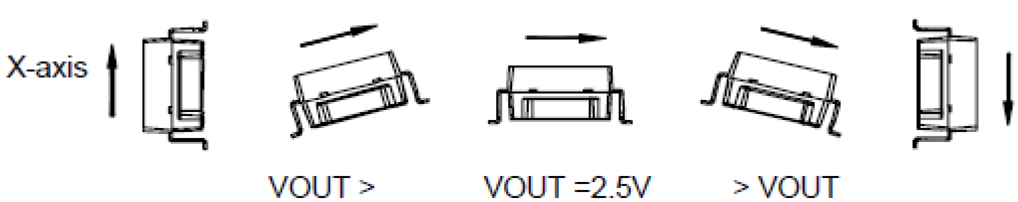


Figure 6: The measuring direction of the SCA61T

4.1 Precession research

Precession refers to a change in the direction of the axis of a rotating object and applies to a motorcycle maneuvering through a turn (see Figure 7). Forces and torques act on the system of machine and rider as it undergoes this change, so one question that testing will have to answer will be how accurately the VTI sensor collects angle measurements on a motorcycle performing a turn. There are many forces and torques that act on this system as it negotiates a turn. What is uncertain to the designers at this point is whether the sensor values collected will be impacted by the gravitational, inertial, frictional, and ground support forces acting on the system.

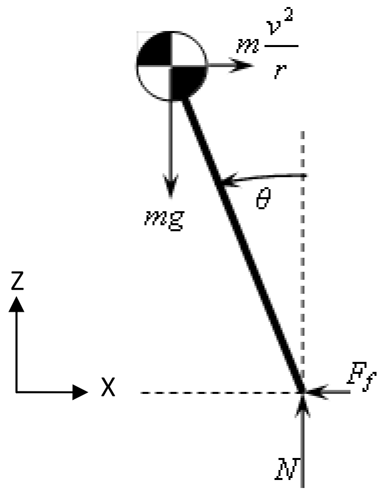


Figure 7: Bike lean forces [7]

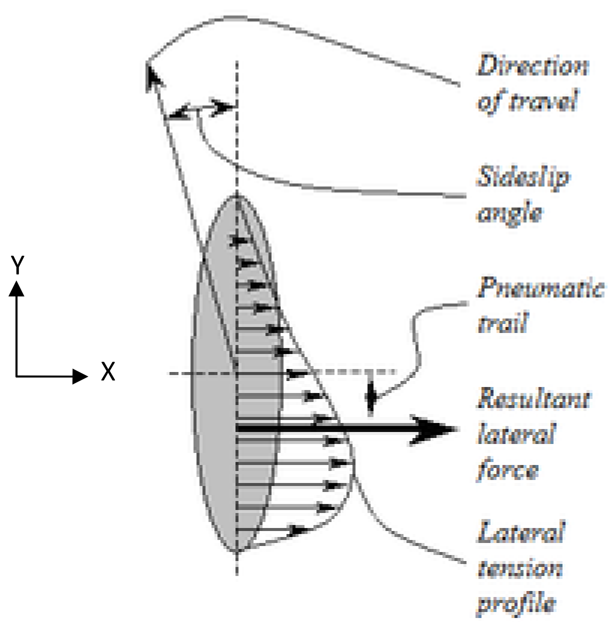


Figure 8: Diagram of tire interaction with the ground [8]

In particular, testing will have to determine what, if any, the gyroscopic moments of the tires exhibit on the inclinometer (see Figure 8). This figure depicts the variation in forces a tire experiences as it undergoes a turn. As this rotating subsystem is unbalanced (i.e. turned), these forces translate through the forks of the motorcycle and act upon the entire system of rider and machine. A direct impact of this translation of forces is that the rider must exert greater force on the handlebars in order lean the motorcycle more to turn through tighter turns.

Using real-world testing, the behaviour of the inclinometer can be characterized and if forces acting on the motorcycle also affect the inclinometer, a compensation factor can be applied within the MCU.

5.0 Wireless Module

Because the product is intended to produce results in real-time, wireless communication was a necessity. For the transmission of data, efficiency, large range of coverage, low power usage, and cost effectiveness were some of the criteria that were kept into consideration during the selection process of the wireless module.

