Design and Realization of A Low Cost Clinometer based on ADXL345 Sensor, Ultrasonic Sensor, and Android based Smartphone

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Abstract. Manually height measurement using a measuring instrument with a limited scale range can hamper the performance of building construction activities. To deal with this problem, a device is needed to be able to measure the height of the building more quickly, has a larger measuring limit, and is easy to use on the measurement of the inner building that is on a flat plane. This paper describes a prototype of clinometer using ADXL345 accelerometer sensors connected to Android-based smartphones. Other components that build this system are HC-SR04 ultrasonic sensor, HC-05 bluetooth module, and Arduino Uno microcontroller. The proposed system is able to connect with Android-based smartphones through the connection of the HC-05 bluetooth module, retrieving distance data through ultrasonic sensor readings and elevation angle data via the ADXL345 sensor, sending or receiving data from an Android smartphone to Arduino and vice versa, calculating the approximate height, and display it on the Android based smartphone. Experimental results show that applications installed in Android-based smartphone can display the results of approximate height. The proposed instrument can quickly calculate the approximate height of a building with an error percentage of 2.5%. The maximum distance from the proposed instrument to the building is 1.75 m.

1. Introduction

Measuring the length or height of an object by using the conventional equipment is limited by its measuring scale. There are two possible approaches to cope such condition. One could employ the equipment with the larger scale and higher precision. However, it is simplest way but costly. The other way applies indirect measurement to render the actual measurement. To make it clear, imagine that a student is given a task to find the height of a building. It is widely known that one can use the theodolite to gain the height of a building. In principle, the theodolite is a device which consists of telescope placed on a rounded base (disk) that can be twisted around the vertical axis, allowing the horizontal angle to be read. The telescope is also mounted on the second disk and can be rotated around the horizontal axis, allowing vertical angles to be read. So far, the theodolite is an expensive equipment to measure the length or height of some objects [1]. To overcome the unavailability of an instrument, an indirect measurement could be done by using a protractor as illustrated in Fig. 1a. The measurement results are provided by such a way using trigonometric rule. If the dangling string is
steady, then the angle between the midpoint of the protractor (90º) and the point where the string crosses the rim can be counted by subtracting one from the other as shown in Fig. 1b. In that case, the height of a building becomes the product between a horizontal distance from an observer to building and the tangent of the angle. Such equipment is called a protractor clinometer [2].

![Fig. 1. Indirect measurement of the height of building by a protractor [2]](image)

The clinometer has been recently used in sport and health [3]–[5], structural health monitoring and geotechnical measurements [6], [7], automatic excavator [8], and so on. In medical field, clinometer was used to measure range of motion of a patient’s body part such as shoulder [4], ankle [5], wrist of patients whose paretic hand [9], and so forth. In this recent our work, the clinometer is designed to measure an angle and calculate the approximate height of the building. As previously described, the information that needed to get the height of an object is the horizontal distance and an appropriate angle. With advances in microelectronics technology, especially fabrication of electronic sensor devices, measuring instruments can be made cheaper, smaller, and more practical. Along with this advancement, we could employ the electronic sensors to gain a horizontal distance and an appropriate angle in indirect measurement of the height of a building. It is widely known that the ultrasonic sensor was used to measure a range detection and obstacle recognition in robots [10], [11], to detect road surface for supporting an elderly and visually impaired people [12], to support vector machine–based fall detection [13], to calculate the liquid volume inside oil tank [14], and so forth. In that case, we employ the ultrasonic sensor to gain a horizontal distance between the instrument and the building. Meanwhile, we obtain an appropriate angle by using the ADXL345 accelerometer sensor. Such sensor has been used in a self-balancing robot [15], a car data recorder for recording the condition of four-wheeled vehicles [16], fall detection for elderly people [17], digital pedometer [18], for name a few.

Nowadays, smartphone user penetration is estimated to touch the two billions in 2015 [19] and there are approximately 2.7 billion smartphone users around the world in early 2019 [20]. In US, smartphone has become the second-most-common product with 87% penetration [21]. Smartphones with an Android-based operating system have been used extensively for applications that enhance the functionality of these smartphones [4], [7], [19], [22]. In line with this advancement, this paper describes the use of Android-based smartphones to realize an altitude measuring instrument with an ADXL345 sensor as the main component that can detect elevation angles and the ultrasonic sensor for gaining the horizontal distance. Furthermore, the data obtained from the sensor is then processed by the microcontroller and displayed in a smartphone via Bluetooth HC-05 module. Using data obtained from the two sensors, the height of objects or buildings is calculated by the principle of simple trigonometry. Furthermore, the measurement results are displayed visually in the smartphone.
2. System design

Block diagram of the proposed instrument is shown in Fig 2. Based on Figure 2, two sensors namely ADXL345 and HC-SR04 are employed in this instrument. An Arduino Uno R3 type microcontroller is used as the main data processor which collects and proceeds data from those sensors to be sent to the smartphone using the Bluetooth module HC-05. Meanwhile, the servo motor is installed to move the laser pointer as a marker of height to be measured.

