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Development of Low-Cost Non-Contacting Thickness of Material Measurement Instrument

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Abstract: The goal of the research was to develop a low-cost, non-contact tool for determining material thickness. The non-contacting thickness is made up of the time-of-flight (ToF) distance sensor, liquid crystal display, and microprocessor. The substance being tested is placed in a rectangular wooden frame, with the ToF distance sensor positioned beneath the upward end of the rectangular frame. The sensor has a dimension of 400 mm range and a resolution of 1 mm. when the device is tested with various materials thickness value is equal to value obtained when used with high accurate precision Vanier caliper. The SD determined is 0.67 is very low that indicate that value tends close to true value.

Index Terms: Time-of-Flight Sensor (ToF), Laser driver, Radiated photons, Microcontroller, Liquid Crystal Display

I.Introduction

Non-contact distance sensors, such as ultrasonic sensors, have proven to be effective in determining the thickness of a material from one side. It is quick, dependable, and adaptable, with little difficulty in gauging. In the late 1940s, the first commercial ultrasonic gauges were introduced, based on echo system principles. In the 1970s, small, portable equipment designed for a wide range of test applications became popular. Later advancements in microprocessor technology resulted in new levels of performance in today's sophisticated, user-friendly small non-contacting thickness of material instruments.

Many companies and universities throughout the world have created non-contacting distance sensors based on various ideas. Sound (ultrasonic), time-of-flight, infrared, and high-frequency waves with wavelengths ranging from micrometers to hundreds of kilometers are used. As a result, this non-contacting sensor is now used to measure distance, depth, thickness, surface roughness, and other parameters.

Contact measurement uses a probe to make contact with the upper and lower surfaces of the material to be measured, allowing the thickness of the test material to be determined. Normal classic contact measurement approach could easily result in scratches on surface of the material to be measured, coating damage and difficulty guaranteeing cleanliness. The non-contact optical measurement technology has been vital in overcoming this difficulty and has continually advanced (Lettner and Zagar, 2013; and Noel *et al*., 2005) [1], [2]. As a result, several systems use a non-contact method to increase transparency, plate thickness assessment accuracy and dependability. Hassani (2016) [3] demonstrated the use of white-light sources in Fresnel diffractometry to increase the sensitivity and accuracy of film thickness measurements, with findings that were in excellent agreement and had fewer than 5% relative errors. Furthermore, Kim *et al*., (2011) [4] used a dual-arm axial-scanning low-coherence interferometer to detect the non-contact thickness of biological samples regardless of shapes, thickness, or transparency of the materials under test. Park *et al*., (2016) [5] and Quangsang*et al*., (2016) [6] presented a dual low-coherence scanning interferometer to detect big height steps on a specimen's topographic surface and the thickness profile of a clear optical plate as a novel concept. At present, all of the non-contacting thickness instruments that are available are high cost, highly specialized and cannot be repaired if they broke down. This low- cost non-contact measurement method has a resolution of 1 mm.

II.Methodology

Single-Channel Non-Contacting Thickness Measurement Block Diagram Figure 1 depicts a single-channel thickness non-contacting measurement that is used to determine the precise location of the top section of the sample's well-prepared surface while the component is resting on a smooth reference surface. The thickness was measured using non-contacting distance sensors in relation to a reference point of measurement. At a reference point, a known measurement is established, and subsequent measurements reveal the amount of variation from that reference point.

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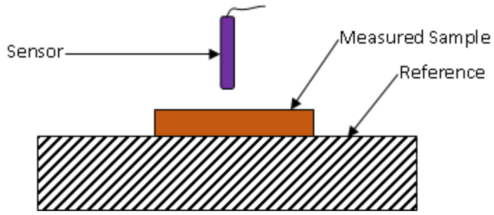

Figure 1: Single-Channel Thickness Measurements (Assuming the sample is flat with thereference surface)

a. Block Diagram of Electronics Circuit

Time-of-flight (ToF), VL53L3CX, ardunio uno r3 for microcontroller, 16 characters 2 lines liquid crystal display (LCD), and power bank are used in the single-channel non-contacting thickness measuring.