One option that was considered was the transmission of data efficiently and easily via the bluetooth method; unfortunately soon after, we learned that the range coverage for bluetooth modules is very low (only a few feet away). As a result, the bluetooth method was an option since the product is intended for racers to be using on racetracks of 400m of perimeter.

Other solutions consisted of using the mobile networks but that would require us to reach a negotiation with the wireless communication networks (i.e. Rogers, Telus, Fido, etc.) so that we can hack into their system and run our own program for the transmission of data via cell phones. That could take months to bypass the legal paper work and hence it was also not an option for such a short timeline to explore further. It is important to note that another issue with using the mobile networks would be the expensive monthly fee, which would not fit into our budget.

In the end, the best solution was the wireless transmission method via wireless chips. The selected chips are known as XBee Pro Transceivers which can transmit and receive data! Even though XBee Pro is a new module in the market and hence won't have as much documentation and support services available for users, Monarch Technologies still chose it as their primary wireless transmission device. The reason for choosing the XBee Pro Chips versus other wireless chips such as its predecessors, the ZigBee modules, XBee Pro covers a larger range of frequency at a low-cost and low-power. Another reason for choosing the chip is because it is optimized for use in US, Canada, and Europe, which can be the main target audience of our product once it hits the production line!

The module is compliant with IEEE 802.15.4 and operates within the ISM 2.4 GHz frequency band. The product satisfies the industrial temperature rating of -40° C to 85° C. The XBee Pro Transceiver chip is designed to operate up to 100 m (within the line of sight), at a range of 2.8-3.4 V power supply, and function at a baud rate of 9600 bps [9]. The following figures demonstrate the schematic of the chips according to the pins:

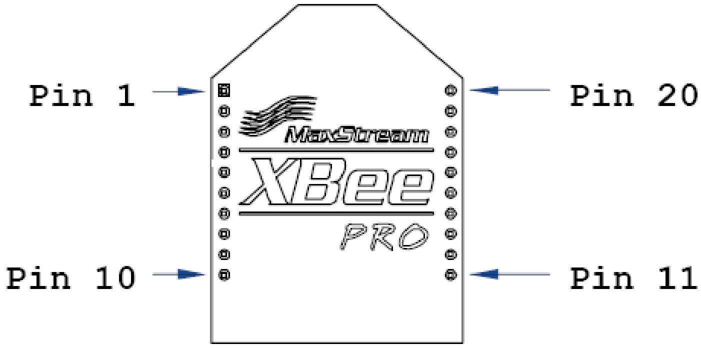


Figure 9: XBee PRO module pin layout [1]

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / **CONFIG**	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	**RESET**	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	**CTS** / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / **SLEEP**	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	**RTS** / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

Figure 10: Pin Assignments for the XBee PRO module [1]

The wireless communication between the stationary computer and the motorcycle is achieved via a pair of XBee Pro chips: one acting as a transmitter and the other as the receiver module; along with that, in order to connect the chip to a PC, an LTI 1081 serial converter is required to be connected to be connected to the receiver chip.

LTI 1081 serial converter offers great results for even noisy environments of the real world where uncertainties of components affect the final outcome of the results. The driver outputs of the serial converter are protected against overload and can be shorted to ±30V. A benefit for using this model, is that it won't load the signal line when in shut down mode. The figure bellow demonstrates the schematic of the LTI1081 used for the project:

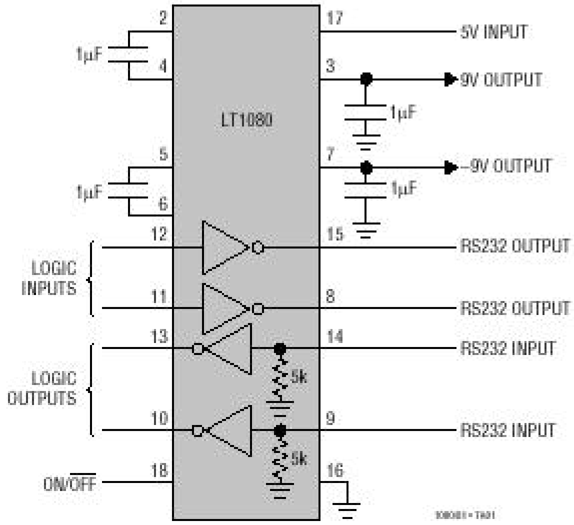


Figure 19: Schematic of LTI 1081 [10]

Clearly the schematic above, we can see that the output pins (pin 8 and 15) are to required to be connected to the RS232 serial cable's input, and that pin 2 (Dout) of the receiver chip will be connected to the input of LTI 1081's pin 11.

