EMBEDDED DATA ACQUISITION PLATFORM FOR SURFACE MEASUREMENTS ON WET CONCRETE

by

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Abstract

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The early detection of roughness over newly poured wet concrete allows correction of the surface before concrete is hardened. The smoothness of the wet concrete can be monitored and controlled at an early stage saving additional effort and cost. The goal of this research study is to examine the techniques to detect the roughness over the surface of wet cement concrete. A sliding profiler is one of the techniques which estimates profile of the surface based on the bumps detected on freshly poured concrete.

This thesis focuses on the data acquired by the sliding profiler using a different measurement sensor and Intel Galileo Board. A tri-axis accelerometer is used as the measurement sensor with Embedded Linux to compute the data acquired by accelerometer on the Intel Galileo Development Board. The resulting computed data will provide the profile measurement of the surface of wet concrete. Also, it has a much lighter measurement platform along with a lighter processing unit. As it can also be used as a general purpose data acquisition system, the sliding profiler provides estimated IRI measurements that can be used for identifying bumps.

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Chapter 1

Introduction

According to recent studies conducted by National Quality Initiative (NQI) - National Highway User Survey and the Federal Highway Administration (FHWA) Infrastructure Survey it was found that public traveling on roads consider traffic flow, safety and pavement conditions as three most important improvement areas for highways. Pavement conditions mainly provide the ride quality based on which the users will consider the roads as good if they are smoother to ride on. If the smoothness of the road is checked during the pavement construction it ensures safer road conditions and the roads last longer. The vehicle is more controlled on smoother roads reducing driver fatigue. Also, as the smooth roads last longer, it requires lesser maintenance which in turn saves cost for the contractors. Due to these factors Texas Department of Transportation assigns high priority for the smoothness of pavements during construction introducing smoothness specifications.

1.1 Background

During the pavement construction using cement concrete the contractors have to take the responsibility of cost and effort to correct any deficiencies in the pavement if it does not follow the existing specifications. A device which can detect these deficiencies early would allow the contractors to repair them even before the concrete hardens resulting in lesser investment of effort and cost while maintain a superior riding pavement. This research for designing a device as a solution was conducted with Texas Department of Transportation (TxDOT) in Project 0-4385. [1]

While the University of Texas at Arlington (UTA) and the Texas Transportation Institute (TTI) of Texas A&M University were working with TxDOT Project 0-4385 a sliding profiler device was proposed as a solution for the need of inadequate smoothness on the wet concrete.

1.2 Problem Definition

The objective of this project is to have an improved portable device identifying the smoothness of the surface of wet cement concrete with the use of the Intel Galileo Development Board along with the use of tri-axial accelerometer sensor and distance encoder which will allow early detection of bumps on wet concrete. Rectification of these bumps before the hardening of concrete will help the contractors save on cost. It also helps saving the effort and additional material that will be used to rectify the bumps over the concrete surface.

1.3 Approach

The hardware and software platforms are chosen to fulfill the recommended improvements suggested while the research was conducted. The primary objective is to use the Intel Galileo Microcontroller Board (32 – bit Intel Platinum-class System on a chip) to enhance the sliding profiler along with the use of sensing devices like a tri-axial accelerometer and distance encoder.

The Intel Galileo Board includes an accessible SD card reader which allows to booting through SD card with the “Bigger” Linux image. The computation for real time data which will further generate a profile for bump detection will run on this board using the Linux distribution. The Intel Galileo Board provides an Ethernet connection and a mini PCI Express (mPCIe) slot allowing mPCIe modules to be connected with wireless connectivity (WiFi, Bluetooth). This can be utilized for communication with a computer and acquire real time data sensed by the accelerometer to measure the smoothness.

This information will then be used to provide the roughness area so that the concrete can be corrected right away if any roughness is detected.

The sensor device includes an accelerometer which is interfaced with the Intel Galileo Board. It calculates the tilt from the accelerations over the wet surface of the concrete measuring the smoothness of the concrete. If any roughness exists it can be detected using the data generated by the accelerometer and wirelessly communicated. This will allow the contractors to correct the roughness while the concrete is pliable.

Figure 1-1 Sliding Profiler over wet concrete surface

Chapter 2

Platform Components

2.1 Intel Galileo Board

The Galileo is an Arduino-certified development board based on microcontroller Intel Quark SoC X1000 (32-Bit) which is a single core, single-thread Atom processor supporting embedded systems. It operates at speeds up to 400MHz. It includes an integrated Real Time Clock (RTC), 512 Kbyte embedded SRAM, 256 MByte DRAM, micro SD Card slot. The development board also features various industrial standard I/O interfaces like 10/100 MBit Ethernet, High speed UART, RS-232 serial port. The board is compatible with Arduino shield ecosystem operating at either 3.3V or 5V. The Intel Galileo Development Board provides simple and cost effective development environment for students. [6]

Figure 2-1 Intel Galileo (Front View) [6]

Figure 2-2 Intel Galileo (Back View) [6]

The Galileo board works on a 400MHz 32-bit Intel Pentium instruction set architecture (ISA)-compatible processor which includes 16 KBytes L1 cache, 512 KBytes of on-die embedded SRAM. It includes a single core running on single thread with constant speed. It provides 10/100 Ethernet Connector, USB 2.0 Host and Client connector. The board has 8 MBytes Legacy SPI flash (stores firmware/boot loader) and latest sketch (between 256 Kbytes and 512 KBytes). Also, it is facilitated with optional micro SD card slot for storage upto 32 GBytes. [6]

Table 2-1 Electrical summary [6]

Input Voltage (recommended)	5V
Input Voltage (limits)	5V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
Total DC Output Current on all I/O lines	80 mA
DC Current for 3.3V Pin	800 mA
DC Current for 5V Pin	800 mA

2.2 Accelerometer

A 3-axis accelerometer is used for detection of bumps by using it to sense the inclination over the wet concrete surface. The data will be computed on the basis of the gravity vector and its projection on the axes of the accelerometer resulting in the data specifying bumps based on the inclinations over the wet surface.

