

WIRELSS LEVEL

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Abstract

The purpose of this project is to design and create a wireless level device. The wireless level will be an improved and wireless version of the traditional angle measuring level. The device contains two modules, the level module and the receiver module. The level module will be responsible in measuring the tilt angle of the intended object and transmit the data to the receiver module where it will be displayed. Contrary to traditional levels, this wireless level will accurately measure tri-axis tilt levels of any surface in correspondence to different application and usage. The transmission distance between the two modules is dependent on the transmission distance of the Bluetooth, which is about twenty meters. Since the applications of this wireless level would be in construction industries, the level of surfaces would often be close to zero degrees.

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1. Introduction

There exists an urgent need on the market for a low-cost, low-power-consumption, and yet accurate wireless tri-axis level device. The current levels available to people in need today only fulfill some of the requirements, causing people trouble and making them inefficient when performing their jobs. The device that we propose to create will be inexpensive, but also provides a handheld receiver that will allow the user to monitor the level from distance away. Our device could solve many problems that plumbers, electricians and construction workers have. For example, a sprinkler fitter has a main pipeline running down a hallway and wants to tap off and run a line through one or more walls to a vertical drop. In most cases the fitter must attach a magnetic level on the vertical drop and go back to the main pipe and tighten the tap pipe with a pipe wrench, but he must make many trips up and down the see if the other end is level. If he had a remote level to put on the vertical pipe and a receiver at the main pipe to tell me what way to tighten the pipe to reach level and when it was level it would save much time. It could also be used by a crane operator setting steel beams, a leveling device could be mounted on both sides of a vertical beam and a remote for each, he could then hold it plumb as it is tightened in place.

1.1 Purpose

The purpose of this project is to employ our knowledge in signal processing and wireless communication to engineering a device that could wirelessly monitor the level of a particular surface so that the working quality for plumbers, electricians and construction workers could improve.

Despite leveling devices are already on the market, but they are not efficient in various perspectives. Our device could not only wirelessly measure the tri-axis tilt level of a surface accurately, but it also consumes small amounts of power.

1.2 Specifications

The specifications of this device will include roughly twenty meters in wireless transmission range, at least 60 hours of battery lifetime, three dimension tilt angle display with error less than 2%, and lost cost, low power consumption in comparison to products on the market.

1.3 Subprojects

The design was broken into two modules, each performing specific tasks. Figure 1 and 2 show the block diagrams of the level module and the receiving module respectively. The internal blocks are independent modules that were bought by us online. Notice that the microcontroller in the level module does not receive its power from the power supply. Instead, it is being powered by the accelerometer by using the accelerometer's Vref output as its input voltage Vcc.

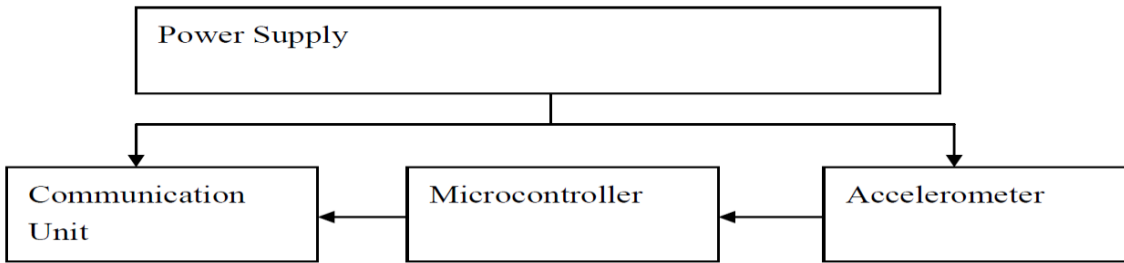


Figure 1. Block Diagram of the Level Module

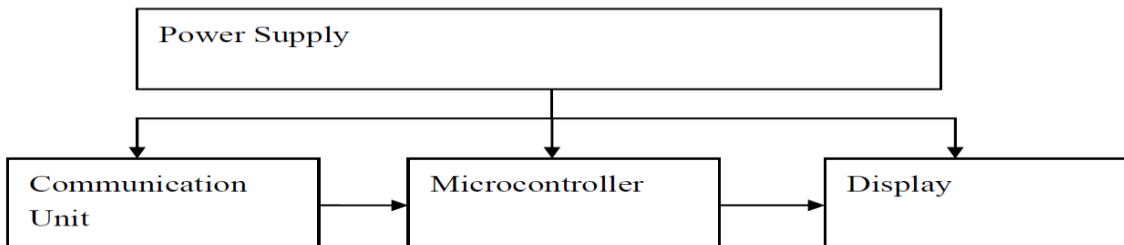


Figure 2. Block Diagram of the Receiving Module

2 Design Procedure

2.1 Level Module

The Level module will be the measuring component of the system. It will determine the tilt level of the surface it's mounted on, translate the analog data into digital and transmit it to the handheld receiver. It will consist of a MSP430, four AAA batteries, a Bluetooth, and an accelerometer.