5.1 XBee PRO interface with PC

As mentioned in the previous section, the wireless chips are connected to the PC via a Schematic below is an example of how the receiver chip is connected to the serial converter (LTI 1081) and the RS232 serial cable which is connected to the PC.

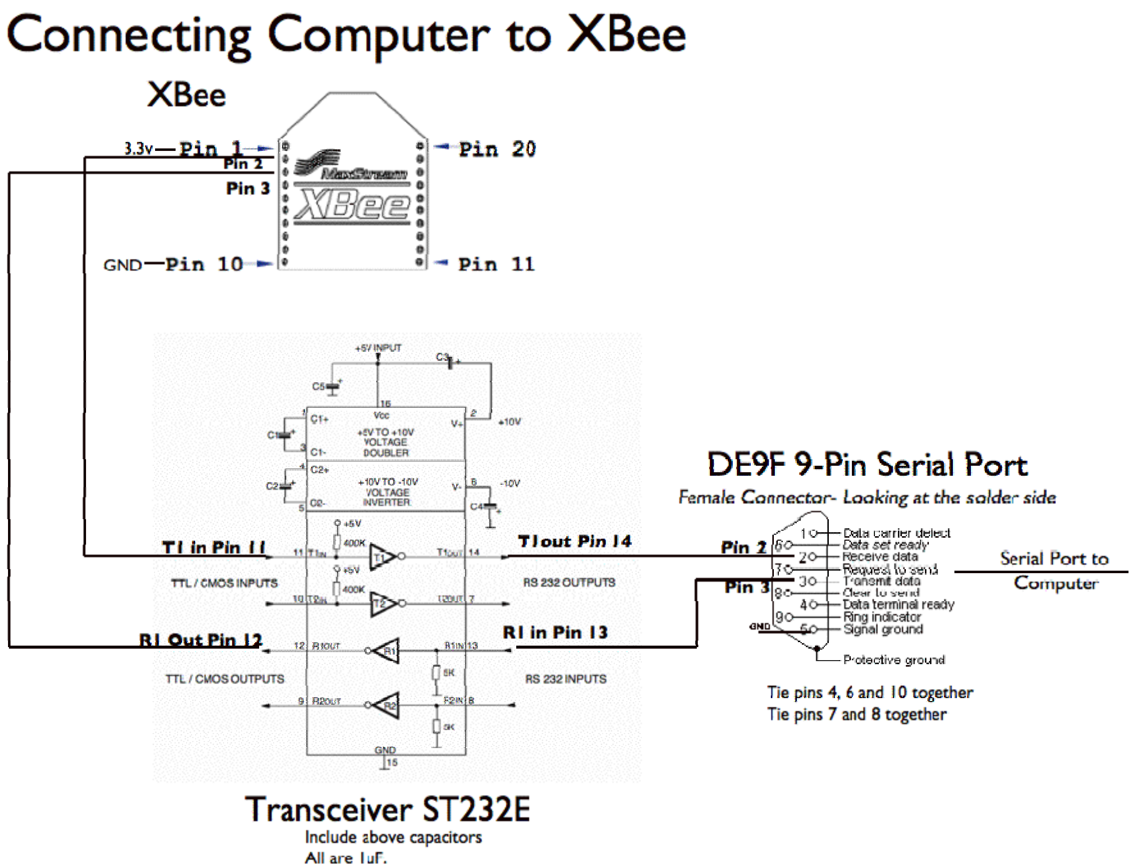


Figure 11: Schematic example to interface XBee to Computer [11]

MaxStream's X-CTU software is used for setting up a connection between the wireless modules and the PC. Please note that the X-CTU software is only compatible with windows operating system. Once the module is installed onto the computer, it can run on the PC (while connected to one of the transceiver chips) via a serial port. Following figure demonstrates the initialization of the wireless chips with the PC:

Figure 12: Setting up the wireless chips to communicate with the PC [12]

Although other terminal programs might work as well, X-CTU software was designed specifically for the XBee series where it is capable of testing signal strength, reading, saving, and writing the state of the module, and updating firmware too! A free copy of the X-CTU software can be downloaded from X-CTU Site (http://www.oricomtech.com/download.htm).