The accelerometer measures acceleration caused by motion and when the accelerometer is still it senses acceleration due to the gravitational pull. The linear acceleration aligned in the direction of the axis of an accelerometer gives positive output from the accelerometer. If the accelerometer is placed on a flat surface with appropriate orientation it will measure 9.81 m/s^2, the g-force (1G). For this research the g-force value used will be 980.1 cm/s^2 as the distance covered is calculated in centimeters. If the 3-axis accelerometer is used, the G component is distributed among those 3 axes. The acceleration is then a vector quantity which senses the orientation if the surface it is moving. They are broadly of digital and analog types. The digital accelerometers are easy to interface with the Development Board as they have similar supply voltage range as Analog Devices ADXL345 is a digital 3-axis accelerometer with high resolution measurement with up to ±16g. Its high resolution (3.9 mG/LSB) enables the measurement of inclination changes less than 1.0°.

Figure 2-3 ADXL345 – LC Electronics

2.3 Distance Encoder

The distance encoder is a sensor with mechanical motion generating digital signals to measure distance. There are two types of encoders: Linear encoder and rotary encoder. A linear encoder is based on motion along a path, while a rotary encoder is based on rotational motion. The encoder is also categorized with its output as incremental encoder and absolute encoder. An incremental encoder generates pulses determining position and speed while absolute encoder generates unique bit configurations for different positions directly. The resolution of incremental encoders is frequently described in terms of cycles per revolution (CPR). Cycles per revolution are the number of output pulses per complete revolution of the encoder shaft. The sliding profiler is attached with the rotary distance encoder. It is attached with a rotating object to measure the distance by generating digital signals based on rotations. [5]

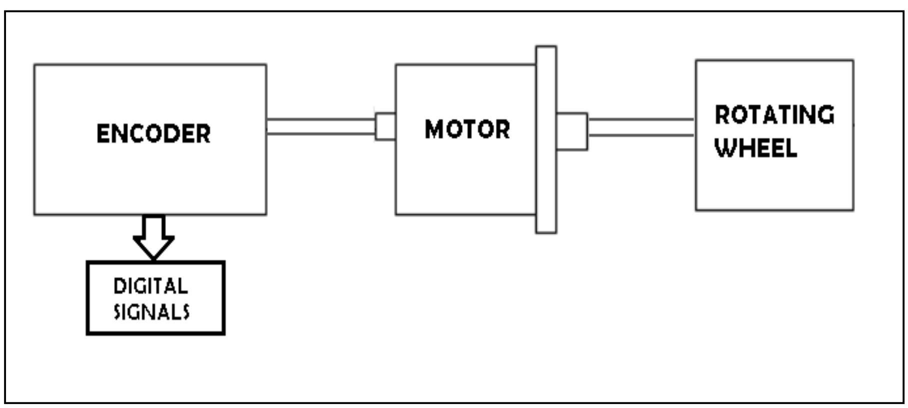

Figure 2-4 Rotary Distance Encoder Block Diagram

The encoder produces signals based on the rotation of the shaft. The shaft is attached to a rotating object which moves in reference with the distance to be measured. The attached rotating wheel for the sliding profiler has radius of 5.4cms.

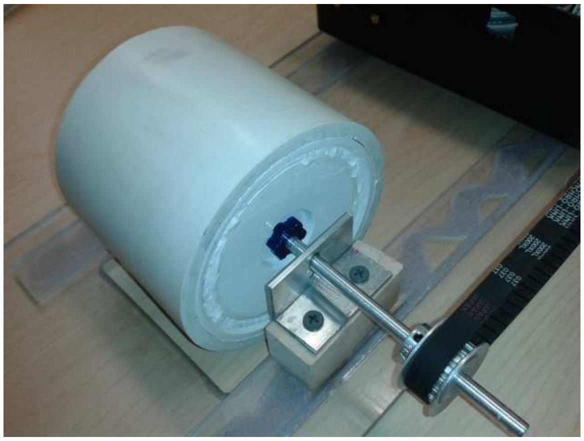

Figure 2-5 Rotating wheel attached to distance encoder

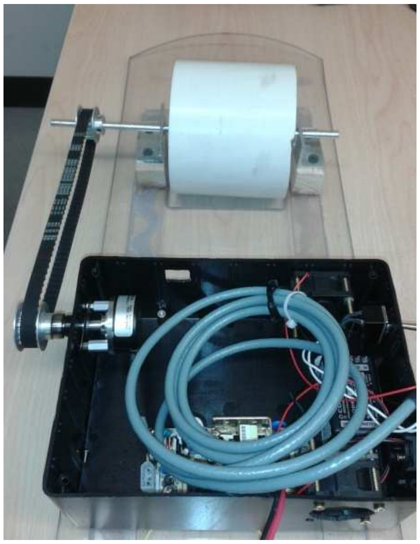

Figure 2-6 Distance Encoder attached with the rotating wheel inside sliding profiler

