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ANALYSIS ON THE PERFORMANCE OF LED AND LASER DIODE WITH CHARGE COUPLED DEVICE (CCD) LINEAR SENSOR MEASURING DIAMETER OF OBJECT

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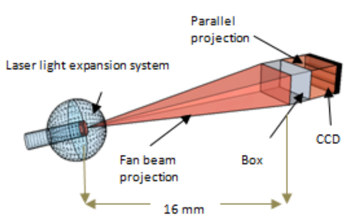
Graphical abstract



Abstract

Simple experiment measuring diameter of a solid object (coin) using LED and laser diode with Charge Coupled Device (CCD) linear sensor was conducted in this early stage study. Mostly, CCD and laser diode system are higher in cost because CCD used in industries equipped with an anti blooming protection system to protect the CCD pixel from receiving too high laser light intensities. Low cost atomic laser (Helium: Neon 10:1) with simple modification on light propagation is introduced. Combination of fan beam and parallel beam projection helps to reduce light intensities and expand laser light coverage area. Statistical analyses based on dot plot graph, Anderson Darling test and T-test were applied to choose the best transmitter for Charge Coupled Device (CCD) sensor. Based on T-test results with 95% confidence interval, low intensity laser diode for 5 and 10 cent diameter measurement gave P-value greater than 0.05, accepts laser as the best transmitter compared to LED. Single sensor data for LED and laser used for image reconstruction as an additional approach to prove the above result.

Keywords: Charge Coupled Device (CCD), laser diode, Light Emitting Diode (LED), measurement

1.0 INTRODUCTION

The inventors of Charge Coupled Device (CCD) are Boyle and Smith from Bells Laboratories [1]. CCD is a multifunction electronic device which is built with more than thousand small Metal Oxide Semiconductor (MOS) capacitors [2], [3]. This sensor widely used in the field of astronomy [1], medical [4], process industries (scanner)] [5], remote sensing applications [6] and electronic appliances [7], [5]. At an early stage of the CCD development, it is used to store and transfer analogue signal or information in the form of electrical charge [3]. Recently, the use of CCD has also made an interest in the measurement fields.

Varieties of new innovations used CCD as an optical displacement sensor [8] [9], surface detection sensor [10], thickness detection sensor [11] and object detection system using a CCD camera [12]. Combination of CCD and high power lasers or molecule lasers is very popular because researchers claimed that this laser gives high sensitivity, accuracy and stability in measurement. The basic principle of measurement used is; by pointing 1 mm diameter laser light source to the object. The same intensity of light source will reflect directly to CCD sensor without existence of filter.

Z. Fei *et al.* [12], has concluded that the combination of laser diode and CCD camera can produce high precision measurement application. It is because; the CCD has high precision for two dimensional image measurement while laser diode provides high precision in the axial direction. In another research done by Yang Ni *et al.* [11], the arrangements of CCD and laser diode are applied to construct thickness detection tools that produce high sensitivity, precise accuracy and high stability in reading.

Regrettably, detection of too high light intensities by CCD cause the degradation of CCD performance and poor measurement results [13]. Hence, CCD occupied with anti-blooming component was introduced to deal with high light intensities problems, but, the cost for CCD system increased [14]. Therefore, laser types, light filtration and expansion were studied to help in producing low intensity laser light source. Experiments between CCD sensor with LED and modified laser were conducted. LED was selected because it recognized as a low intensity light source (because it spectral ranges is not consistent) compared to laser [15].

2.0 LITERATURE REVIEW

CCD sensor consists of thousands number of small pixels and each pixel represent as a converter, where each pixel will convert the light strike that hit on its surface into a photon charge [3]. There are two types of CCD device; monochromatic and color sensor [1]. This project had chosen monochromatic CCD (Sony ILX551A) because its time scans rate ratio is 1:3 lower than colour CCD [16]. Colour CCD consists of red, green and blue photosensitive elements and needs a large memory for saving output signals [17]. The other disadvantages given by colour CCD are; its limits the speed of CCD charge transfer, lower temporal and spatial resolution, reduce the dynamic range and increase noise in colour [18]. This type of CCD has 2048 number of sensitive pixels with 0.014 mm x 0.014 mm in size [19]. Sony ILX551A CCD linear sensor's spectral graph shown in Figure 1.