6.0 AVR Butterfly Microcontroller

We have chosen to utilize the AVR Butterfly Microcontroller from ATMEL because of many of its small size (smaller than a business card!), low energy consumption, and high efficiency. The microcontroller uses the ATmega169 and contains many versatile features; the relevant functions to our project are:

- 100 segment LCD Display
- 4Mbit Data flash
- 32kHz oscillator for RTC
- 4-way directional button (joystick)
- Access to peripherals through header connectors
- RS-232 Level Converter
- Analog Voltage Reading 0-5V (8 channel, 10 bit ADC)

Figure shows where on the butterfly MCU the relevant connections are to other components of our system. The LCD display's purpose will be to display to the user which mode of operation it is in and to display the maximum lean angle after each turn or sample. During testing, the LCD is significantly useful for cases when we cannot connect the butterfly to a PC to view data due to the USART being used elsewhere. The joystick will be used by users to choose the mode of operation. The USART port is used for serial communication and so the GPS and RF transmitter will be connected to the USART receive and transmit pins, respectively. The analog output of the inclinometer will be connected to the ADC port.

Lastly, the LED bar circuit will be powered by the Port D pins. The butterfly MCU will be supplied a power of +3.3 V.

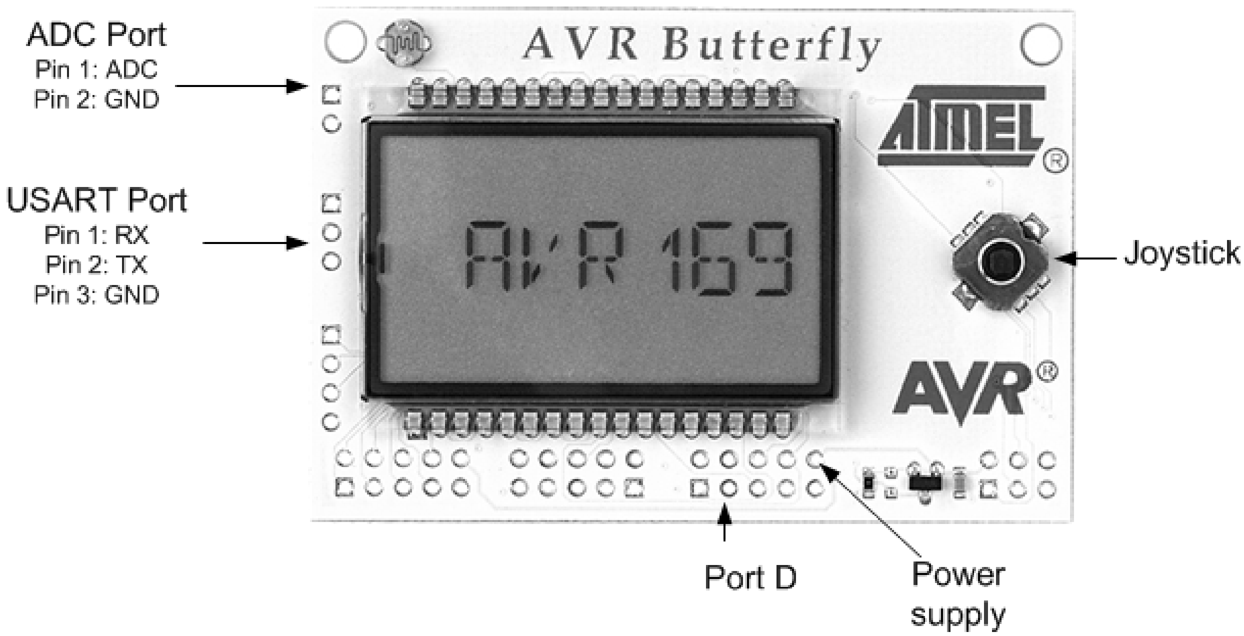


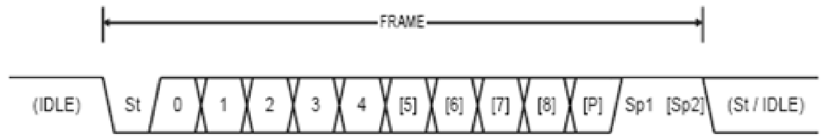
Figure 13: Diagram of the ports used in the AVR butterfly to communicate with other components

The software used to program the butterfly MCU is AVR Studio (which is free and available to the public), and the program language used is C. There are various terminal programs that can be utilized to directly talk to the butterfly such as HyperTerminal and Bray's Terminal.

