AC 2011-1376: SMART ROD

Mohamad A. Mustafa, Savannah State University

Mohamad Mustafa is a Professor of Civil Engineering Technology at Savannah State University (SSU). He has six years of industrial experience prior to teaching at SSU. He received his BS, MS, and PhD in Civil Engineering from Wayne State University, Detroit, Michigan. Research Interest is: Sensors Applications in Civil Engineering.

Asad Yousuf, Savannah State University
Jeff Kesling

SMART ROD

Abstract

The application of scientific and mathematical principles to the method of differential leveling as applies to the Civil Engineer in the planning and design of the construction of buildings, highways, and bridges were investigated. Such planning and designing requires the surveying of locations to determine what changes may need to be made prior to any construction or alteration. Differential leveling is the independent measurement of an unknown elevation relative to a known elevation. One of the key elements to perform accurate differential leveling is the ability to keep the rod and the instrument plumbed to the earth. Current state of the art is to use an automatic level and graduated rod, both of which employ bubble-levels to determine plumb.

The purpose of this project is to design a smart rod that will improve the accuracy of the measurements of differential leveling over the currently used industry methods. The smart rod consists of graduated rod that employs a tilt sensor (Parallax Memsic 2125 Dual-axis Accelerometer), transmitter (Parallax XBee 1mW Chip Antenna (XB24-ACI-001)), and Parallax Discovery board (Board of Education carrier board with BASIC Stamp 2 module). The tilt sensor is used to measure the rods' angle with respect to the earth, and the transmitter wirelessly transmits the angle data to an automatic level that is also equipped with a Parallax Discovery board (Board of Education carrier board with BASIC Stamp 2 module). The Parallax Discovery boards are used to bridge the components together and run a program to interpret the angle data. In order to achieve this communication a program using Basic Stamp Editor was developed. The program reads the Smart Rod's angle data and transmits the leveling condition which will activate an LED that is attached to the automatic level. The LED is activated once the rod is plumbed with the earth indicating to the surveyor to read and record the rod measurement.

It is expected that the use of the smart rod will increase the accuracy ratio of a differential leveling survey.

Introduction

In civil engineering, various types of surveys are performed prior to any new construction or land alteration. These surveys provide a topographical layout of a site, which is then used to determine if and where alteration to the land must be made during construction. One type of survey, called differential leveling survey, is used to determine the differences in elevation between points, called stations (STA), which are some distance apart. The survey requires a surveyors' level, a graduated measuring rod, an engineer to operate the level, and a rods-man to move the rod to a desired location of interest.

The surveyors' level consists of a cross-hair-equipped telescope and an attached spirit level tube, which are mounted on a tripod. At each station, the rod is placed directly above the station on a permanent or semi-permanent object. The object used must resist vertical movement for the duration of the job; otherwise the measured elevation could not be used again. The first station will usually be a benchmark. A benchmark is a permanent point published by federal, state, provincial, and municipal agencies. These points are established, known elevations and are set to resist vertical movement.

To determine the elevation at a station, first, the level needs to be placed at a location such that it can sight the rod at both a previous and the next station, and should be as close to equidistant to both as possible. The first reading is to determine the backsight (BS), found by recording the rod measurement at the benchmark, also called STA 1. All readings taken on a point of known elevation are considered a BS. The rod is placed at a benchmark and the surveyor takes the BS by sighting the rod through the level and recording the measurement. The second reading, taken by sighting the rod at STA 2, is known as the foresight (FS). To establish the elevation at the second station, the FS is subtracted from the height of the instrument (HI). The HI is determined by adding together the known elevation of the benchmark with the BS. After the elevation of STA 2 is determined, the level is moved to a new location such that it can sight both STA 1 and STA 2. Each time the level is moved, a reading must be taken on a station of known elevation in order to establish the new HI. The process for finding the next stations elevation is the same as for the previous station.

In order for the surveyor to take a rod reading, the rod must be plumb with the earth. To find the plumb, the rods-man uses a bubble level attached to the rod. Since finding plumb is done by swaying the rod in different directions until the bubble is within the level tolerance, the plumb could potentially be slightly off by the time the surveyor reads the measurement. Once the rod is plumbed he signals to the surveyor to read and record the measurement. To read the rod, the engineer sights the rod through the instrument and records the measurement between the crosshairs.