The Accu coder 15H is used in the sliding profiler. The model 15H is Hollow Bore and provides a high performance feedback solution in a low profile package. The Model 15 utilizes an integral bearing set, and an innovative flexible mounting system which is much more tolerant to axial misalignment or radial shaft run-out than "Kit" encoders. The easily installed slotted flex mounts provide 20 or 30 degrees of rotational adjustment for commutation or index pulse timing. For brushless servo motor applications, three 120° electrical phase tracks can provide up to 12 pole commutation feedback, while an optional 100° C and 120° C temperature options allow servo motors to operate at higher power outputs and duty cycles. [3]

Figure 2-7 Accu Coder 15H

Table 2-2 Accu coder specifications

Input Voltage (recommended)	5V
Output Types	Open Collector, Pull-Up, Line Driver, Push-Pull
Resolution	Up to 2540 CPR
Bore Sizes	Range from 0.1875" to 0.375", 5 mm to 10 mm
Sealing	Up to IP64 available

Chapter 3

Processing System

3.1 Interfacing components with the system

The Intel Galileo Development Board, distance encoder and accelerometer are mounted on a light weight plastic board. The board is used as profiling carriage as it leaves lesser markings on the wet concrete then the original sliding profiler module. It also provides a broader area to hold the boards and encoder. [2]

Figure 3-1 Sliding profiler

3.1.1 Block Diagram

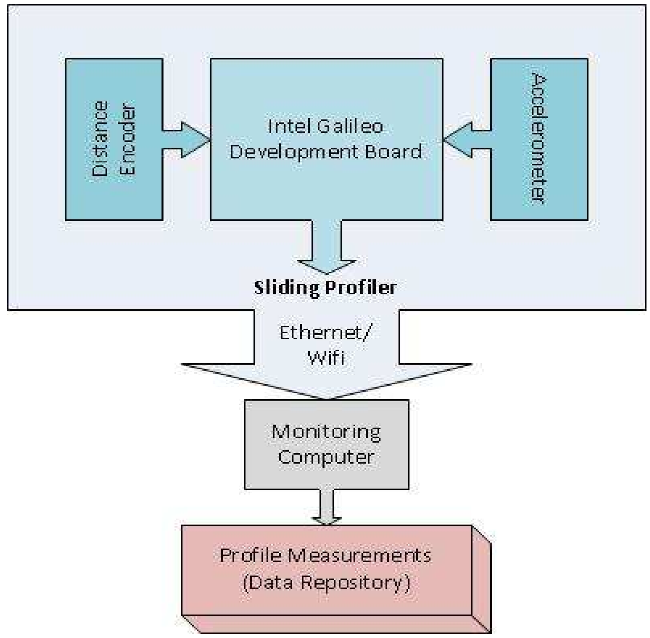

Figure 3-2 Block Diagram

The Galileo reads the measurements from accelerometer and distance encoder simultaneously. The accelerometer communicates with the Intel Galileo Development Board using I2C protocol. The distance encoder is connected to the Galileo Board through digital input/output pin. The Galileo Board reads data from the accelerometer for the x-axis and z-axis for the distance measured by the distance encoder.

3.1.2 Hardware Interface

The Intel Galileo Board and the sensors are connected as shown in figure 3-2. The Intel Galileo Board works on 5 volts DC power supply. The Galileo board includes pins that operate on 3.3 volts and 5 volts in the POWER pin set. The pin operating at 3.3 volts is used to power the board ADXL345 while the pin operating at 5 volts is used to power Accu coder 15H. The GND pin is used as ground for both ADXL345 and Accu encoder 15H.

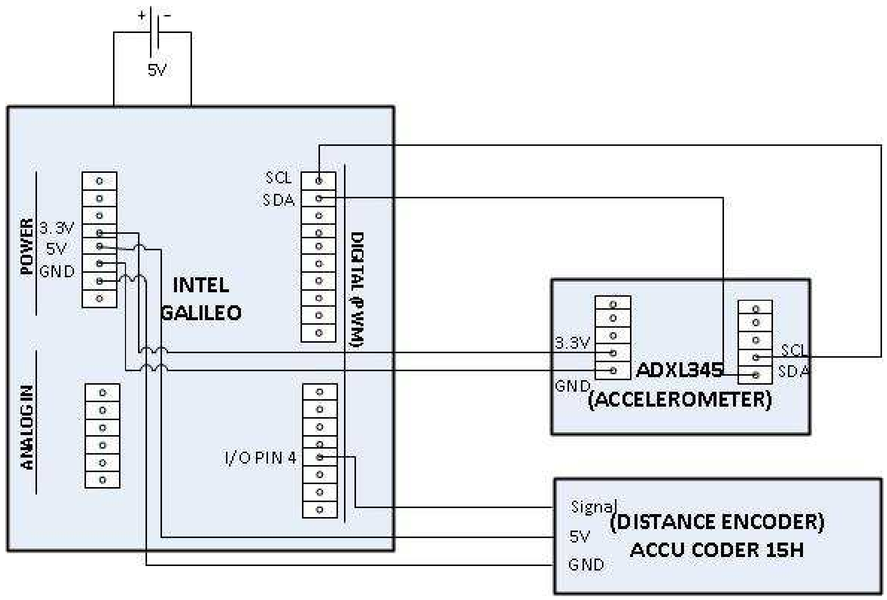

Figure 3-3 Hardware Interface with Intel Galileo

3.1.2.1 Intel Galileo Board interfaced with ADXL345

The ADXL345 is 3-axis accelerometer with 10 bit resolution with ±2G. The data is accessed through I2C digital interface by Intel Galileo Board. The ADXL345 is provided with 3.3V voltage supply and ground. For I2C communication, SCL (Clock) and SDA (Serial Data Line) are connected between Galileo and ADXL345. SCL is the clock signal used by ADXL345 and SDA is the data signal from which the measurement values are read by the Galileo.