6.1 Microcontroller and GPS

The ZX4120 GPS data is received via serial communication through the USART RX pin of the AVR butterfly. As part of the initialization routines, the USART is initialized and the baud rate and frame format are set, USART related interrupts are enabled, and transmitter (because of the RF transmitter) and receiver are enabled. The frame formats are initialized to asynchronous normal mode, no parity, 8 data bits, and 1 stop bit so this ensures that serial communication between AVR butterfly and GPS is consistent and eliminates any information provided by the GPS.

The frame format used by the USART is set by the UCSZ2:0, UPM1:0 and USBS bits in UCSRB and UCSRC [13]. It is integral to note that the receiver and transmitter use the same setting! Figure 12 displays a sample frame set. Data bits are transmitted "upside down and backwards", meaning you read from right to left and inverted logic is used.



St	Start bit, always low.
(n)	Data bits (0 to 8).
P	Parity bit. Can be odd or even.
Sp	Stop bit, always high.
IDLE	No transfers on the communication line (RxD or TxD). An IDLE line must be high.

Figure 12: Frame set [13]

To set the baud rate, we have to update the UBRR registers of the MCU. The AVR Butterfly's system oscillator clock frequency is 2 MHz. Since we want the baud rate to be 9600, then the UBRR registers are set to the result of the following equation:

Equation 1: UBRR equation given baud rate and oscillator clock frequency [13]

$$UBRR = \frac{f_{OSC}}{16BAUD} - 1$$

Where: f_{osc} = oscillator frequency
Baud = 9600

The receiver begins data reception when there is a valid start bit detected and the contents are shifted into the Receiver shift register until the first stop bit is detected [13]. Then the contents are moved to the receive buffer which enables the Receive Complete (RXC) flag. Checking for this high flag tells us that a GPS message string is in the receive buffer. Our algorithm checks for the completion flag, then checks the message prefix; if it's not "GPGGA" then the MCU will keep on reading data from the GPS until the message prefix starts with "GPGGA". Once the MCU has ensured that a "GPGGA" message string is in the receiver buffer then it parses the string and extracts the relevant information: longitude, latitude, and UTC time.

6.2 Microcontroller and Inclinometer

The MCU will poll the ADC port on the Butterfly every 100ms to collect a lean angle sample. Lean angle samples will be stored sequentially until a GPS sample is collected, at which point lean angle and GPS data will be transmitted to the PC base station via the wireless transceiver. Each voltage sample collected by the MCU will be converted to an angle measurement using the calculation in Equation 2,

Equation 2: Angle conversion

$$\alpha = \arcsin\left(\frac{V_{out} - Offset}{Sensitivity}\right)$$

where α represents the numerical angle value and V_{out} is the voltage collected at the ADC port. The offset is a constant, calculated as half the V_{DD} value, while the sensitivity is also a given constant (35mV/° for the FA1H1G used in this device). A reading of 2.5V at the ADC port will be interpreted as 0°.

Given that this device will only be operated within a subset of the entire range (±70°), this equation will work for all calculations. Accuracy will be important in race situations, so at least 3 decimal places should be maintained. Output to the LCD of the onboard system, though, may be truncated to its whole number value (e.g. 30.112 would be displayed as 30 on the LCD).

6.3 LED bar circuit

In addition to using the LCD to display lean angles to the user, rather than force the user to read a value off the LCD display, an LED light bar will also be lit to indicate lean direction and magnitude. 2 LED bars, each consisting of 5 lights, will be placed side by side to create a row of 10 lights. At start, lights 5 and 6 will be lit to indicate the system is powered. As the motorcycle leans to the left, lights 4 though to 1 will be lit as the angle magnitude increases. As the motorcycle leans to the right, lights 7 through 10 will be lit in the same fashion. This simple display takes the least amount of attention away from the rider and provides the safest output with which to inform the rider.

Port D of the MCU is connected to an 8-bit data register and fittingly, Port D has 8 pins. Each pin will be connected to a corresponding LED light (8 pins, 8 LEDs). The circuit diagram of Port D and the LED circuit is shown in Figure 13.