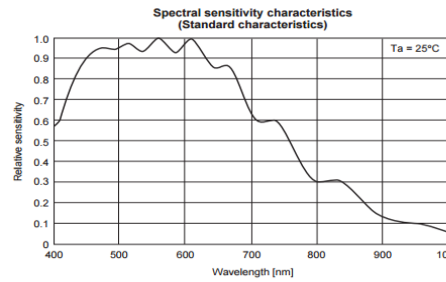


Figure 1 Spectral sensitivity graph Sony ILX551A [20]

Referring to Figure 1, this CCD is very sensitive towards 450 nm to 650 nm light wavelength. Both LED and laser wavelengths lay in this high spectral range [21], [15]. However, LED output energy will become nonlinear due to the increasing of temperature and it produced incoherent light source which covers a wide range of wavelengths [15].

Table 1 summarized the advantages and disadvantages of LED and laser diode. The experiment preferred low cost laser diode (Class IIIA) with a mixture of Helium and Neon gases in the ratio of 10:1. It is an atomic laser with low power device [15] and it emits photons with spectral range of 630 nm to 650 nm. According to Madigan *et al.* [22], red colour range 630 to 650 nm wavelength less scattered compared to shorter wavelength colours such as blue and purple (visible light source).

Table 1 Advantages and disadvantages of LED and laser

Types	Advantages	Disadvantages
LED	Small in size and light Mechanically rugged Low power device Low cost	Incoherent light source Spontaneous emission Nonlinear output characteristic
Atomic Laser	Small in size and light Mechanically rugged Low power device Low cost Linear output characteristic Stimulated emission	High intensity

3.0 SYSTEM DESIGN

The development of the system consists of two parts; software and hardware. Details of software and hardware construction are as follows.

3.1 Software Construction

CCD linear sensor Sony ILX551A requires two signals; Read Out Gate (ROG) and a clock pulse generator to function. Figure 2 shows ROG (yellow) and clock pulse (blue) that programmed using C language.

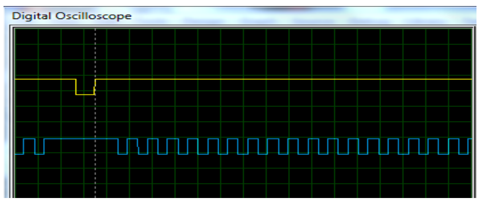


Figure 2 ROG and clock pulse generator for CCD Sony ILX551A

The programmed burned in PIC16F877A. ROG signal acted as a trigger signal to determine the end of each scan. In clock signals programming, total of 2090 clocks including dummy signals is programmed. Total time per frame was equal to 18.4 ms or 54 frames per second.

3.2 Hardware Construction

To produce a low intensity laser, combination of fan beam and parallel beam projection concepts were applied. Parallel light beam strikes perpendicular to object surface and give high precision on object location and size. Fan beam projection helps to reduce cost where one laser covered 2048 numbers of CCD pixel. Figure 3 shows the mechanical design of laser beam projection. In laser light expansion system (Figure 4), the components involved are; laser, two convex surfaces lens (simple magnifier) and white table tennis ball which performed as a filter to reduce laser light intensity. 5-diopter on shelf lens was used. Parallel projection produced when 16 mm fan beam light distance goes through 40 mm x 10 mm box aperture. Size of the aperture controlled laser light expansion area.

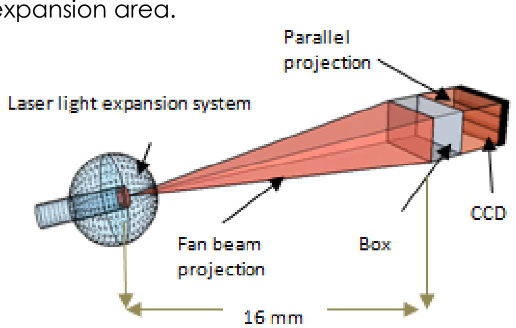


Figure 3 Mechanical design of laser beam projection

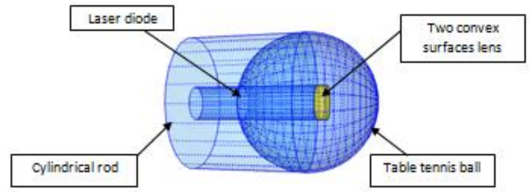


Figure 4 Laser diode light expansion system

CCD linear sensor was placed in a closed black box to avoid the interference of external light and reflection of internal light by absorbing the light source that hitting it walls. Light holder seized LED and modified laser with 16 mm distance from the CCD. Data from CCD send to Agilent oscilloscope (handheld U1620A) with 2 Giga sample per second. Figure 5 shows the CCD result with effected pixels [23] (T_1 to T_2) and Equation (1) to (3) were used to obtain the diameter coin.