A common type of differential leveling survey is a bench loop. A bench loop consists of a series of stations such that the whole survey will begin and end with the same station. The purpose of a bench loop is to determine the elevations at each of the stations compared to the elevation of the first station. If the measured elevation of the final station is not equal to the known value of the first station, there is an error. If the error is within tolerances, the surveyor can adjust for the error.

A survey is allowed a certain amount of error based on the survey’s order and class. If a survey has a greater error than is allowed, the survey must be performed again.

The goal of this research is to build a smart rod, which will automate the process of finding the plumb and notifying the surveyor of when to read the measurement. Through this automation it is hoped we can increase accuracy and reduce time. The paper describes the following:

- Physical Overview
- Hardware and Software Design
- Results
- Future Directions

Physical Overview

Over the past few years, we have seen numerous changes in the microprocessor and microcontroller market. Motorola stopped the development of its popular 8-bit 68HC11 microcontroller for approximately 10 years. With these advancements in technology, modern system design requires the use of advanced microcontroller chips and tools. Several new companies have emerged in the microcontroller market to meet the complex design requirements. A PIC microcontroller is a single chip computer that is commonly found in everyday products such as microwave ovens, cell phones, alarm clocks, etc. If the device consists of push buttons and displays, chances are it also contains a programmable microcontroller. The PIC is a popular, inexpensive single chip microcontroller for a low powered, complex embedded system. A design project by enlarge is focused on developing a product that is robust, reliable, and economical. Keeping this in mind, our project team decided to incorporate Parallax Inc.'s BASIC Stamp2 module, shown in figure 1.0, in the smart rod project. This compact BASIC Stamp2 module plugs into Parallax Inc.'s board of education carrier board, shown in figure 2.0. Memsic 2125 accelerometer was used to measure the rods' angle with respect to the earth. XBee 1mW chip Transceiver antenna was used to wirelessly transmit the angle data to the automatic level.

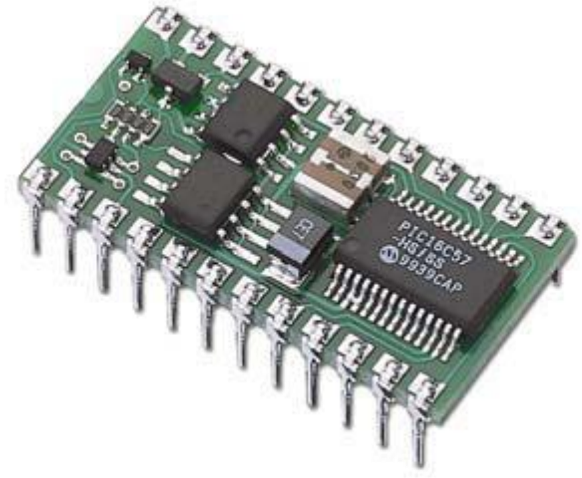


Figure 1.0 BASIC Stamp2 module

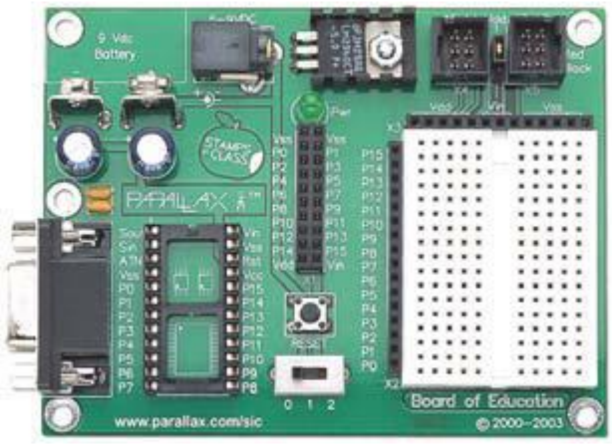


Figure 2.0 Parallax Inc.'s board of education carrier board

The major physical feature of the Smart Rod is composed of a Parallax microcontroller, along with the tilt sensor, and transmitters. Figure 3.0 (a) and 3.0(b) shows the physical layout of the components. The physical layout is composed of the following:

- PIC 16C57 Microcontroller Chip
- Parallax Basic Stamp Discovery Board
- Tilt Sensor
- XBee Transceiver
- LED
- Automatic Level Machine

Figure 3.0 (a) Smart Rod Parallax Board

Figure 3.0 (b) L.E.D Attached to Automatic Level Machine

Hardware and Software Design

Typically, development tools needed for the microcontroller can be divided into two different groups: software and hardware. Software tools include assemblers, compilers, program editors, debuggers, simulators, communication programs, and systems integration environments to implement solutions. In the Smart Rod project, the BASIC Stamp2 microcontroller is interfaced to the BASIC Stamp2 Editor software, which is used to write programs that the BASIC Stamp2 module will run. The software is also used to display messages sent by the BASIC Stamp2. The BASIC Stamp2 Editor is free software, and the two easiest ways to get it are:

- Download from the Internet. Search for "BASIC Stamp2 Windows Editor Version 2.0" on www.parallax.com, the Parallax Web site.
- Included on the Parallax CD.

Hardware and software control architectures were designed to communicate with the Smart Rod and the automatic level. The project team was composed of a Civil Engineering Technology student and two faculties from Civil and Electronics Engineering Technology. During the early execution stage the students handled the mechanical design portion of the SMART Rod project. The electrical concepts which included programming of the microcontroller was faculty led and the student was informed about the resources to use for implementing the hardware and software for the Smart Rod project. Student also kept a record of his progress including design ideas and sketches, issues faced and their solutions in his notebook. The hardware section of Smart Rod uses PIC16C57 microcontroller. The student programmed the microcontroller in PBASIC to take the measurements from the tilt sensor and transmit the angle data to automatic level machine which also is equipped with the Microcontroller and the XBee Transceiver. The block diagram of the hardware and software interface is shown in Figure 4.0. The hardware-interfacing diagram to connect various components is shown in Figure 5.0. The Smart Rod System is built by plugging the components into small holes called sockets on the prototyping area. This prototyping area has black sockets along the top left. The black sockets along the top have these labels above them: Vdd, Vin, and Vss. These are called power terminals, and they are used to supply power to the Smart Rod system. The black sockets on the left have labels like P0, P1, up through P15. These sockets are connected to the BASIC Stamp2 module's input and output pins. The software developed is downloaded to the board of education via a serial or USB cable. The integration of the hardware and the software produces an integrated embedded system, which controls the Smart Rod. The Smart Rod focused on important learning concepts such as physical layout, electronics, programming, and cross disciplinary interaction. The physical layout symbolizes the interrelationship between various substructures of the Smart Rod. This includes an understanding of components and the manner in which all these components function together as a deterministic whole system. Basic components, such as the rod, automatic level machine and electronics, which include microcontrollers, sensors, and transceivers, are the major components of the Smart Rod. Integrating these components offered an opportunity for the student to understand the design/development of Smart Rod embedded system.