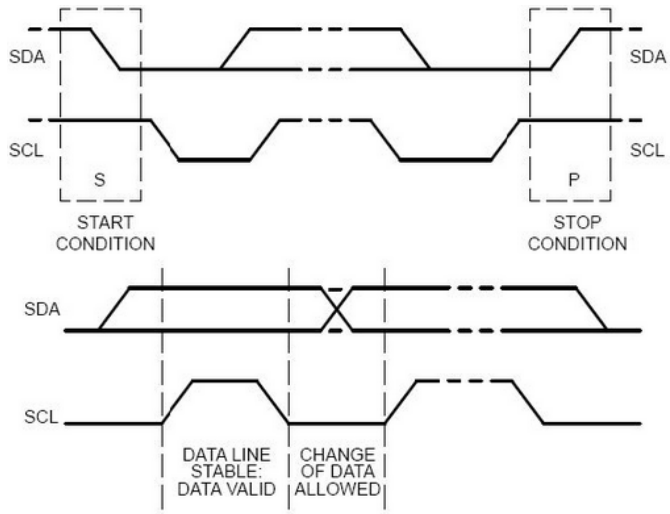

Figure 3-4 I2C protocol [7]

Messages on I2C protocol are broken up into two types of frame: an address frame, where the master indicates the slave to which the message is being sent, and one or more data frames, which are 8-bit data messages passed from the master to slave or vice versa. Data is placed on the SDA line after SCL goes low, and is sampled after the SCL line goes high. The time between clock edge and data read/write is defined by the devices on the bus and will vary from chip to chip.

To initiate the address frame, the master device leaves SCL high and pulls SDA low. This puts all slave devices on notice that a transmission is about to start. If two master devices wish to take ownership of the bus at one time, whichever device pulls SDA low first wins the race and gains control of the bus. It is possible to issue repeated starts, initiating a new communication sequence without relinquishing control of the bus to other masters. [7]

The address frame is always first in I2C communication sequence. The address for the ADXL345 is 0x53; the address is clocked out most significant bit (MSB) first, followed by an R/W bit indicating whether this is a read (1) or write (0) operation.

The 9th bit of the frame is the NACK/ACK bit. This is the case for all frames (data or address). Once the first 8 bits of the frame are sent, the receiving device is given control over SDA. If the receiving device does not pull the SDA line low before the 9th clock pulse, it can be inferred that the receiving device either did not receive the data or did not know how to parse the message. In that case, the exchange halts, and it's up to the master of the system to decide how to proceed. [7]

After the address frame has been sent, data can begin transmission. The master will simply continue generating clock pulses at a regular interval, and the data will be placed on the SDA by either the master or the slave, depending on whether the R/W bit indicated a read or write operation. The number of data frames is arbitrary, and most slave devices will auto-increment the internal register, meaning that subsequent reads or writes will come from the next register in line. [7]

Once all the data frames have been sent, the master will generate a stop condition. Stop conditions are defined by a 0->1 (low to high) transition on SDA after a 0->1 transition on SCL, with SCL remaining high. During normal data writing operation, the value on SDA should not change when SCL is high, to avoid false stop conditions. [7]

3.1.2.2 Intel Galileo Board interfaced with Accu Coder 15H

The Accu coder 15H requires 5V input voltage and the output is in the form of square waves. The output is given to the digital input/output pin 4 on Galileo. For ungated output the encoder provides 1 to 189 cycles per revolution. As the rotating wheel attached has 5.4 cms radius, the circumference of the wheel is 33.94 cms. Thus, every pulse represents 0.1786 cms covered by the sliding profiler.

3.1.3 Interfacing code flow

The Galileo Board is software compatible with the Arduino software development environment. The Arduino software is used to program the Intel Galileo Board. An SD card with bigger Linux image is used to boot the Galileo. The program is kept persistent on this SD card. After booting the Galileo using the Linux image immediately runs the program. This is indicated by the LED on the board which is attached to input/output pin 13. The LED glows once the setup is complete indicating that the sliding profiler is ready to start data acquisition. As soon as the sliding profiler starts moving on the surface the reading are taken and saved in a file. The program reads the measurements from the accelerometer's x-axis, y-axis and z-axis based on the pulses generated by the distance encoder. The distance encoder output changes from low to high for every 0.17879 cm of distance covered. This data is continuously saved on to a file in the SD card until the file limit exceeds or till program is stopped. The LED then stops glowing indicating that the data acquisition process is stopped. The SD card attached to the Intel Galileo board retains the data file even after the board is powered down.

The Ethernet setup ensures the Intel Galileo board has the static IP address of 169.254.1.10. By using Ethernet cable the file can be retrieved from the SD card to the computer. Further, data processing helps in finding the bumps over the surface measured.

