Practical Application of Low-Cost Sensors for Static Tests

Seyedmilad Komarizadehasl[1], Behnam Mobaraki[2], Jose A. Lozano-Galant[2], and Jose Turmo[1]

[1]Department of Civil and Environment Engineering, Universitat Politècnica de Catalunya, BarcelonaTech. C/ Jordi Girona 1-3, 08034, Barcelona, Spain. Seyedmilad.komarizadehasl@upc.edu, jose.turmo@upc.edu

[2]Department of Civil Engineering, Univesidad de Castilla-La Mancha. Av. Camilo Jose Cela s/n, Ciudad Real, 13071, Spain. behnam.mobaraki@uclm.es, Joseantonio.lozano@uclm.es

Abstract. *Structural Health Monitoring (SHM) is essential to assess the accuracy of durability predictions of structures. Using low-cost sensors on structural evaluation has gained significant attention compare to high-cost sensors. Although these may not be as accurate and sensitive as the expensive electronic devices, with efficient code and right use, there is a possibility of getting useful information from them. These sensors can vary based on their functionality and the measurements they provide. For example, one is highly sensitive to the light of its environment while the other kind would give different results in different temperatures. In this paper, three different displacement measuring sensors have been studied. An ultrasonic sensor (HC-SR04) and two different types of laser sensors (VL53L0X and VL53L1X) are investigated in the paper. An Arduino Mega has captured their measured data, and a raspberry pi has made the acquisition. Not only issues regarding coding and placing of these sensors have been presented ultimately, but precise solutions for the aforementioned problems as well as an efficient way of assembling all the sensors are also presented in this paper. The data generated from these electronic devices can be used for Structural Health Monitoring applications.*

Keywords: *Low-Cost Sensors, Distance Measurement, Internet Of Things (IoT), Accuracy and Sensibility, Structural Health Monitoring.*

1 Introduction

Recently, the need for using sensors in structures for monitoring and inspection of their health state is growing. With this, the need for more economical means of doing SHM is getting very great attention. In this paper, a few models of static sensors have been presented. Moreover, the characteristics of each of them have been explained. Each type could be used in specific situations, and each one has advantages as well as disadvantages in different ambient (Komarizadehasl *et al.,* 2020a; Komarizadehasl *et al.,* 2020b). For being able to work with these sensors, first briefly, Arduino Uno (which is the central programable logic controller (PLC) in this project) would be introduced. Secondly, three different types of ranging sensors would be introduced along with their specifications. Each type of sensor may use a different way to send its data. Thirdly, different ways of communicating with this PLC will be presented. Finally, the results of these sensors against different situations, objects, and colors would be illustrated (Mobaraki *et al.,* 2020; Mobaraki and Vaghefi, 2016).

2 State of the Art

In this section, the sensors and a microcontroller that has been used in the project will be reviewed along with their technical descriptions.

2.1 Arduino Uno

Arduino (Figure 1) is an open-source electronics platform based on easy-to-use hardware and software. Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins, six analog inputs to measure and convert the voltage to a digital value. It facilitates numerous interfaces to communicate with other microcontrollers and computers such as Inter-Integrated Circuit (I2C), Serial Peripheral Interface (SPI), and Universal asynchronous receiver/transmitter (UARTA). The board can work on an external power supply via a USB port or a power jack. An integrated development environment (IDE) is available for writing, compiling, and developing the code. This IDE supports a dialect of C/C++ using specific regulation of code organizing (Pasha, 2016).
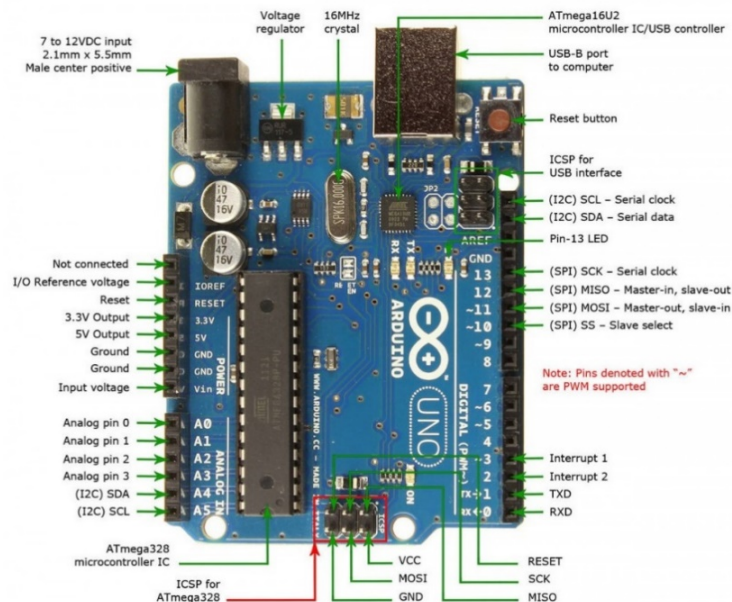

Figure 1. Schematic of the Arduino Uno.