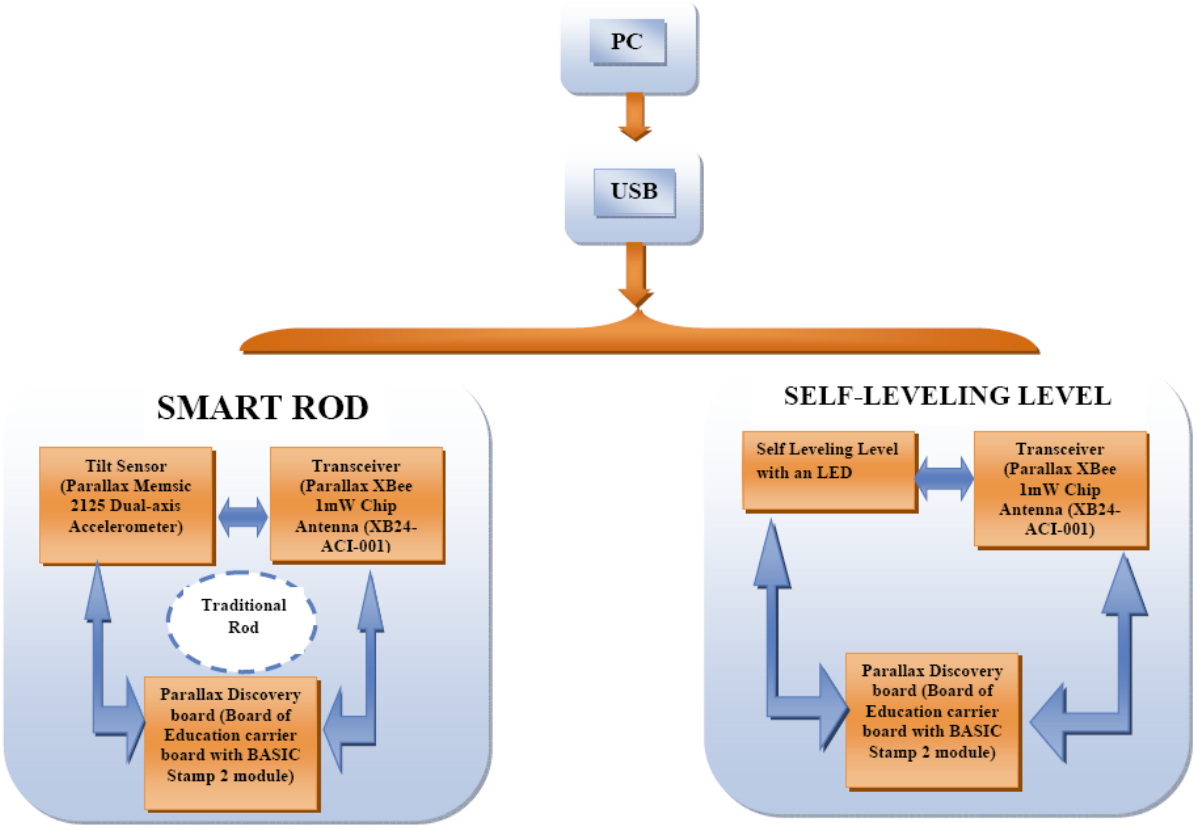
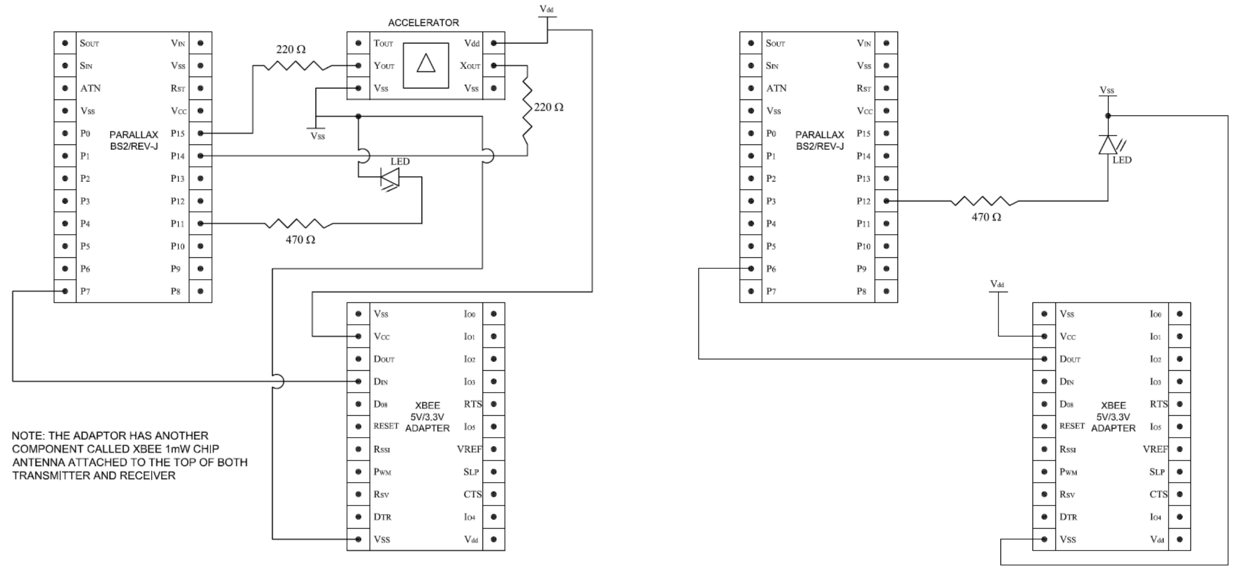