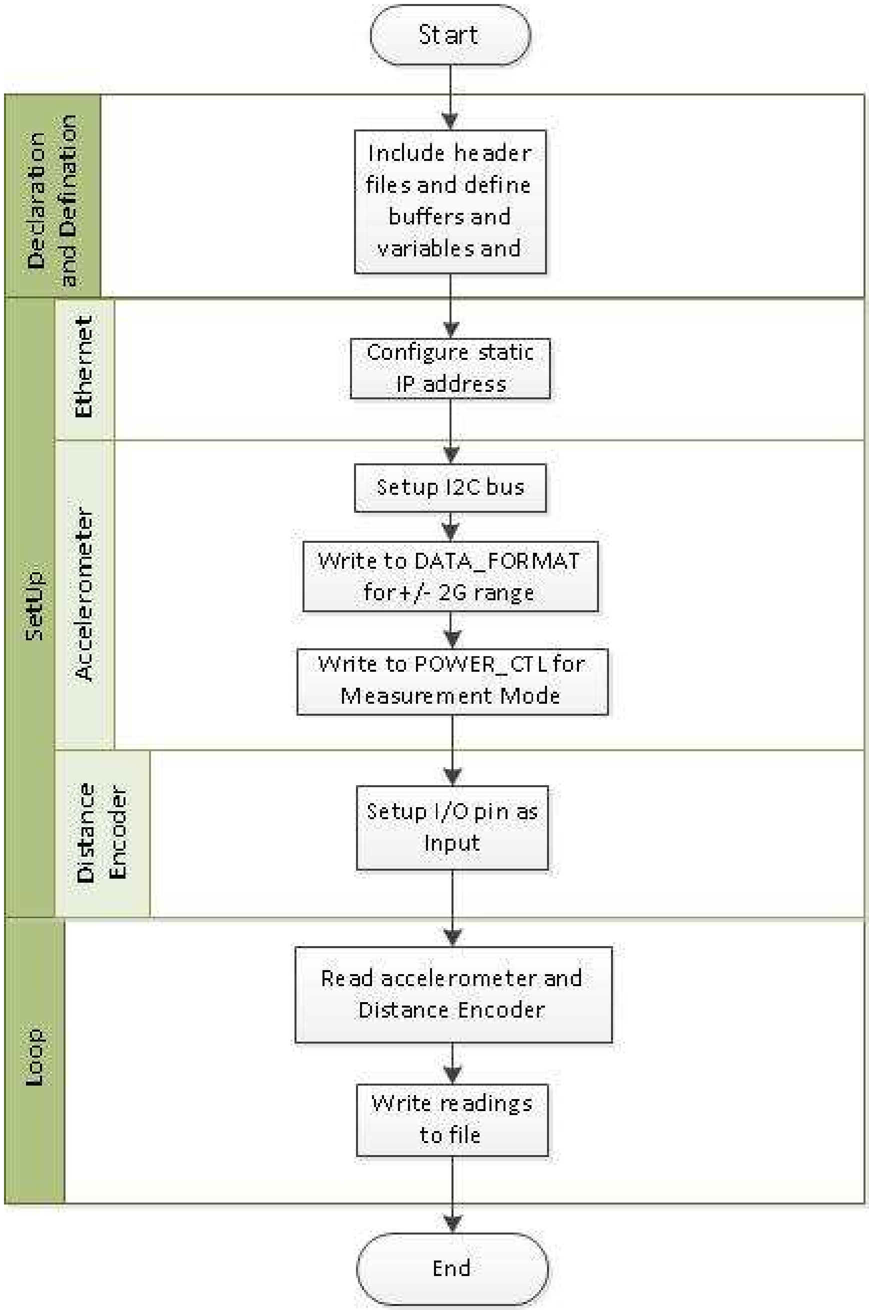

Figure 3-5 Code Flow

Chapter 4

Measurement Sensors

4.1 Accelerometer

4.1.1 Angle of Inclination using ADXL345

Figure 3-2 and figure 3-3 shows the orientation of the accelerometer ADXL345. The angle of inclination for the sliding profile can be derived using the acceleration along the axes. The angle can be calculated using only x-axis, as sin ϴ = x. To increase the sensitivity of the measurement even above the tilt angles 45° to -45°, both x-axis and z-axis can be used.

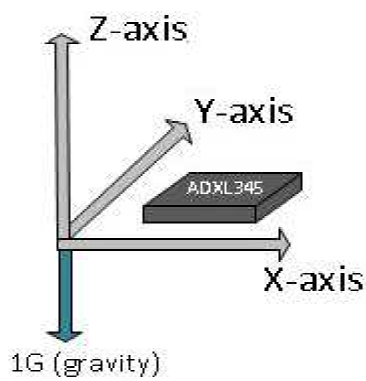

Figure 4-1 Orientation of ADXL345

Using two axes increase the measuring range from 90° to -90° without any loss to sensitivity. As in figure 3-3, tan ϴ = (x/z), ϴ = arc tan (x/z) gives the angle of inclination using two axes. Using x-axis and z-axis to find the tilt improves the accuracy of the measuring angle significantly compared to the use of one axis.