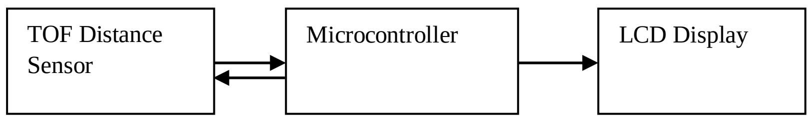

Figure 2: Block Diagram of a Single-Channel Non-Contacting Thickness Measurement

b. Time-of-Flight (ToF) Distance Sensor

Based on the FlightSense Time-of-Flight (ToF) technology, STMicroelectronics developed new generations of high performance proximity and range sensors based on Figure 3 below. Many proximity sensors rely on simple ultrasonic and IR (Infrared) technology, which can only measure the signal strength and are heavily influenced by the object's reflectivity. FlightSense sensors, on the other hand, directly measure the distance to an object based on the time it takes for radiated photons to be reflected thus, allowing accurate distance ranging regardless of the object's surface characteristics. Figure 3 shows how equation 3 was used to calculate the time for photons to leave and strike the target before being reflected to a photon sensing device while Figure 4 shows the sensor’s connection with an Arduino Uno r3 board.

The laser driver and emitter, as well as the Single Photon Avalanche Diode (SPAD) light receiver which provide ST's sensors the unequaled range and speed with reliability, are all housed in a "all-in-one" small module.

The advantages of ST's unique SPAD technology are combined with its established imaging process and highvolume packaging facilities in this advanced ToF solution. It is appropriate for a wide range of applications that call for easy integration with adaptable mechanical design, high-speed and accurate distance measurement with low power consumption and competitive system cost.

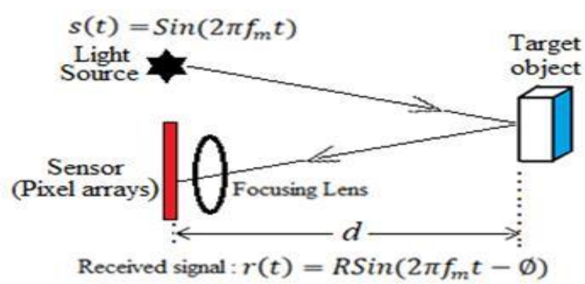

Figure 3: ToF sensor measurement method

Most ToF sensors consist of light sources that are being modulated using light emitting diodes or laser diodes with array of pixels that detects the phase change of the incoming reflected signal including optical focusing system onto the sensor as shown in Figure 3.The signal source is modulated and enveloped by turning it on and off at intervals**.** The time of flight of the signal from light source to the target object and back to the sensor’s pixel array is used to calculate the distance of the object using the phase change of the received signal**.** In practice, square waves are utilized for the signal modulation but to ease the calculations, sine waves are assumed as follows Gokturk*et al.*, (2004) [9].

When $s(t) = Sin(2\pi f_m t)$ 1

is the source signal, withf_m as frequency of modulation. The reflected signal with phase shift ϕ is received on the sensor’s pixel as;

$$r(t) = RSin(2\pi f_m t - \emptyset) = R(sin2\pi f_m\left(t - \frac{2d}{c}\right)) \quad 2$$

Where the amplitude of reflected light is R, *d* equals the distance of the target object and c is the speed of light.

Thus, distance *d* is determined from the phase shift as in equation 3.

$$d = \frac{c\emptyset}{4\pi f_m} \quad 3$$

Signal processing techniques are used in the sensor to extract the amplitude and phase of the reflected signal via low-pass filters and mixers.