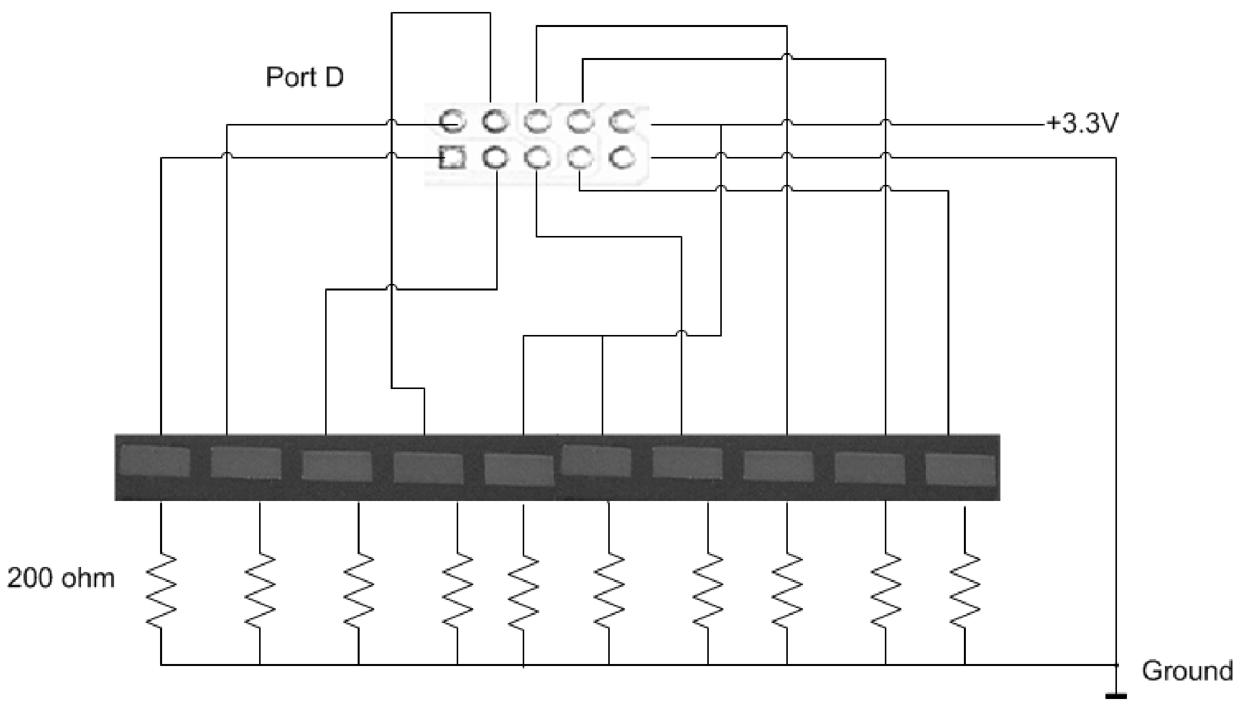


Figure 13: Circuit diagram of LED bar circuit

Referring to Figure 13, the algorithm of the LED bar function will comprise of if-else statements comparing the digital output of the inclinometer (this is the result after doing analog to digital conversion) to specific constants (i.e.: 0, 0.75, 1.5, 2.25, 2.75, 3.5, 4.25, 5 volts)to determine the "range" of lean. For instance, if the voltage output is 1 V, then 2 LED lights to the left will turn on because 1V is less than 1.5, but more than 0.75.