The accelerometer used in the Level Module will be the DE-ACCM3D buffered 3D accelerometer. This device will measure the level using static acceleration, gravity, and outputting voltage amplitudes. The outputted voltage amplitudes will then be directed to the microcontroller for further process. The accelerometer will be powered by the power supply, which provides a constant 6V voltage to the device. The primary reason for choosing this particular accelerometer is that it provides accurate tri-axis tilt sensing. The input voltage, V_{cc} , of the accelerometer can range from 3.5 volts to 15 volts. The output voltage V_x , V_y , and V_z , will be different based on the tilt angles measured using static acceleration, gravity, and orientation of the hardware in reference to the earth's surface. The voltage readings range from 1.33 volts to 1.99 volts with 1.66 being the "normal" orientation. The accelerometer will also provide power through a constant 3.3 volts regulator V_{ref} . The voltage levels of the output are shown below.

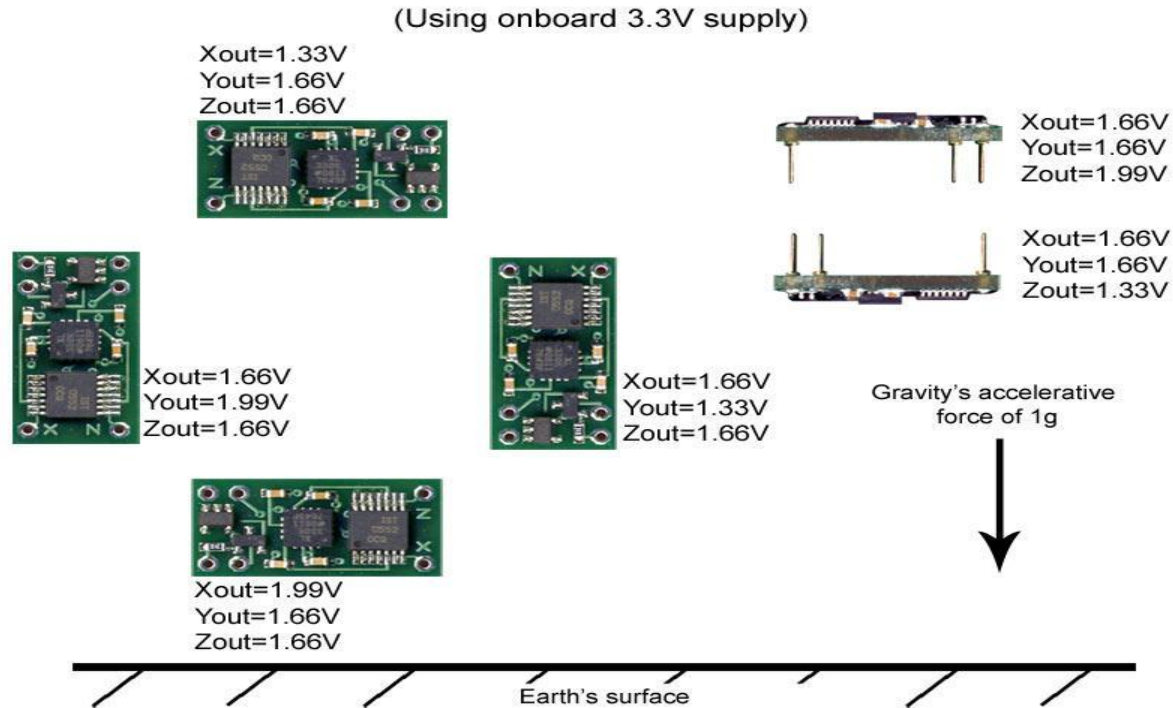


Figure 3. Accelerometer Voltage Outputs

The microcontroller used in the Level Module will be the MSP430. This device is the primary control unit of the level Module. The reason for using this device is the low power consumption, low cost, and versatile customization. Its objective is to translate analog input from the accelerometer into digital outputs to the communication module. It will be powered by the accelerometer by using the accelerometer's V_{ref} output as its input voltage V_{cc} . The advantage of using the accelerometer's V_{ref} as input is that V_{ref} is regulated by accelerometer to be a constant 3.3 volts with maximum current up to 50 mA, providing a reference voltage for the analog-to-digital conversion while providing voltage supply within the supply-voltage range of 1.8 volts to 3.6 volts that differs from the supply-voltage range of the accelerometer.