Figure 4.0 block diagram of the hardware and software interface



NOTE: THE ADAPTOR HAS ANOTHER COMPONENT CALLED XBEE 1mW CHIP ANTENNA ATTACHED TO THE TOP OF BOTH TRANSMITTER AND RECEIVER

TRANSMITTER

RECEIVER

Figure 5.0 Hardware Interfacing Diagram

The BASIC Stamp Editor 2.5 (BSE) software was used to create program for use with the Parallax BASIC stamps and Parallax boards. The Parallax BASIC stamp is a microcontroller that is used on the Parallax Discovery boards. The BSE uses key words to tell the BASIC stamp what to do. While writing the program, it was found that the raw data that the Parallax tilt sensor was providing was not in the conventional 360 degree format. To convert the data to a 360 degree format required dividing the angles by 7. The purpose of this conversion was to provide ease of understanding. While our BSE program is running and connected to a computer, the program creates a window to display the angle information. To make the angle easier to understand, we set plumb to be equal to an angle of 0 rather than 90 degrees. We arbitrary set our program to only allow an error of 2 degrees. When the rod is within the 2 degrees of plumb, the program activates an LED we equipped to the Smart Rod. In addition, the board attached to the level will also activate an LED which will be the signal for the surveyor to take record the measurement. All of the data is transferred from the Smart Rod to the level using our attached transceivers.

Approach

The smart rod was set to consider plumb to be within 2 degrees of true plumb. The reason for this threshold is that an accuracy greater than 2 degrees caused increased difficulty in finding plumb. To test the smart rod versus the traditional graduated rod, a bench loop consisting of 8 stations was set up.   Differential leveling is performed for this bench loop multiple times, using the smart rod and the traditional graduated rod method to compare the accuracy of each method.

Results

An eight stations bench loop was established to compare the accuracy ratio of differential leveling survey using the traditional graduated rod versus the proposed Smart Rod. The bench mark for this survey is assumed to have the name STA1 with and assumed elevation of zero feet above mean sea level. Rod readings are recorded in a standard tabular form, see table 1 and 2, to calculate the elevations of the subsequent stations. The bench loop is closed by checking on the beginning station elevation at the end of the survey to determine the error and calculate the accuracy ratio. The differential leveling survey of the established bench loop is performed several times and the average accuracy ratio is calculated for both methods.

The elevations, errors, and accuracy ratios are calculated using the following equations:

Let,
HI = Height of Instrument
BS = Backsight
FS = Forsight
Station = STA
HI = Elevation of the BS STA + BS rod reading
Elevation of the FS STA = HI –FS rod reading
Error = the difference between the known elevation of STA 1 and the measured elevation of STA1
Ratio (Accuracy Ratio) = the error/total distance

Tables 1-.and 2 are samples of the recorded and calculated measurements using the traditional graduated and the smart rods.

STA	BS	HI	FS	Elev
1	7.854	7.854		0.000
2	5.938	6.709	7.083	0.771
3	6.958	10.375	3.292	3.417
4	7.479	17.104	0.750	9.625
5	5.292	18.438	3.958	13.146
6	5.104	19.584	3.958	14.480
7	0.958	14.709	5.833	13.751
8	0.292	7.876	7.125	7.584
1			7.958	-0.082
			ERROR	0.082
			Accuracy Ratio	1/20000

Table 1: Traditional Graduated Rod- Run 1

STA	BS	HI	FS	Elev
1	7.958	7.958		0.000
2	6.250	7.020	7.188	0.770
3	6.438	9.854	3.604	3.416
4	7.500	17.146	0.208	9.646
5	4.688	17.876	3.958	13.188
6	5.021	19.543	3.354	14.522
7	0.521	14.293	5.771	13.772
8	0.521	8.106	6.708	7.585
1			8.083	0.023
			ERROR	0.023
			Accuracy Ratio	1/72000

Table 2: Smart Rod-Run 1

The first column contains the station numbers, the second column represent the recorded BS readings, the third column shows the calculated height of instrument above mean sea level, the fourth column has the recorded FS reading at individual stations and the last column shows the calculated elevations at all stations other than the first station. The first station elevation was assumed to be zero.. Once the data is recorded and calculated for all stations including checking on the first station elevation, the error is calculated by finding the difference between the assumed elevation and the measured elevation at STA1. In the case of this bench loop, the assumed elevation of STA 1 was assumed to be zero ft above mean sea level. Therefore any difference would be the error.