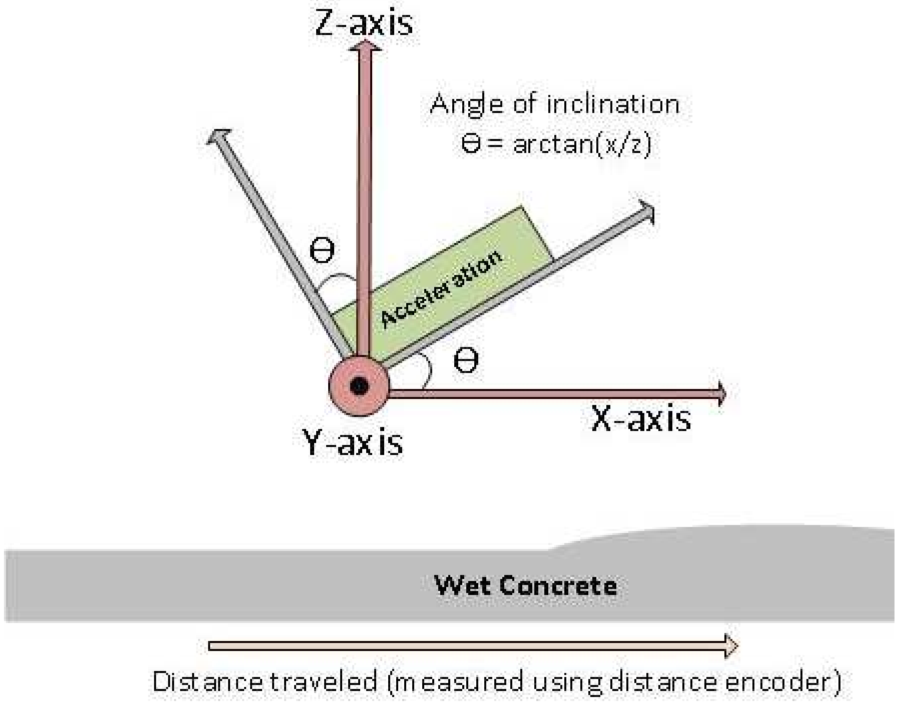

Figure 4-2 Angle of Inclination over the surface

4.1.2 Test Results

The raw data values for the x-axis and z-axis of the accelerometer are taken against the distance measured over the surface. The distance increments by 0.17864 cms as a single pulse covers the distance equal to the circumference by 190 pulses.

$$Distance\ covered\ by\ each\ pulse = \frac{2\pi r}{190} = \frac{2\pi(5.4cms)}{190} = 0.17864cms$$

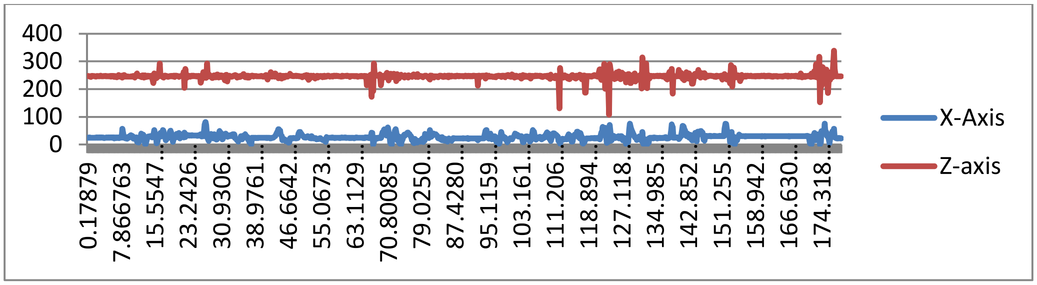

Figure 4-3 Raw data

For data processing, the raw data for x and z axis are used to calculate the tan inverse to find the tilt felt by the accelerometer.

$$tan\theta = \frac{x}{z}$$

The angle of inclination (Θ) of the vehicle is measured and for each point along the distance of travel, the change in the height (dY) is calculated.

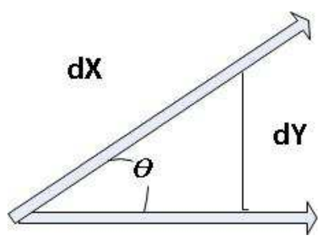

Figure 4-4 Change in height using angle of inclination

$$dY = sin\theta \times dX$$

This provides each incremental change in height along the distance traveled by the sliding profiler. The graph for the incremental changes for height show spikes for any bump that the sliding profiler detects.

4.1.2 Distance Encoder

Incremental encoders are available in two basic channel types, single channel and quadrature output. A single channel encoder, often called a tachometer, is normally used in systems that rotate in one direction only, and require simple position and velocity information. Quadrature encoders have dual channels (A and B), phased 90 electrical degrees apart. These two output signals determine the direction of rotation by detecting the leading or lagging signal in their phase relationship. Quadrature encoders provide very high speed bi-directional information for complex motion control applications. [3]

4.1.2.1 Analysis

Each incremental encoder has a defined number of cycles that are generated for each full 360 degree shaft revolution. These cycles are monitored by a counter or motion controller and converted to counts for position and speed control. [3]

Figure 4-5 Single channel square wave output for distance encoder [3]

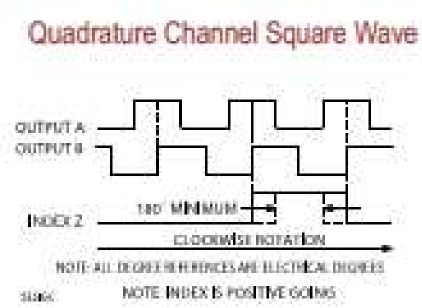

Figure 4-6 Quadrature channel square wave output for distance encoder [3]

4.1.2.2 Test Results

The output of the distance encoder for ungated output A are pulses for the distance measure in the form of 5V. The signal pulses generated are provided to the Intel Galileo board on input/output digital pin 4.