The communication unit that we decided to use is the Bluetooth HC-05. This component is selected for the design is because it is easy to set up and it has good communication range. Also it is low cost.

2.2 Receiving Module

The main purpose of this module is to display the wirelessly transmitted measurements of the Level Module a LCD screen mounted on the receiving module. The module consists of a microcontroller, a Bluetooth, four AAA batteries, a power switch, and a LCD display. The LCD displays the level of a surface in the x, y, z directions, and also the temperature of the immediate environment of the level module. This module will wirelessly communicate with the level module.

The display used in the Receiver Module will be the Hitachi HD 44780 dot matrix LCD module. This certain LCD display allows two lines of 16 characters display. The screen will take inputs

from the microcontroller and display them for users.

The microcontroller used in the Receiver Module will also be the MSP430. This device is the primary control unit for the Receiver Module where it will be responsible for translating the digital output from the Bluetooth into signals for the LCD display.

3 Design Details

3.1 Level Module

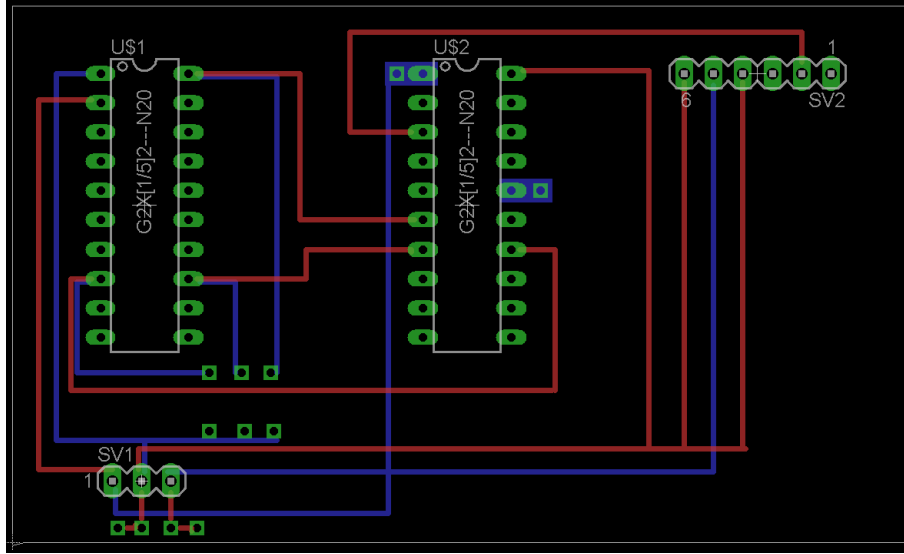


Figure 4. Level module PCB

One of the main components in this module is the DE-ACCM3D accelerometer. If the accelerometer is not moving, it will sense the gravity and the tilt angle and output 3 analog signals to represent the three directions. Just as mentioned in 2.1, the voltage value with 0 tilt angle is 1.66 and the corresponded voltage from -90 to +90 is about 1.33 to 1.99. This is not always accurate; it is necessary to use a known perfect horizontal plane to calibrate the 0-tilt angle V_0 , and the sensitivity. After measuring the calibrated value, the below equation can be used to calculate the tilt angle:

$$\text{angle} = \sin^{-1}\left(\frac{V_{xyz} - V_0}{\text{sensitivity}}\right)$$

The V_{xyz} in the equation are the output voltage and the sensitivity can be given by the below chart:

Operating voltage	Sensitivity
3.6V	360 mV/g
3.33V (default when using onboard regulator)	333 mV/g
3.0V	300 mV/g
2.0V	195 mV/g

Figure 5. Accelerometer Sensitivity

Since the regulate reference voltage is 3.3, the sensitivity in the design is 333 mV/g. The output analog signals will then be converted in to digital signals via msp430g2553. In the msp430, the ADC10 module in the chip is used to make the analog signal in to 10 bit digital signal. Below is a flow chart of the ADC10 function:

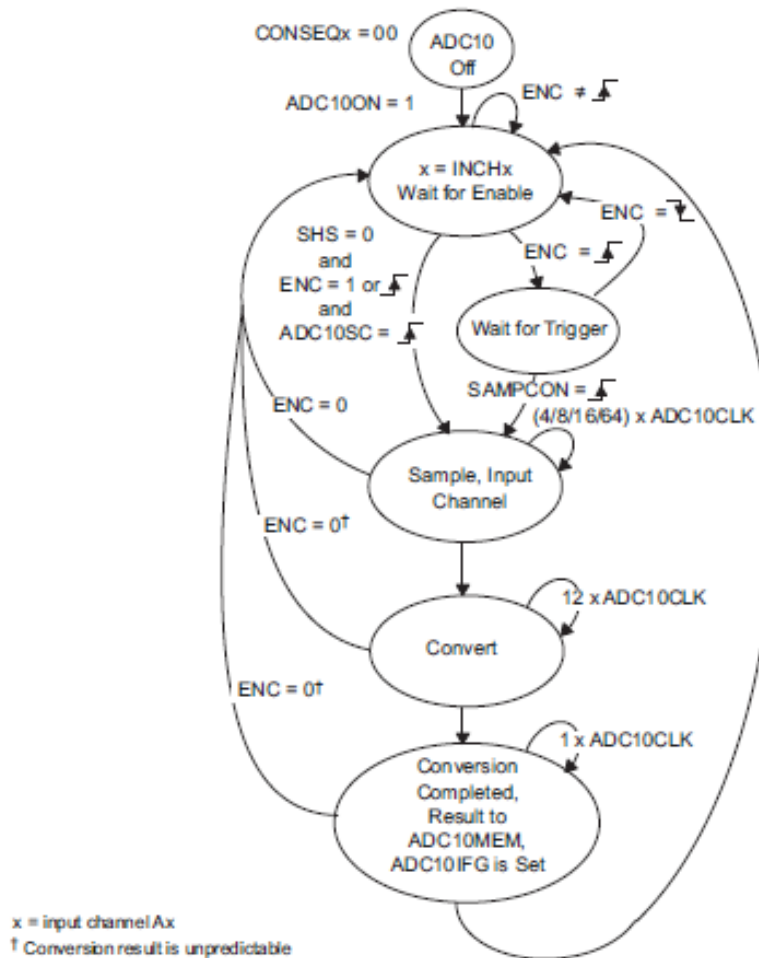


Figure 6. ADC10 State Diagram

From the flow chart we can see that $1 + 1 + 1 + 8 + 12 + 1 = 24$ clock cycles are used to complete each conversion. Since we need 4 cycles (including the temperature) and the clock

cycle used is 1 MHz, the time used to make the ADC is about 96 us. The digital data can be calculated by the below equation:

$$N = 1023 \times \frac{V_{in} - V_{ref-}}{V_{ref+} - V_{ref-}}$$

In the design

$$V_{ref+} = 3.3$$

$$V_{ref-} = 0.$$

After converting, the data will be transferred to characters and transfer to the receiving module by using the Bluetooth. The wireless connection design will be explained in 3.3.