The accuracy ratio is then calculated. The accuracy ratio is the deviation in elevation for every ft. of horizontal distance. The deviation is rewritten in terms of ft. per distance rounded to the nearest thousand. As an example, 0.001/100 would be recorded as 1/100,000 meaning for every 100,000 ft. of horizontal distance the elevation would be off by 1 ft.

Based on the calculated accuracy ratio for individual run, the average ratio is compared for the two methods. The results show that the average accuracy ratio is 1/21,000 when the traditional graduated rod is used. When the Smart Rod is used the average accuracy ratio is found to be 1/57,000. To understand this comparison, an accuracy ratio multiplier is calculated as shown in Figure 6. This figure clearly indicates that the use of the Smart Rod has increased the accuracy ratio by approximately three times.

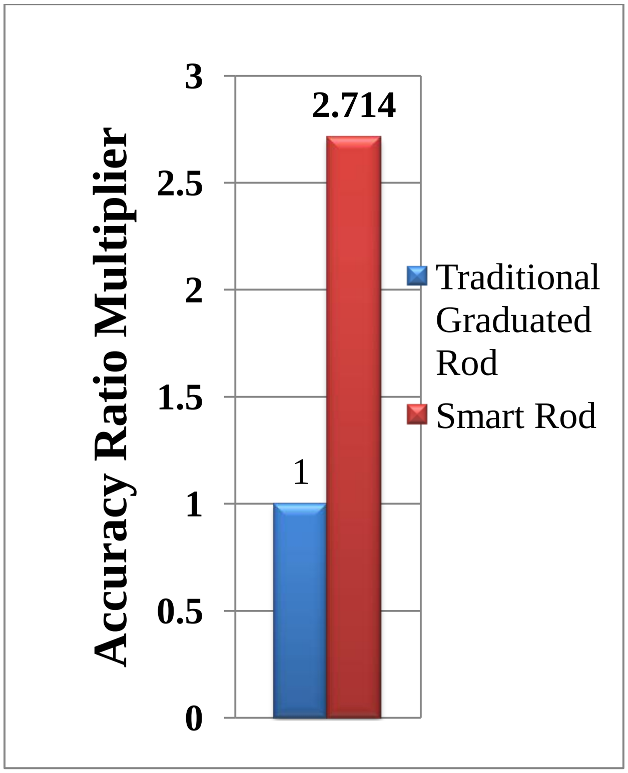


Figure 6.0 Comparison of the average Accuracy Ratio multipliers: Smart Rod vs. Traditional Graduated Rod

Future Directions

The comparison of the accuracy ratio results between the traditional graduated rod and the Smart Rod proves that the Smart Rod has increased the accuracy ratio of the differential leveling survey. The Smart Rod is successfully able to determine its angle and transmit it to the receiver.

Although time efficiency is not the aim of our project, the Smart Rod tests shows an increase in time efficiency of an average of 40s per station for a total of about 5 min faster than the traditional graduated rod method.

This case study proves the feasibility of this project. However this project lacks the full automation of the system between the self leveling level and the Smart Rod. The human error is still a factor as the engineer wait for the LED to light to take the reading. The future work is to provide an LCD display on the Smart Rod to let the Rodman (in this case the Rodman will be the engineer rather than the technician) knows that the rod is leveled and the signal is transmitted to the self leveling level to take the reading. This will also require automating the self leveling level reading process. The Smart Rod should send the signal to the level that it is plumbed and the level should respond by automatically sending the laser beam to take the vertical measurement and store it in its memory as well as displaying the result on the Smart Rod LCD display to let the engineer know that the reading is done and to move to the next station.

Bibliography

1. FEMA. http://www.fema.gov/pdf/nfip/alt_elevations/elevations_appb.pdf.
2. Kavanagh, Barry F. Surveying Principles and Applications. 7th. Upper Saddle River: Pearson Education, Inc, 2006.
3. Parallax. www.Parallax.com.