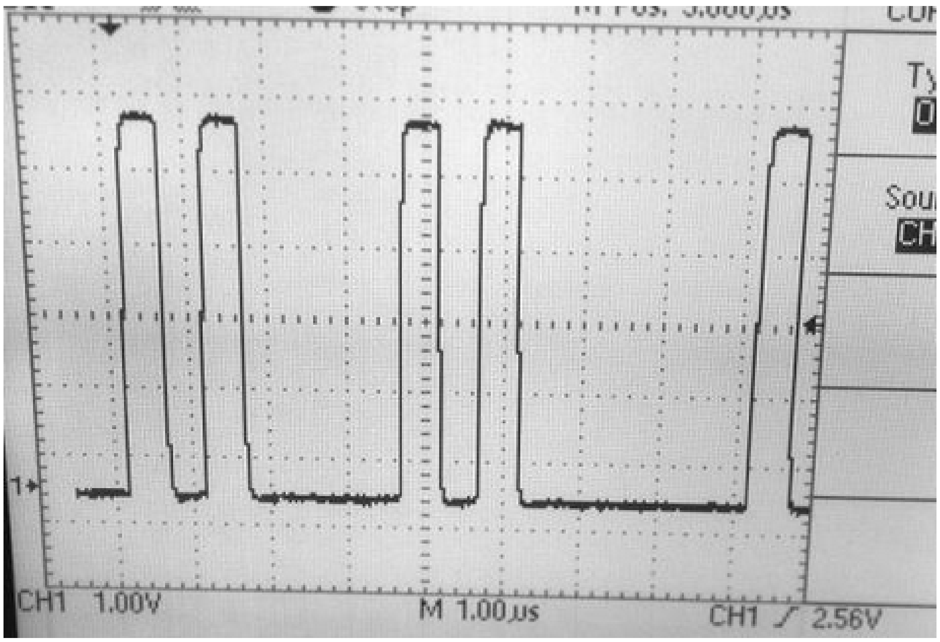

Figure 4-7 Distance encoder output on CRO

Chapter 5

Testing and Simulation

5.1 Unit testing

The preliminary testing was to verify if the sliding profiler is able to detect any bump. The equipment was tested over a single bump to check if the displacements calculated were identifying a single bump after processing the data. There is a single spike in the graph which represents the bump. The displacement relative to the tilt was larger when the sliding profiler was moved over it successfully showing the results.

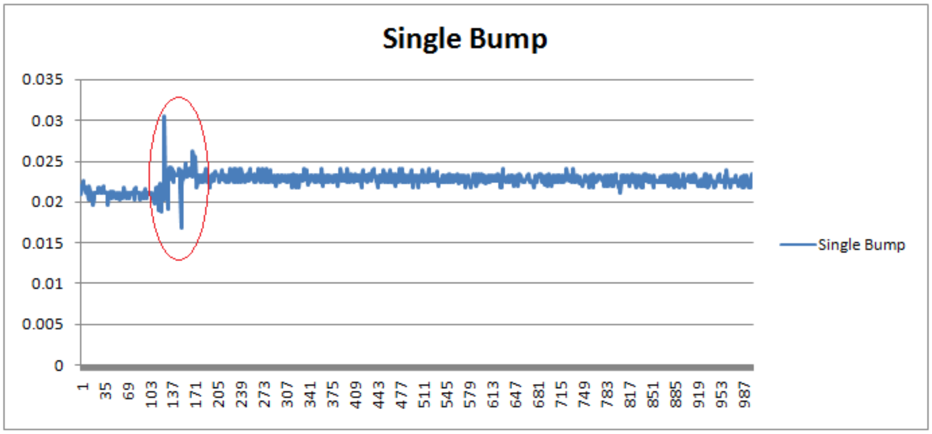

Figure 5-1 Single bump test

Another test was run in the corridor which had five distinct bumps the sliding profiler was tested on. The surface of the floor is smooth with only bumps while moving from the lab to the hallway and to the exit.

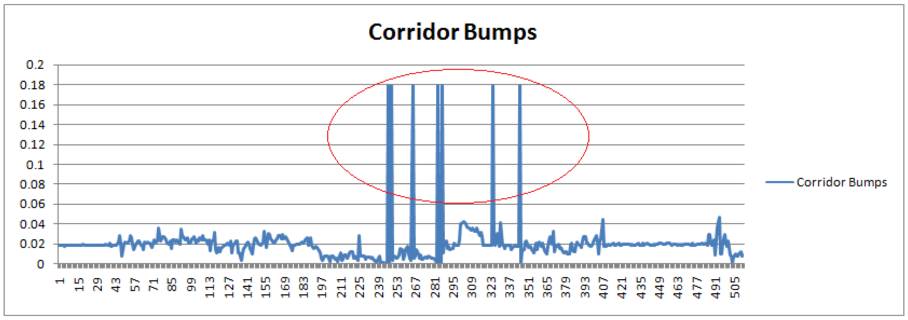

Figure 5-2 Corridor near the lab

5.2 System Test Results with data processing

The Tri-C parking lot was considered for test runs as there was an IRI prediction model equation derived using Walker Constant. This value was obtained by a colleague in the same lab and is explained in detail in the paper 'Embedded Data Acquisition System using low-speed automated unit on Asphalt surface'. The test run over a rough patch in the parking lot was conclusive in the sense that the resultant data obtained by me had very high correlation with the empirical data from the above mentioned research paper.

Figure 5-3 Rough patch near Tri-C parking lot - 1

Figure 5-4 Rough patch near Tri-C parking lot - 2

Figure 5-5 Rough patch near Tri-C parking lot - 3

Figure 5-6 Rough patch near Tri-C parking lot - 4

Figure 5-7 Sliding profiler over the rough patch in Tri-C parking lot

That specific statistics focuses on the International Roughness Index (IRI). The IRI estimate that was obtained from the sliding profiler is 239.13. The IRI value is calculated using the IRI prediction model with the equation $y = 0.23x + 30.67$, where x is the slope variance. The value of the IRI is higher since the parking lot is extremely rough.