3.2 Receiving Module

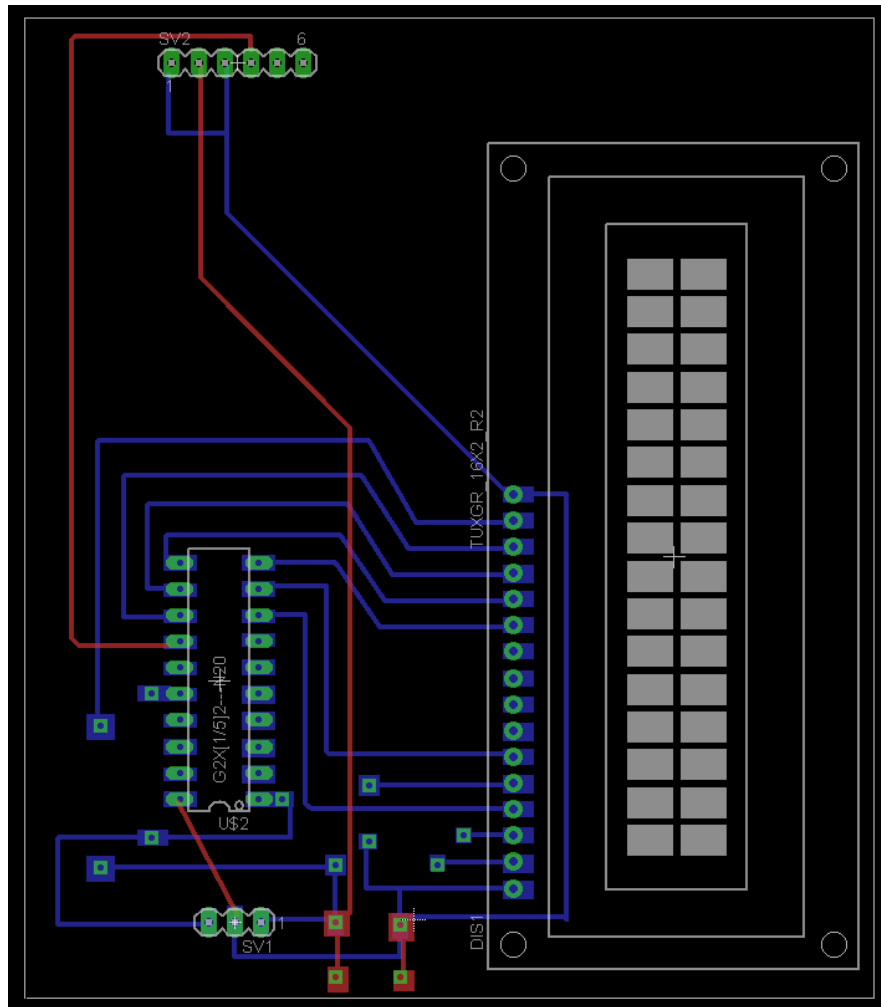


Figure 7. Receiver module PCB

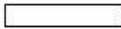
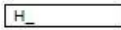
The receiving module receives data from the level module and displays the data in HD44780. The HD44780 is a 2*16 dot-matrix liquid crystal display that can display alphanumeric and Japanese kana characters. The display can be used in two different mode, 8-bit mode or 4-bit mode. The difference between them is 4-bit mode send 8-bit data in 2 cycles. However they use same instruction sets. The examples of instructions are as below:

FUNCTION	WRITE	D7	D6	D5	D4	D3	D2	D1	D0	WAIT TIME
Clear Display	Instruction	0	0	0	0	0	0	0	1	5 ms after write
Cursor Home	Instruction	0	0	0	0	0	0	1	N/A	5 ms after write
Entry mode	Instruction	0	0	0	0	0	1	I/D	S	120 μ s
Display on/off	Instruction	0	0	0	0	1	D	C	B	120 μ s
Cursor & display shift	Instruction	0	0	0	1	S/C	R/L	N/A	N/A	120 μ s
Function set	Instruction	0	0	1	DL	N	F	N/A	N/A	120 μ s
Set cursor address	Instruction	1	A	A	A	A	A	A	A	120 μ s
Write data to cursor location	Data	D	D	D	D	D	D	D	D	120 μ s

Figure 6. LCD Instruction Set

The HD44780 changes cycle every time enable changes from high to low.

The 4-bit mode is selected for the design because we want to use less pins. However, we need to initialize the HD44780 before entering the 4-bit mode. The below table shows how the initialization is setup:

Step No.	Instruction						Display	Operation
	RS	R/W	DB7	DB6	DB5	DB4		
1	Power supply on (the HD44780U is initialized by the internal reset circuit)							Initialized. No display.
2	Function set 0 0 0 0 1 0							Sets to 4-bit operation. In this case, operation is handled as 8 bits by initialization, and only this instruction completes with one write.
3	Function set 0 0 0 0 1 0 0 0 0 0 * *							Sets 4-bit operation and selects 1-line display and 5 x 8 dot character font. 4-bit operation starts from this step and resetting is necessary. (Number of display lines and character fonts cannot be changed after step #3.)
4	Display on/off control 0 0 0 0 0 0 0 0 1 1 1 0							Turns on display and cursor. Entire display is in space mode because of initialization.
5	Entry mode set 0 0 0 0 0 0 0 0 0 1 1 0							Sets mode to increment the address by one and to shift the cursor to the right at the time of write to the DD/CGRAM. Display is not shifted.
6	Write data to CGRAM/DDRAM 1 0 0 1 0 0 1 0 1 0 0 0							Writes H. The cursor is incremented by one and shifts to the right.

Note: The control is the same as for 8-bit operation beyond step #6.

Figure 7. 4 Bit Mode Initialization

After the initiation it takes 3 clock cycles to display a character. To refresh a full display we need no more than 96 clock cycles which is about 96 μ s since the clock rate used in the msp430 is also 1MHz. Although the time is not longer than the converting time in the level module, for stability reason, the function is delayed 100 clock cycles every time before conversion to prevent transmitting error.