6.4 Microcontroller and XBee Pro

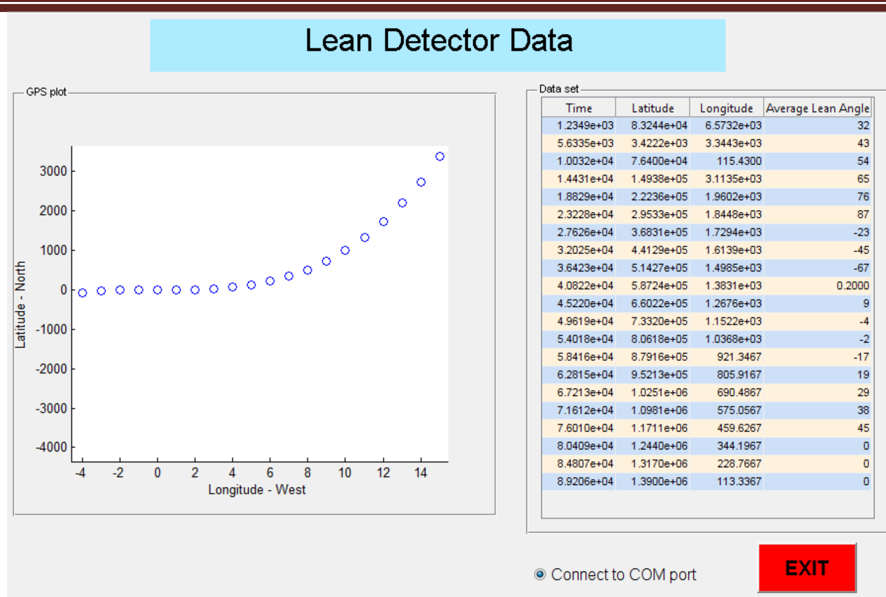
The XBee transmitter will be connected to the USART TX pin directly. This is possible because the voltage levels of both the XBee PRO and the Butterfly are 3.3 V, so there is no serial level converter required in between. An integral factor is that the USART is initialized to the correct serial communication settings that fit both the GPS *and* the XBee PRO. This is not an issue because the GPS and XBee PRO have a baud rate of 9600, stop bit is high, 8 data bits and no parity [1], [2].

Another important consideration is the USART RX and TX uses the same data register, UDR, which stores the data to be transmitted or data that was just received, this means that receiving and transmitting cannot occur at the same time. We will use an interrupt driven algorithm to ensure that transmitting and receiving data does not happen at the same time.

A data transmission is initiated by loading the transmit buffer with the data to be transmitted. The CPU can load the transmit buffer by writing to the UDR location [13]. The buffered data in the transmit buffer will be moved to the Shift Register when the transmit buffer is empty [13]. The Transmit Complete flag (TCX) is set to one when the entire data frame has been sent and the buffer is empty.

7.0 PC Data Model Software

We plan to create a simple program and GUI through MATLAB or Java and to be used on a HP laptop. The program is expected to form a connection with the RF receiver-USB port, read the data being received by the RF chip, and updates the GUI with plots and tables in real time with the incoming information. A feature that we would like to include in the software is an image of a vertical bar that leans from left to right and reflects the direction and magnitude of the rider leans in real time. To provide a visual example, Figure 14 is a Matlab GUI with a GPS plot and data table, one of our colleagues has been working on.



Time	Latitude	Longitude	Average Lean Angle
1.2349e+03	8.3244e+04	6.5732e+03	32
5.6335e+03	3.4222e+03	3.3443e+03	43
1.0032e+04	7.6400e+04	115.4300	54
1.4431e+04	1.4938e+05	3.1135e+03	65
1.8829e+04	2.2236e+05	1.9602e+03	76
2.3228e+04	2.9533e+05	1.8448e+03	87
2.7626e+04	3.6831e+05	1.7294e+03	-23
3.2025e+04	4.4129e+05	1.6139e+03	-45
3.6423e+04	5.1427e+05	1.4985e+03	-67
4.0822e+04	5.8724e+05	1.3831e+03	0.2000
4.5220e+04	6.6022e+05	1.2676e+03	9
4.9619e+04	7.3320e+05	1.1522e+03	-4
5.4018e+04	8.0618e+05	1.0368e+03	-2
5.8416e+04	8.7916e+05	921.3467	-17
6.2815e+04	9.5213e+05	805.9167	19
6.7213e+04	1.0251e+06	690.4867	29
7.1612e+04	1.0981e+06	575.0567	38
7.6010e+04	1.1711e+06	459.6267	45
8.0409e+04	1.2440e+06	344.1967	0
8.4807e+04	1.3170e+06	228.7667	0
8.9206e+04	1.3900e+06	113.3367	0

Figure 14: PC Data model sample

Other requirements of the software will be to calculate the lean angle from the inclinometer voltage reading and displaying this in the table (using equation 2 in section 6.2). The longitude and latitude values will be utilized in the plot to and to show the rider's position on the track with the corresponding lean angle values.

8.0 Prototype Test Plan

It is important to have a test platform to inspect the software, firmware, and mechanics of the device as much as possible! The performance of the device can be verified by ensuring that it is in agreement with the theoretical calculations. By calibrating the results of the collected data individually in the lab to agree with the theoretical calculations, a tremendous amount of time will be saved while testing the module as a whole. The initial testing phase, where the inclinometer's performance is observed in the lab, will be able to cover a larger range of possibilities where it will be much more difficult to regenerate via the motorcycle without harming the vehicle or the test driver.