5.2.1 Calculation of IRI

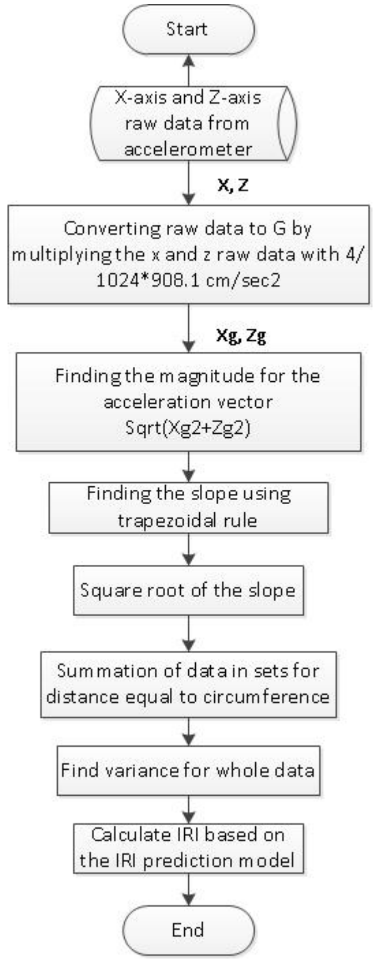

Figure 5-8 Calculation of IRI

The change of height along the distance was calculated for the same data and the graph is plotted indicating the patch in the parking lot is rough and needs maintenance.

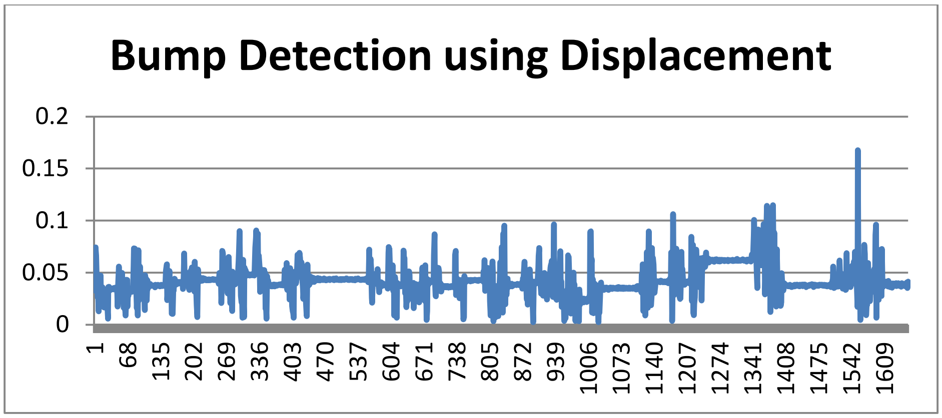

Figure 5-9 Bump Detection Using Displacements

5.3 Comparison with existing data

The test results taken in Grand Prairie Prairieon a construction project on SH161 during August 2006 were also available and used to further verify the accelerometer based profiling device. This earlier model of the sliding profiler test run was over 300 feet detecting 6 bumps. The spikes for the displacement are similar to the improved sliding profiler and it indicates the bumps at the distance which has a spike of the height change at around 56 feet. Since the IRI based sliding profiler provides similar results we can assume it will work on other freshly poured wet concrete.

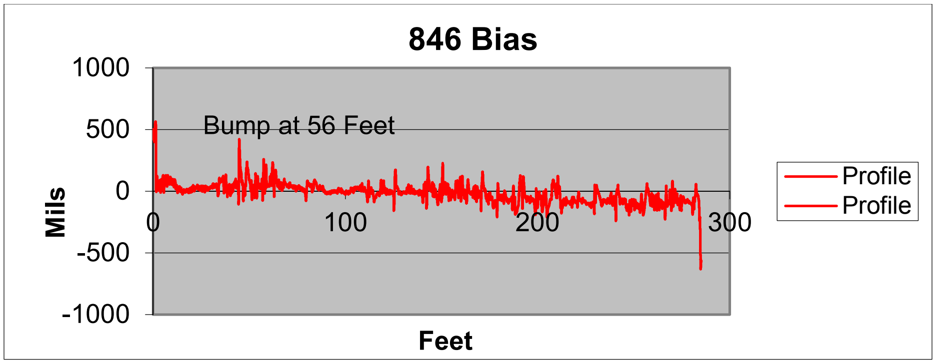

Figure 5-10 Test results from Grand Prairie

Chapter 6

Summary and Conclusion

This research project is an effort to establish a device which can be able to slide over wet concrete to measure any early bumps so as they may be immediately corrected before the concrete is hardened. Many improvements were carried out which were successfully implemented on the device. The Intel Galileo Board enhances the profiler with the ability to store data as well as transfer to it over different communication protocols. During this project the Ethernet cable was used to communicate and transfer the data. The capture sensors like the accelerometer and distance encoders were integrated with the Intel Galileo Board which helped in estimating the data results. One of the important improvements was that new the sliding profiler does not detect any false bumps. The use of the Intel Galileo Board and the ADXL345 also reduced the overall weight of the profiler making it lighter than any of the earlier models. There is a future scope in changing the mode of communication by using Wi-Fi which requires an additional Wi-Fi antenna and adapter. The sliding profiler is a general purpose stand-alone data acquisition platform for surface measurements mainly suitable for wet concrete surfaces as it successfully detected bumps over various surfaces as well as correlation with the estimated IRI prediction model.

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