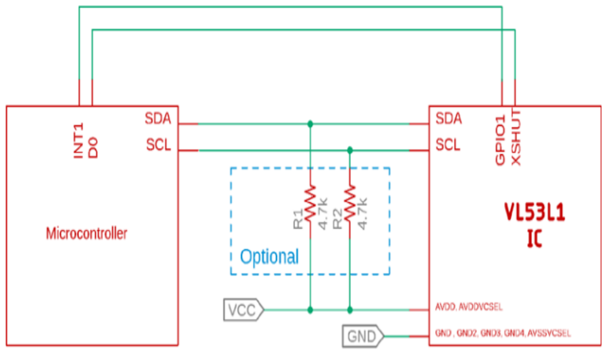

Figure 4: VL53L1 connection to an Arduino Uno r3 inputs

c. Microcontroller

A microcontroller is a miniature computer that consists of a processing core, memory, and programmable input-output peripheral on a single IC. Microcontrollers, in contrast to microprocessors, are developed for use in embedded applications. Microprocessors are utilized in personal computers and other general-purpose applications. The Arduino Uno R3 is a microcontroller board based on the ATmega328P. It is a low-power, high-performance CMOS 8-bit microcontroller with the AVR improved RISC architecture. The Atmega2328P has 32 KB of flash memory, 0.5 KB of which is used by the boot loader, 2 KB of in-system, self-programmable memory, read and write capability, a clock speed of 16 MHz, and a 1 Kbyte EPROM. (Ewetumo*et al*., 2019, Osinowo*et al*., 2022) [7], [8].

d. Liquid Crystal Display (LCD)

The thickness of the sample under test is displayed on the LCD. The system built uses a Dig chip to create a 16 character 2 line JHD162A liquid crystal display. The display is a 16-pin device that requires a maximum power supply of 5.0 V to operate, and data can be delivered in 4 bit, 2 operations or 8 bit, 1 operation to interface with an 8-bit microcontroller. It employed a four-bit, two-operation scheme in this case. (Ewetumo*et al.*, 2019, Osinowo*et al.*, 2022) [7], [8].

III.Results and Discussion

Plate 1 depicts the development of a single-channel non-contact thickness measurement system. When various objects of varying surface type are inserted into the interior slot, the value is displayed on the LCD screen.

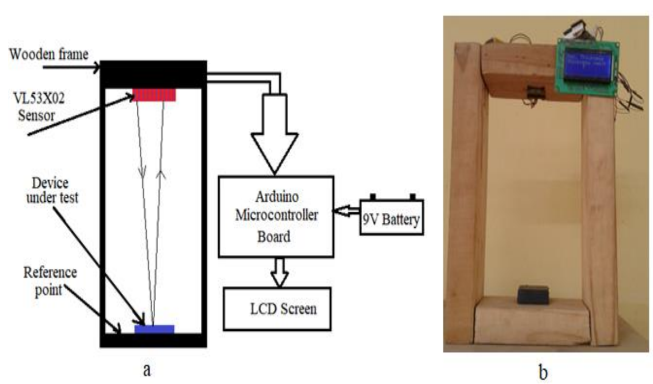

Plate 1: The developed material thickness measurement device

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The thickness is calibrated by first determining the maximum distance (Lh) between the top of the bottom frame and the position of the ToF sensor at the bottom of the top frame on Plate 1. The thickness of the test object is equal to the new value detected by the ToF sensor from Lh. Table 1 illustrates measurement consistency by placing a well-shaped substance inside the measurement slot and leaving it for twenty minutes, with the value of the reading recorded at two minutes interval. This was done to determine measurement precision and standard deviation. The thickness of a material placed inside the wooden frame was measured with Vanier caliper is 43 mm. The non-contact measurement result is displayed on Table 1, average reading is 43 mm and standard deviation is 0.67.

Table 1: Measurement Consistency

Thickness Measured with Vanier Caliper	43 mm
Time Interval	Thickness Material(mm)
1	43
2	43
3	42
4	43
5	43
6	44
7	43
8	43
9	42
10	44
Mean	43
SD	0.67

IV.Conclusion

The current technological trend is to develop a device that makes work easy, fast with high accuracy and precision. Therefore, to remove a lot of human error from manual measurement of thickness of a material and completely inaccuracy in calibration of such thickness measuring device such as Vanier caliper, the developed device plays a major role. The standard deviation which shows the amount of variation or dispersion of a set of values from mean and SD is 0.67. Low SD indicates that the values tend to be closed to the mean of the set of values. When tested with many thickness materials with capacity of the developed device, the value is exactly the same when measured with accurate and high precision Vanier caliper.

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