3.3 wireless

The wireless part is completed by the Bluetooth HC-05. The data send into the master module will be output to the slave module with some delay depending on the distance. In order the character transition to work wirelessly, both msp430 in level module and the receiver module in required to work in the UART mode. The below graph show how the UART is set up:

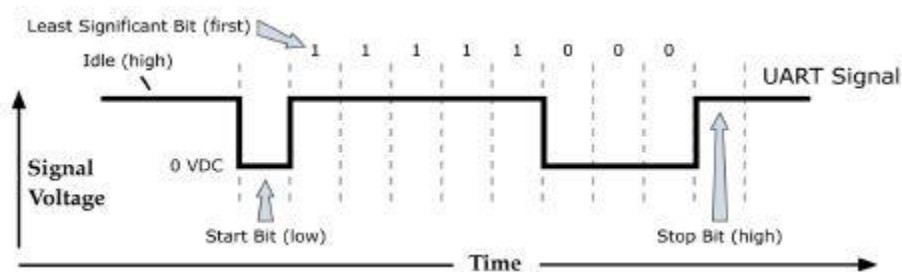


Figure 8. UART Signal Waveform

The transmitter will start by sending a low bit as a start bit. Then the data bit will be sending from the least significant bit to the most significant bit. The transition will end by pulling the signal to high. On the receiver end, the receiver will start receiving data every time it detects a high to low transmission when it is in idle state. The baud rate used in this design is 9600.

4. Design Verification

4.1 Accelerometer

The accelerometer chips purchased are ready to use but tests are required in order to verify proper usage. The test results of the accelerometer are below. The accelerometer is outputs V_x , V_y , V_z based on the orientation of the accelerometer position and the acceleration forces that it detects. The voltage outputs are directly connected to the microcontroller in the level module and further processed within the micro controller.

For the accelerometer, there were three main tests conducted, the first being the power on/off tests, the second being the V_{ref} measurement test, and the third bring the V_x , V_y , V_z voltage measurement testing. Power was connected to the accelerometer and it passed the power on/off test with ease. For the second and third test, the data results were made with LABVIEW and are below:

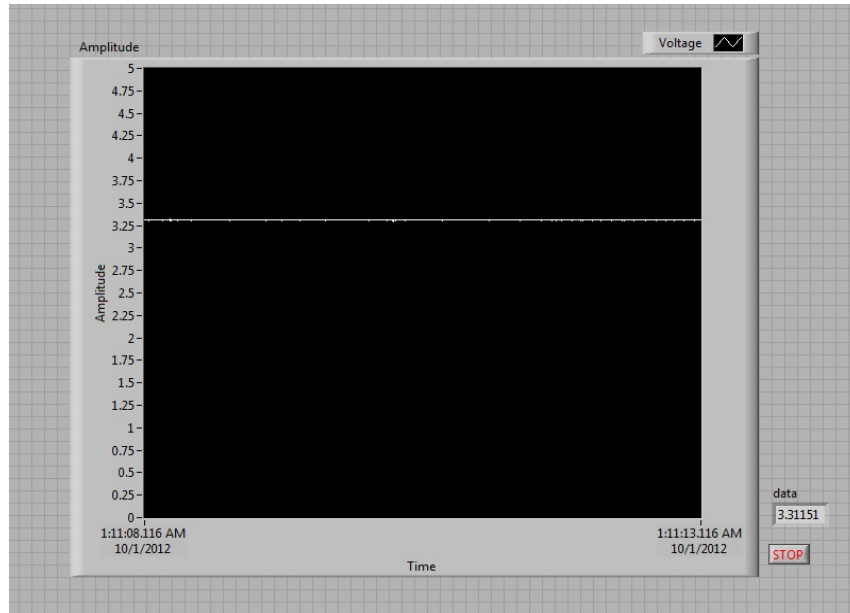


Figure 9. Voltage Reference

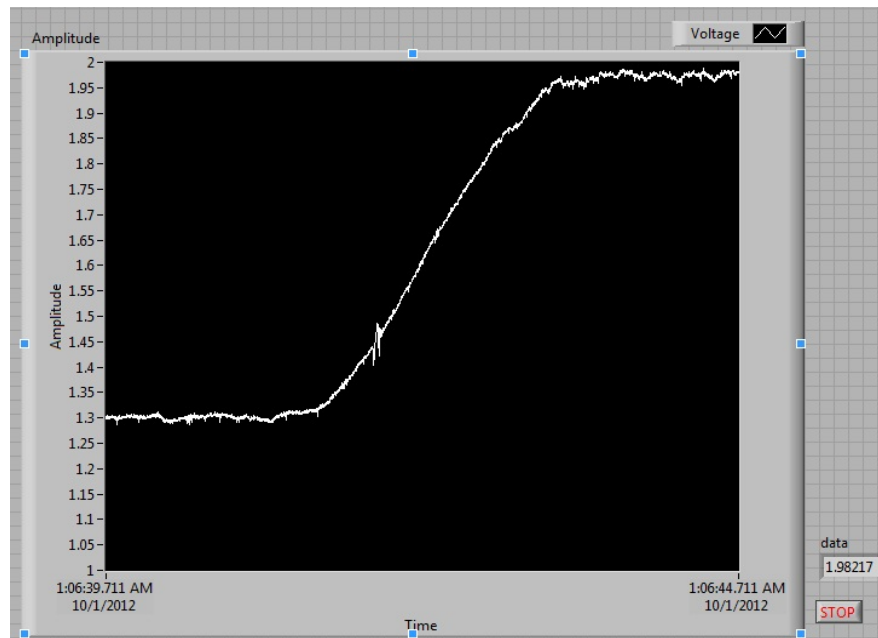


Figure 10. Accelerometer Angle Voltage

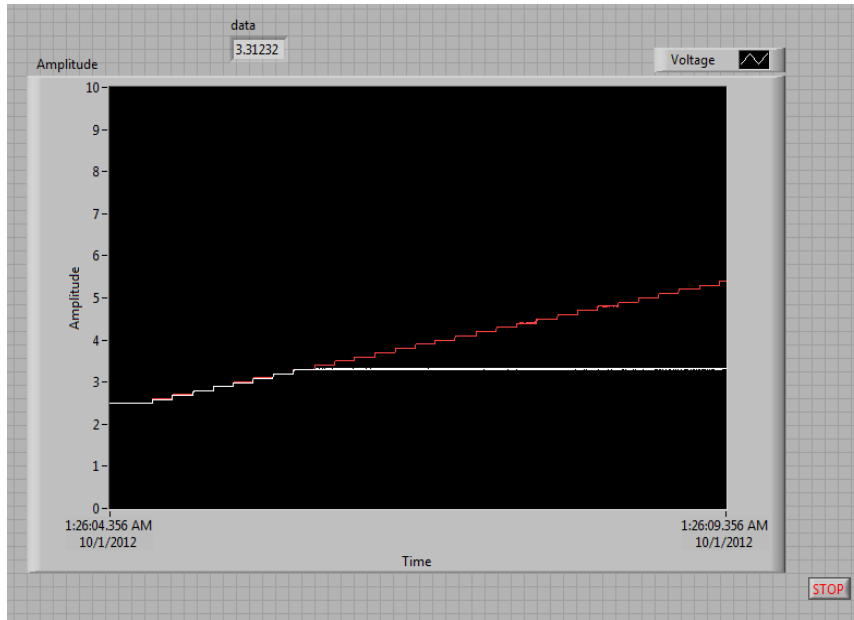


Figure 11. Reference Voltage vs. Power Supply

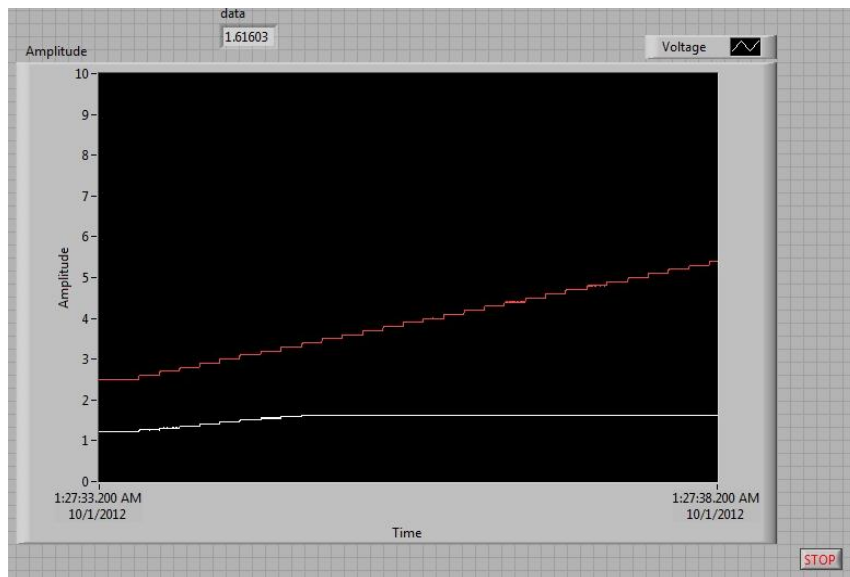


Figure 12. Accelerometer Angle Voltage vs. Power Supply

Figure 9 shows that V_{ref} is relatively stable at 3.3V. Figure 10 is the voltage swing of V_x , V_y , V_z as the accelerometer is rotated from -90 degrees to +90 degrees. Figure 11 shows that V_{ref} will stable at 3.3V regardless of power supply input. Figure 12 shows that angle voltage swing will also be stable regardless of power supply input.