2.2 Ultrasonic Sensors

Ultrasonic ranging module HC - SR04 (Figure 2) provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules have transmitters, receivers, and processing circuits. The basic concept of work is: firstly, using the I\O trigger for at least 10uS (microsecond) high-level signal. Secondly, The Module automatically sends a frequency of 40 kHz and detects whether there is a pulse signal back. Finally, the range can be calculated through the time interval between sending trigger signals and receiving an echo signal. Test distance = (time × velocity of sound (340M/S)) (Kamal and Hemel, 2019). The technical specification of the use sensor is in Table 1.

**Figure 2.** Schematic of an Ultrasonic ranging module HC-SR04.

Table 1. Technical specification of the ultrasonic sensor.

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	20Hz
Max Range	4m
Min Range	2cm
Measuring Angle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm

The speed of sound can vary based on temperature and humidity. For calibrating the speed of sound, another kind of sensor had to be used.

2.2.2 Temperature and humidity sensor

As it has been written in section 2.2, for measuring the distance using that sensor, the speed of sound is needed. The sound travels at different speeds in different temperatures and humidity. DHT22 (Figure 3a) has already been calibrated during the production process and provides accurate information (Liu, 2013). The technical specification of the use sensor is in Table 2. Wire connecting illustration is as follows:

a)   b)   c)
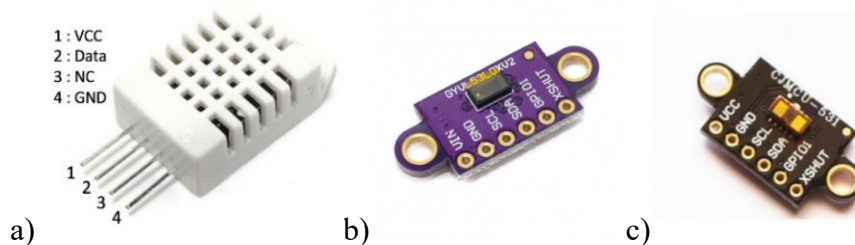
Figure 3. a)Schematic of a DHT22, digital temperature, and humidity sensor, b) Schematic of a VL53L0X, c) Schematic of a VL53L1X.

Table 2. Technical specification of DHT22.

Working Voltage	3.3-6V DC
Working Current	0.3mA
Sensing element	Polymer capacitor
Operating range	Humidity: 0-100%RH Temperature: 40~80Celsius
Accuracy	Humidity: +-2%RH(Max+5%RH) Temperature: <+0.5Celsius
Resolution or sensitivity	Humidity: 0.1%RH Temperature: 0.1Celsius
Repeatability	Humidity: +-1%RH; Temperature: +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	14*18*5.5mm

2.3 The VL53L0X

The VL53L0X (Figure 3b) is a new generation Time-of-Flight (ToF) laser-ranging module housed in the smallest package on the market today, providing accurate distance measurement whatever the target reflectance, unlike conventional technologies. The technical specification of the use sensor is in Table 3.

Table 3. Technical specification of VL530L0X.

Working Voltage	2.6-5.5V DC
Working Current	10mA up to 40mA
Working Frequency	50Hz
Output format (I²C)	16-bit distance reading (in millimeters)
Distance measuring range	Up to 2m with a minimum range of 3cm
Weight without header pins	0.5 g
Dimension	13*18*2mm

It can measure absolute distances up to 2m, setting a new benchmark in ranging performance levels, opening the door to various new applications. The VL53L0X integrates a leading-edge SPAD array (Single Photon Avalanche Diodes) and embeds ST's second generation FlightSenseTM patented technology. The VL53L0X's 940 nm VCSEL emitter (Vertical-Cavity Surface-Emitting Laser), is invisible to the human eye, coupled with internal physical infrared filters, it enables longer ranging distances, higher immunity to ambient light, and better robustness to cover glass optical crosstalk (Adafruit, 2016).