ADXL345 sensor is an accelerometer sensor that is used to obtain an elevation angle between buildings measured by horizontal lines, while the HC-SR04 sensor is an ultrasonic sensor that is used to determine the horizontal distance between objects or buildings as measured by instruments. ADXL345 is a 13-bit resolution 3-axis motion sensor / acceleration module that can detect a pull at a range of up to 16 g (g = gravitational acceleration). The application includes detecting slope by monitoring changes in static attraction and dynamic acceleration arising from movements or collisions. With the high resolution it produces, this sensor is able to detect inclination smoothly less than one degree. It can detect movement activity status by comparing the acceleration on any axis with a sensitivity threshold that can be set through the programming code. In addition, this module provides tap sensing that can detect single or multiple beats in various directions. It can also detect free-fall sensing. These functions can be mapped separately on the two output pins contained in the device. The ADXL345 sensor has a 32-bit static internal memory management system with FIFO (first-in first-out) queue type that can be used to store measurement variables / temporary data so as to reduce microcontroller loads and generally reduce system energy consumption. This module has a sophisticated power management circuit where the modules are placed in a very small power consumption mode until detected movements that pass a certain threshold that reactivate normal mode. After the reading process is complete, the module is automatically returned to standby mode to save energy. The physical form of ADXL345 is shown in Figure 3.
Meanwhile, the HC-SR04 sensor is a ready-to-use ultrasonic sensor that can be used to measure the distance of objects from 2 cm to 4 m with an accuracy of 3 mm. This sensor has 4 pins, namely Vcc, GND, Trig, and Echo. Trig pins are used to trigger signals sent from sensors, while Echo pins are used to capture reflected signals from objects to be measured. The physical form of the HC-SR04 sensor is depicted in Figure 4. In ultrasonic sensors, ultrasonic waves are generated through a material called piezoelectric with a certain frequency. This piezoelectric will produce ultrasonic waves (generally with a frequency of 40 kHz) when an oscillator is applied to the sensor. In general, this device will direct ultrasonic waves towards an area or a target. After the wave touches the target surface, the target will reflect back the wave. Reflection waves from the target will be captured by the sensor. Furthermore, the distance could be calculated based on the difference between the wave delivery time and the reflected wave time received.

As the main processor in this instrumentation system, the Arduino Uno R3 type microcontroller is used to process data and connect among components in the system. It is an ATmega328P chip-based microcontroller development board which has 14 digital input-output pins with six pins can be used as PWM output, six analog input pins, using 16 MHz crystal oscillator, USB connection, ICSP header, and reset button. The physical form of the microcontroller is shown in Figure 5.

All components used in the proposed instrument are placed in a black plastic box with dimensions of 5 cm high, 12 cm long, and 8 cm wide. The compact shape of the proposed instrument is given in Figure 6(a). At the front of the box there are two holes for placing the transmitter and receiver of ultrasonic sensor. In addition, a laser pointer is installed to give a marker of the top of the object or building to be measured in height. The pointer can move freely through the motion mechanism produced by the servomotor. The servomotor motion is adjusted by sending the instructions from the smartphone. Meanwhile, the application program created and displayed on the smartphone is given in Figure 6(b). In this view, section 1 is used to access the list of addresses and available Bluetooth names, while section 2 is enabled to activate the application with the chosen Bluetooth address and name. Section 3 is used to drive a servomotor in the proposed instrument. The servomotor is moved up and down by pressing parts 4 and 5, while the laser pointer is turned on by pressing section 6. Section 7 is the result of reading the ADXL345 sensor, while section 9 marks the results of the HC-SR04 sensor.
sensor reading. Section 8 is filled with the height of the instrument from the ground. After all the required data filled in, a button whose number 10 in display is used to execute the calculation result and the approximate height of the building is shown in section 11. Meanwhile, realization of the proposed instrument is shown in Figure 7.