4.2 Accelerometer to MSP430

To test whether the msp430 correctly converted the analog inputs into digital data, some if-else statement and LEDs are used. Each of the digital data representing the tilt angles is stored in individual variables. If-else statement is used to test whether the tilt angles is in the range or not. Each range of tilt angle should correspond to a LED. After setting up the LEDs and the test code, the LEDs successfully turned on in the corresponding range of angle.

After this a new set of floating point variable is use to represent the tilt angle. The same method is use to check whether the tilt angles are correctly calculated.

LED	1	2	3	4	5
Digital Data	819~ 1023	614~ 818	409~ 613	204~ 408	0~ 203
Angle	+54~ +90	+18~ +53	-18~ +17	-54~ -19	-90~ -55

Figure 13. Corresponding digital data to angle

4.3 MSP430 to LCD

To test whether the LCD functions correctly, we had followed the data sheet provided by the LCD to initialize the LCD and display a cursor.

To test whether the MSP430 and the LCD can communicate, we had programmed the MSP430 such that it stores the digital data in the registers and see whether it can convert the digital data into tilt angles and output to the LCD. We checked whether the angle is correct by using the formula sheet provided by the accelerometer package.

4.4 Bluetooth

Oscilloscope is used to check the Bluetooth. A square wave is sent to verify the basic connection. The output and input are same when the characters are transferred.

4.5 Power supply

The output current for the level module is 25mA and 36mA for the receiver module. For an AA battery that has 2200 mAh, the life time is 88hr and 61hr. this fulfill the 60hr use time.

4. Costs

4.1 Parts

Table 1 Parts Costs

Part	Manufacturer	Retail Cost (\$)	quantity	Actual Cost (\$)
Accelerometer/DE-ACCM3D	Dimension Engineering	35.00	1	35.00
MSP430 Package	Texas Instrument	4.00	1	4.00
LCD/44780	Hitachi	13.00	1	13.00
Bluetooth/HC-05	Itead Studio	25.00	2	25.00
Acrylic Board	Home Depot	20.00	1	20.00
Voltage Regulator/UA78M33C	Texas Instrument	0.056	2	0.112
AA Battery	Duracell	1.19	8	9.52
Total				106.632

4.2 Labor

Table 2 Labor cost

Name	Hourly Rate	Total hour Invested	Total cost
Stephone Shieh	\$30.00	120	\$3600
Thurston Lee	\$30.00	120	\$3600
Po-Yu Kung	\$30.00	120	\$3600
Total	\$90.00	360	\$10800

4.3 Total cost

From the below equation:

Total cost = Parts + (ideal salary (hourly rate) x actual hours spent x 2.5)

Our total cost is $106.632 + 30 \times 120 \times 2.5 = 9106.632$.

5. Conclusion

5.1 Accomplishments

We are pleased with how our project turned out. The level module has proven to be successful in transmitting the data to the receiving module and the receiving module can display the tilt level accordingly.

5.2 Ethical considerations

We ensure that we will comply with the standards of the IEEE Code of Ethics

Ethic	
1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment	Using our project will not create harm to the safety, health, and welfare of the public through inconsistent data output that might lead to dangerous actions.
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist	All of our design and data will be available for public view.
3. to be honest and realistic in stating claims or estimates based on available data	We will not falsify data through programming simplifications. We will also give credit, and cite our sources whenever sources are used through IEEE citation.
4. to reject bribery in all its forms	We will not be bribed. We will design our products based on the best solution instead of choosing parts or designs based on bribery.
6. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others	We will seek and accept criticism of technical work from all to ensure an error-free product. We will also credit properly the contributions of others.
7. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin	All will be treated fairly regardless of personal factors. The product that we intend on pursuing will be a product for all.
8. to avoid injuring others, their property, reputation, or employment by false or malicious action	We will avoid injuring others, their properties, reputation through any usage of our product.

5.3 Future work

There are a number of design parameters that could be improved in future designs of this product. To increase to range of our product (currently being 20 meters), we can replace the communication unit from Bluetooth to XBee. This could increase the range to about 150 meters.

To conserve energy, we can also add a function that could turn off the power of the level module remotely from the receiver module. Another possible feature could be the connection of our device with computers.

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