2.4 The VL53L1X

The VL53L1X (Figure 3c) is a state-of-the-art, Time-of-Flight (ToF), laser-ranging sensor, enhancing the ST FlightSense™ product family. It is the fastest miniature ToF sensor on the market with accurate ranging up to 4 m and fast ranging frequency up to 50 Hz Housed in a miniature and reflowable package, it integrates a SPAD receiving array, a 940 nm invisible Class1 laser emitter, physical infrared filters, and optics to achieve the best ranging performance in various ambient lighting conditions with a range of cover window options. Unlike conventional IR sensors, the VL53L1X uses ST's latest generation ToF technology, which allows absolute distance measurement, whatever the target color and reflectance. It is also possible to program the size of the ROI on the receiving array, allowing the sensor FoV to be reduced. The technical specification of the use sensor is in Table 4.

Table 4. Technical specification of VL53L1X.

| Working Voltage	2.6-5.5V DC
Working Current	10mA up to 40mA
Working Frequency 1-Short: up to ~130 cm 2-Medium: up to ~300 cm in the dark 3-Long: up to 400 cm in the dark	1-50 Hz max sampling rate (most immune to interference from ambient light) 2- 30 Hz max sampling rate 3- 30 Hz max sampling rate
Output format (I²C)	16-bit distance reading (in millimeters)
Distance measuring range	Up to 2m with a minimum range of 4cm
Weight without header pins	0.5 g
Dimension	13*18*2mm

2.5 Price

In Table 5, information regarding prices of the introduced sensors has been given, VAT included.

Table 5. Price of used electronic gadgets.

Arduino Uno	10.99€
Ultrasonic Sensor	3.00€
VL53L0X	6.5€
VL53L1X	15.0€
DHT22	6.5€
16 GB SD card + Sd card module	5.56€+2.5€

3 Communication Ways

While many sensors use digital and analog ports for uploading the measured data to the microcontroller, some sensors use the inter-integrated circuit (I2C) protocol. This is a protocol that allows multiple "slave" digital integrated circuits (Sensors) to communicate with one or more "master" chips (Arduino). Like the Serial Peripheral Interface (SPI), which is only intended for short-distance communications within a single device. The ultrasonic sensor and DHT22 have been connected to the Arduino's digital ports. The laser ones had to be connected to I2C port (SCL, SDA) on the board. Since both of these laser sensors had the same board addresses, introducing them to the Arduino raised a problem. For solving this issue, the X shut pin of these two sensors has been used to change their circuit address. The code was written on the Arduino platform and uploaded to the board via a USB cable. For getting the main characteristics of these sensors, a few tests have been carried on. All the different types of ranging circuits have been connected and glued together like Figure 6, so data from all 3 of them would be measured almost the same and simultaneously.
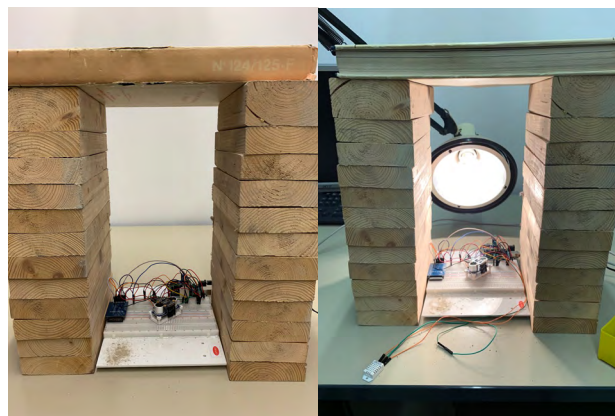
Figure 6. Experiment formation.

4 Experiments

The device was tested against the same measurement against different materials. In Figure 6, 2 tests with and without extreme ambient light have been done for getting the distance from the big book. For the one with the light bulb, the temperature sensor has been moved a bit far from the source of the light and heat. The reason was that the excruciating heat coming from the light bulb would not harm the sensor. The other tested objects were a white paper, a black paper, a clear and transparent plastic cover, and some thin tissues. In Table 6, standard deviations driven from the performed tests have been illustrated.

Table 6. Ranging results of the same experiment under different circumstances.