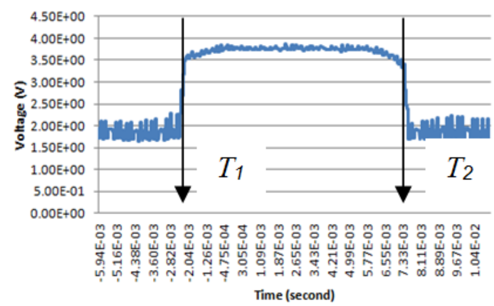


Figure 5 CCD voltage output result versus time in second

$$Time\ range = T_2 - T_1 \quad (1)$$

$$Total\ pixel = \frac{Time\ range(s)}{clock\ per\ cycle(s)} \quad (2)$$

$$Diameter\ (mm) = Total\ pixel\ x\ 0.014 \quad (3)$$

CCD clock per cycle was equal to 8.8 x 10^{-6} s. Every total pixel needs to multiply with CCD per pixel length; 0.014 mm to obtain the object diameter.

4.0 RESULTS AND DISCUSSIONS

Two different diameter coins were measured using three methods; Vernier Caliper as targeted mean value, CCD linear sensor with LED and modified laser. Luminosity of LED and laser during the experiments was maintained. A total of 30 numbers of measurements was conducted for each light source; LED and laser diode.

4.1 Vernier Caliper

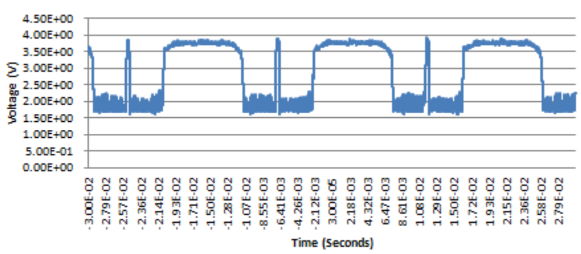
In Figure 6, the diameter for 5 cent is 16.22 mm and 10 cent is 19.47 mm using Vernier Caliper.

(a) (b)

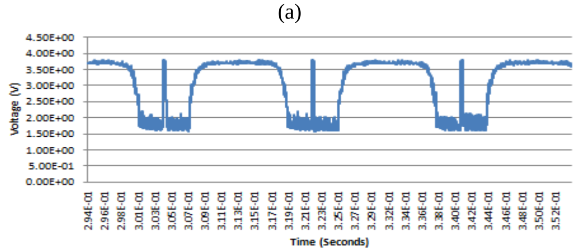
Figure 6 Results for (a) 5 cent diameter and (b) 10 cent diameter using Vernier Caliper

4.2 CCD Linear Sensor with LED

For measurement with LED, each coin is placed at the middle of CCD glass surface. Figure 7 shows the data plotted as voltage versus time for diameters of 5 and 10 cent coins using LED.



(a)

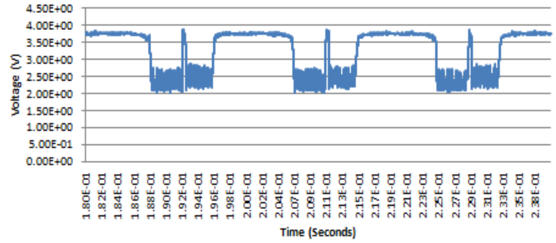


(b)

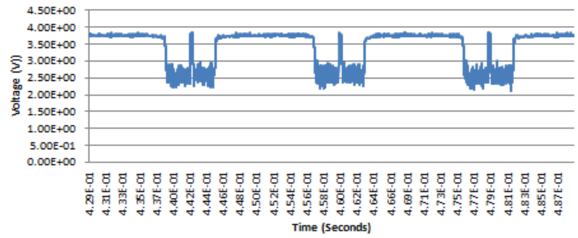
Figure 7 CCD measurement graph for (a) 5 cent and (b) 10 cent using LED

4.3 CCD Linear Sensor with Laser

Figure 8 shows the graph where voltage is plotted versus time for the diameter of coins using laser diode and CCD linear sensor. Comparing Figure 7 and 8, laser diode gives sharpness of coin graph edges compared to LED which, the coin graph edges given is curved.



