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DETAILED EVALUATION OF LOW-COST RANGING SENSORS FOR STRUCTURAL HEALTH MONITORING APPLICATIONS

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ABSTRACT

To evaluate the safety of structures, choosing a proper maintains protocol to assess the performance/ workability of the structures in the future, Structural health monitoring (SHM) applications are required. The SHM application usually applies to unique structures with high budgets. For using them on structures with low-budgets low-cost sensors required. Low-cost sensors are getting considerable attention compared with the expensive traditional alternatives. This paper introduces 3 types of low-cost displacement measuring sensors. These sensors were programmed and controlled by an Arduino. Acquiring data from them was done by a connected computer to the Arduino. By engaging these sensors in a few experiments and evaluating their responses, their functionality and accuracy in different situations are investigated. Moreover, the pros and cons of each one of them for each test are illustrated. By taking into account their price, their advantages on exceptional circumstances, and their reliability, different sensors for different situations have been proposed.

Keywords: Low-cost sensors, Distance measurement, Internet Of Things (IoT), Arduino Uno, Structural Health Monitoring.

1 INTRODUCTION

Recently, the need for using sensors in structures for monitoring and inspection of their health state is growing (Straub et al., 2017). With this, the need for more economical means of doing SHM is getting considerable attention (Sumitro and Wang, 2005). In this paper, a few models of static sensors have been presented. Moreover, their informative characteristics have been explained. Each type could be used in specific situations, and each one has advantages as well as disadvantages in different ambient circumstances. For being able to work with these sensors, in the first place, Arduino Uno (which is the central programable logic controller (PLC) in this project) is introduced. In the following, 3 different types of ranging sensors would be introduced along with their specifications. Each type of sensor may work in a different way to interact with the microcontroller. These different ways of interaction and communicating in the third section were explained. Finally, results of these sensors in various situations, against different objects and colors has been presented(Vaghefi and Mobaraki, 2018).

2 STATE OF THE ART

In this section, the sensors and a microcontroller that are used in this project are 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, 6 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 (Blum, 2013).

Figure 1. Schematic of the Arduino (Blum, 2013)

2.2 Ultrasonic sensor

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 the echo signal. Test distance = (time × velocity of sound (340M/S)) (Kamal and Hemel, 2019).

Figure 2. Schematic of an Ultrasonic ranging module HC-SR04 (Kamal and Hemel, 2019)

The technical specification of this sensor is illustrated in Table 1.

Table 1. Technical specification of the ultrasonic sensor (Kamal and Hemel, 2019)

Characteristic	Value
Voltage	5 V
Current	15mA
Frequency	20Hz
Range	2 cm- 400 cm
Dimension	4.5*2.0*0.15 cm

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.

2.2.1 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 3) has already been calibrated during the production process and provides accurate information (Liu, n.d.). Wire connecting illustration is as following:

Figure 3. Schematic of a DHT22, digital temperature, and humidity sensor (Liu, n.d.)

The technical specification of this sensor is illustrated in Table 2.

Table 2. Technical specification of DHT22 (Liu, n.d.)

Characteristic	Value
Voltage	3.3 DC
Current	0.3mA
Range	Humidity: 0-100%RH Temperature: 40~80Celsius
Accuracy	Humidity: +-2%RH(Max+5%RH) Temperature: <+0.5Celsius
Resolution	Humidity: 0.1%RH Temperature: 0.1Celsius
Humidity hysteresis	+-0.3%RH
Stability	+-0.5%RH/year
Sensing speed	Average: 2s
Dimensions	1.4*1.8*0.55 cm

2.3 VL53L0X

The VL53L0X (Figure 4) 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.

Figure 4. Schematic of a VL53L0X (Adafruit, 2016)

The technical specification of this sensor is illustrated in Table 3.(Mobaraki et al., n.d.)

Table 3. Technical specification of VL530L0X (Adafruit, 2016).

Characteristic	Value
Voltage	3.3 DC
Current	40mA
Frequency	Up to 50Hz
Range	3 cm- 200 cm
Dimension	1.3*1.8*0.2 cm

It can measure absolute distances up to 2m, setting a new benchmark in ranging performance levels, opening the door to various new applications (Mobaraki et al., n.d.). 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 VL53L1X

The VL53L1X (Figure 5) 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 (Adafruit, 2018).

Figure 5. Schematic of a VL53L1X (Adafruit, 2018).

The technical specification of this sensor is illustrated in Table 4.

Table 4. Technical specification of VL53L1X (Adafruit, 2018)

Characteristic	Value
Voltage	3.3 DC
Current	40mA
Frequency	
Short: up to ~130 cm	Up to 50 Hz
Medium: up to ~300 cm	Up to 30 Hz
Long: up to 400 cm	Up to 30 Hz (in the dark)
Range	4 cm – 400 cm
Dimension	1.3*1.8*0.2 cm

2.5 Price Comparison of the Sensors

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

Table 5. Price of used electronic gadgets (€)

Sensor	Price
Arduino Uno	10.99
Ultrasonic Sensor	3
VL53L0X	6.5
VL53L1X	15
DHT22	6.5
Sd Module	8.06

3 COMMUNICATION WAYS

While many sensors use digital and analog ports for uploading their 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 [1]. 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 was not possible in the usual ways. For solving this issue, the X-shut pin of these 2 sensors has been used to change their circuit addresses. A code was written on the Arduino platform and uploaded to the Arduino board via a USB cable to control the data flow of the attached sensors (Mobaraki and Vaghefi, 2016).

4 EXPERIMENT

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 simultaneously. This made device (Figure 6) was tested with different materials and in various ambient situations. In Figure 6, tests with and without extreme ambient light have been done for measuring the distance from the sensor up to a thick book. For the one with extreme ambient light, 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.

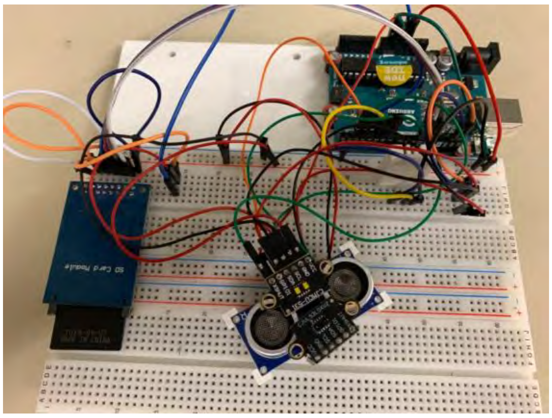

Figure 6. Experiment formation

In Table 6, standard deviations driven from the performed tests have been illustrated. In this Table, each row shows the result of a different test. Each column indicates the results of a different sensor.

Table 6. Ranging result of the same experiment under different circumstances (cm)

Tests/Sensors	Ultra	Laser1	Laser2
a thick book	0.61	2.50	1.50
a white paper	1.87	2.67	1.48
a black paper	1.00	7.18	1.87
a transparent plastic cover	0.70	5.46	3.12
a tissue	352.00	4.66	1.62
Extreme ambient light	3.23	3607	21.94
Extreme ambient light*	_	39.86	_

It was noticed that the Laser1 is highly sensitive to the ambient light. In the presents of extreme light instead of reporting the range, it reports 8190. By investigating in the datasheet, it was realized that this number indicates the inability of the sensor for measurement in this situation. When this sensor is not able to read, or the measurement distance or the distance is more than its capacity range, it declares this number.

In 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 outputs equal to 8190.

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 an 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 sensor, and 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.

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