Tests Sensors type	a thick book	a white paper	a black paper	a transparent plastic cover	a tissue	Extreme ambient light	Extreme ambient light*
Ultra	0.61	1.87	1	0.7	352	3.23	_
Laser1	2.5	2.67	7.18	5.46	4.66	3607	39.86
Laser2	1.5	1.48	1.87	3.12	1.62	21.94	_

On this table, the last column has been created to provide filtered data from the first laser sensor due to the extreme environmental light and heat test. The filter has deleted the ranging out-puts equal to 8190. When this sensor is not able to read, or the measurement distance is more than its capacity, it declares this number.

It should be mentioned that the ultrasonic sensor, which was the chipset sensor and the easiest one to install, had shown better performances compared to the laser ones. On the downside, this sensor needs 5v interaction digital ports and needs at least 4 volts for its full functionality. The only problem with this sensor could be its data providing speed. Although the laser has a faster rate (50Hz data production), this sensor has a frequency of only 20Hz. In other words, this sensor can provide up to 20 data each second. The biggest problem with the ultrasonic sensors would be their dependence on ambient temperature and humidity, since the speed of sound changes from an environment to another. This sensor needs an accurate speed of sound for its calculations. The proposition of this paper would be using the ultrasonic sensor with a laser sensor if there was the probability of changing temperature or of extreme ambient light. Using the first laser sensor or the second one is due to what range and circumstances the experiment may experience.

5 Conclusion

Notwithstanding that the laser sensors did not have as good results as the ultrasonic one, they can be useful as well. They are smaller, lighter, and faster than the ultrasonic sensors. Moreover, have noise-free technology (no noise can enter from the wires). Moreover, they work independently of the temperature of their testing situation. Best results will only appear if an ultrasonic sensor (attached to its temperature and humidity sensor) be used alongside a Laser sensor. They can cover the downsides of each other and provide an accurate, useful set of data. The selection of Laser type one or two depends on the circumstances of the experiment. If there is enough budget, Laser type 2 provides a way better set of data and is less sensitive to ambient light.

Acknowledgments

ORCID

Seyedmilad Komarizadehasl: https://orcid.org/0000-0002-9010-2611
Behnam Mobaraki: https://orcid.org/0000-0002-2924-643X
Jose Antonio Lozano Galant: http://orcid.org/0000-0003-0741-0566
Jose Turmo: https://orcid.org/0000-0001-5001-2438

References

Adafruit, (2016). Adafruit VL53L0X Time of Flight Micro-LIDAR Distance Sensor Breakout data-sheet.

Kamal, A. and Hemel, S. (2019). Comparison of Linear Displacement Measurements Between A Mems Accelerometer and Hc-Sr04 Low-Cost Ultrasonic Sensor. ieeexplore.ieee.org.

Komarizadehasl, S., Mobaraki, B., Lozano-Galant, J.A. and Turmo, J. (2020)a. Detailed evaluation of low-cost ranging sensors for structural health monitoring applications, in: *International Conference of Recent Trends in Geotechnical and Geo-Environmental Engineering and Education*. "RTCEE/RTGEE 2020, 8–12.

Komarizadehasl, S., Mobaraki, B., Lozano-Galant, J.A. and Turmo, J. (2020)b. Evaluation of low-cost angular measuring sensors, in: *International Conference of Recent Trends in Geotechnical and Geo-Environmental Engineering and Education.* "RTCEE/RTGEE 2020,17–21.

Liu, T. (2013). Digital-output relative humidity & temperature sensor/module DHT22 (DHT22 also named as AM2302) Capacitive-type humidity and temperature module/sensor.

Mobaraki, B., Komarizadehasl, S., Castilla-Pascual, F.J. and Lozano-Galant, J.A. (2020). Determination of Enviromental Parameters Based onArduino Based Low-Cost Sensors, in: *International Conference of Recent Trends in Geotechnical and Geo-Environmental Engineering and Education.* "RTCEE/RTGEE 2020.

Mobaraki, B. and Vaghefi, M. (2016). Effect of the Soil Type on the Dynamic Response of a Tunnel under Surface Detonation. Combust. Explos. Shock Waves 52, 119–127. https://doi.org/10.1134/S0010508216030175

Pasha, S. (2016). Thingspeak Based Sensing and Monitoring System for IoT with Matlab Analysis. Int. J. New Technol. Res. 2, 19–23. https://doi.org/ISSN : 2454-4116