By testing the electrical components of the design, we can ensure that the components will accomplish the safety standards and will not harm the motorcyclist. In order to do so, by changing the currents and voltages up to the limits, we can observe the collected data to make sure that it meets the safety standards set by Transport Canada, IEEE, etc.

To ensure a crash-free system, the firmware will be rigorously tested in the lab so that in no situation the system will fail to respond. By testing the device in noisy environments, we can minimize our uncertainties that would result in unexpected outcomes (the output should remain the same irrespective of the applied noise).

The test plan consists of various testing phases to ensure that each and every component will deliver at its peak. The motorcycle lean indicator will be tested in the lab via DMM (Digital Multi-Meter) and the supply voltage to ensure that the data collected from the inclinometer is accurate and calibrated with respect to the specified lean angle. Upon the completion of testing phase of the inclinometer's calibration-testing phase in the lab, the component will be attached to a motorcycle for additional testing purposes.

The system integration will be tested to ensure that all components will work together seamlessly. In particular, the GPS component and the wireless module will be both required to be tested in an open environment. Once all the components are mounted onto the motorcycle and the stationary laptop is setup accordingly, the vehicle will be racing down the designated racetracks within the line of sight. At this stage, the data will be continuously collected from the GPS and Inclinometer units and transmitted via the wireless transmitter chips to the stationary laptop. The MCU's data retention will be tested by transmitting data at a higher than expected rate to ensure that it will not fail during runtime. The focus of the test will be on making sure that the location indicated by the GPS unit is accurate and that the collected data will be investigated in real time. It is important to ensure that the centripetal force does not affect the collected data by the inclinometer; hence, comparing the results collected in the lab with the ones collected on the racetrack, one can guarantee that the information collected will match the desired outcome.

It is important to note that, in order to ensure the reliability of the collected data, by close examining a series of sampled data on MATLAB, we can make certain that the program will run as smoothly as possible once the testing phase in real time takes place.

Once all the components have passed their individually tests, the team will instigate the Beta testing phase where the module as a whole will be tested at various angles and speeds on the racetrack to ensure that the data from the components will not interfere with one another.

At the production line's testing phase, the model's packaging will be tested to make sure that all the material (i.e. manuals, warranty documents, the module, etc) is included in the package and that the method of packaging will protect the module during the shipping and handling. Because the module will be sold globally, it needs to guarantee that it will operate error free in various conditions such as a range of temperatures and humidity.

9.0 Environment Considerations

The team will ensure that the production module will not only be safe in all aspects (i.e. can hold up incase of impact or accidents), but also that the material will be recyclable such that it won't harm the environment in any way and all components shall be built with components that satisfy RoHS. As well as satisfy the following regulations:

- CSA standardCAN/CSA-C108.4-M92 (R2003)—Limits and methods of measurement of radio interference characteristics of vehicles, motorboats, and spark-ignited engine-driven devices
- CAN/CSA-C108.6-M91 (R2003)—Limits and methods of measurement of electromagnetic disturbance characteristics of industrial, scientific, and medical (ISM) radio-frequency equipment
- FCC CFR 47 Part 15 Subsection 247 - RADIO FREQUENCY DEVICES Radiated Emission Limits
- General Requirements for All Electronic Products which Emit Radiation (21 CFR § 1000 - 1005)

10.0 Conclusion

This document explains our design method, relevant circuit schematics, and features of the subcomponents that will be used to build the Lean Detector system. Specifically, we have chosen to use:

- ZX4120 GPS for position tracking and its low power consumption, miniature size and high sensitivity will prove to be an advantage
- VTI inclinometer for lean detection of the motorcycle during turns and its resistance to strong mechanical vibration is an asset
- XBee PRO transceivers for wireless transmission and its outdoor range of 1 mile makes XBee PRO the ideal candidate because of the outdoor environment range
- AVR Butterfly microcontroller for control of sampling and sending data and its small size, LCD component, and support for ADC and USART function is a benefit to our design.

We will follow the specifications to provide a convenient unit that can sense the lean angle and GPS data of its motorcycle host during a turn and then wirelessly transmit this data to a base PC in real time. The first prototype system will be completed April 2009.

11.0 References

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