![Fig. 6. The compact shape of the proposed instrument (a) and display on the smartphone (b)](image)

3. Results and Discussion

In experimental setup, we firstly tested the accuracy of sensor readings by comparing the values that appear in the Arduino IDE serial monitor with those randomly sent to the Android interface via HC-05 Bluetooth module. The ADXL345 sensor will move along with the servomotor movement. Whenever the servomotor is actuated by pressing the button on the Android interface, the ADXL345 sensor will move up, down, or go to its initial position according to the instruction signal sent from an Android based smartphone. Experimental results show that the reading of the ADXL345 sensor is the same as that shown on the Android interface so that it can be used as measurement data. Meanwhile, ultrasonic sensor testing is done by comparing the sensor readings to the horizontal distance between the proposed instrument and the wall of the building to be measured in its actual distance. The results of ultrasonic sensor testing are given in Table 1. As observed from Table 1, the discrepancy between measurement data gained by sensor and its actual distance is below 0.001 % for horizontal distance of more than 0.15 m. Based on those results, measurement data obtained by employing ultrasonic sensors can be used as reference data for determining the horizontal distance between the proposed instruments and buildings to be measured.

After all the components are integrated, experimental testing of the proposed instrument is done by comparing the results of sensor measurements and height calculations by the application program.
installed in a smartphone with actual height measured manually. In this experiment, the proposed
instrument is placed 1 m above the ground. Experimental results are tabulated in Table 2. The fist
column on Table 2 indicates the readings of angle data in degree when the ADXL345 sensor is moved
by the servomotor such that the laser pointer points to the tip of the measured building. Meanwhile,
the second column of Table 2 shows the readings of horizontal distance in metres between the
proposed instrument and wall of the measured building. The maximum distance from the proposed
instrument to the building is 1.75 m. Based on the results of that experiment, the designed clinometer
shows quickly calculate the approximate height of a building with an error percentage of 2.5 %.

Table 1. Comparison of HC-SR04 ultrasonic sensor data and actual distance

| sensor data (m) | actual distance (m) |
|----------------|--|------------------|
| 0 | 0.01 |
| 0 | 0.02 |
| 0.15 | 0.15 |
| 0.30 | 0.30 |
| 0.50 | 0.50 |
| 1.20 | 1.20 |
| 1.34 | 1.35 |
| 1.61 | 1.60 |
| 2.32 | 2.30 |
| 2.67 | 2.65 |

Table 2. Experimental results of the proposed clinometer

| ADXL345 (deg) | HC-SR04 (m) | Approximate height displayed in smartphone (m) | Actual height (m) |
|---------------|--|------------------|--|
| 30 | 0.25 | 1.14 | 1.14 |
| 30 | 0.50 | 1.28 | 1.29 |
| 30 | 0.75 | 1.43 | 1.43 |
| 30 | 1.00 | 1.58 | 1.58 |
| 30 | 1.25 | 1.72 | 1.72 |
| 30 | 1.50 | 1.87 | 1.87 |
| 30 | 1.75 | 2.50 | 2.01 |
| 45 | 0.25 | 1.25 | 1.25 |
| 45 | 0.50 | 1.50 | 1.50 |
| 45 | 0.75 | 1.75 | 1.75 |
| 45 | 1.00 | 2.00 | 2.00 |
| 45 | 1.25 | 2.25 | 2.25 |
| 45 | 1.50 | 2.50 | 2.50 |
| 45 | 1.75 | 2.75 | 2.75 |
| 60 | 0.25 | 1.43 | 1.43 |
| 60 | 0.50 | 1.87 | 1.87 |
| 60 | 0.75 | 2.29 | 2.30 |
| 60 | 1.00 | 2.73 | 2.73 |
| 60 | 1.25 | 3.17 | 3.17 |
| 60 | 1.50 | 3.59 | 3.60 |
| 60 | 1.75 | 4.03 | 4.03 |
4. Concluding remarks
This paper has discussed the design and realization of the clinometer using the ADXL345 accelerometer sensor as a slope detection sensor and HC-SR04 ultrasonic sensor as a horizontal distance measuring sensor between instruments with objects or buildings to be measured in height. Data from the sensor is then processed by the microcontroller and then sent via HC-05 Bluetooth module to an Android-based smartphone. Data from sensors and measurement results are displayed in the smartphone device. Experimental results show that the proposed instrument provides measurement accuracy with an error percentage of around 2.5%.

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