(a)



(b)

Figure 8 CCD measurement graph for (a) 5 cent and (b) 10 cent using laser diode

Statistical analyses using Minitab16 software were applied to evaluate the data of LED and laser diode. Figure 9 shows dot plot graph data distribution of LED and laser. Here, laser gives precise data because laser data distributed within its population, while LED data spread at large area.

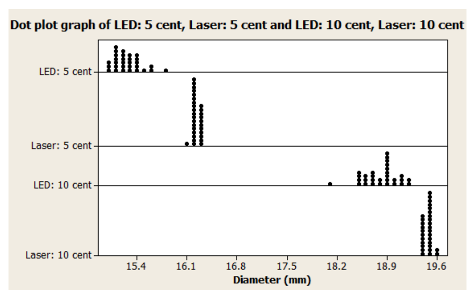


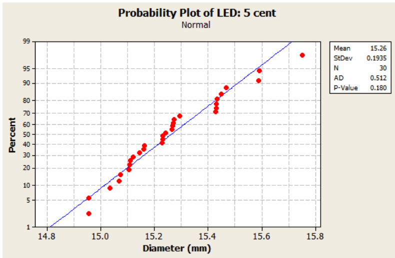
Figure 9 Dot plot graph for diameter measurement using LED and laser

Anderson Darling test was used to check data normality. Figure 10 show (a) LED 5 cent, (b) laser 5 cent, (c) LED 10 cent and (d) laser 10 cent normality test results. The graphs show that all data are normally distributed because P-values are greater than 0.05 and these data valid for hypothesis testing. There are two hypotheses involved in the analysis between LED and laser diode measurement;

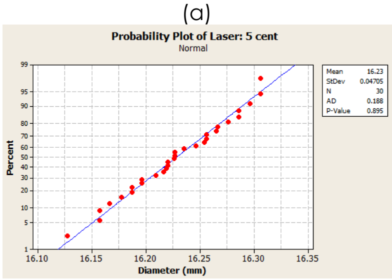
H_0: Diameter 5 cent/10 cent = 16.22/19.47 mm

H_1: Diameter 5 cent/10 cent ≠ 16.22/19.47 mm

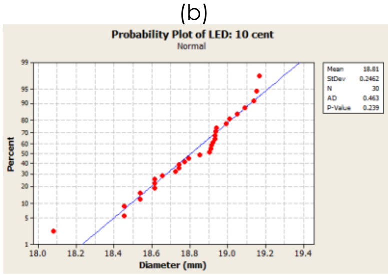
The targeted mean shown at the right side of hypothesis referred to the Vernier Caliper measurement with ±0.01 mm accuracy. T-test was applied because only 30 data and single targeted value involved.



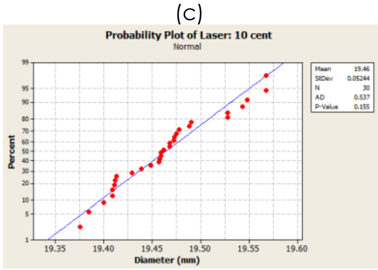
(a)



(b)



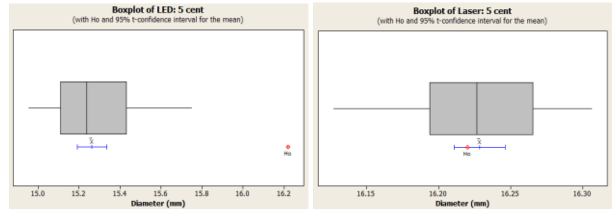
(c)



(d)

Figure 10 Probability plot graphs for (a) LED 5 cent, (b) laser 5 cent, (c) LED 10 cent and (d) laser 10 cent

Based on Figure 11 and Figure 12, box plot graph LED automatically rejected the null hypothesis because targeted means of 5 and 10 cent far from sample mean LED and P-values for both measurements are less than 0.05. But, P-values for 5 and 10 cent measurements using laser are 0.3250 and 0.5530. These results failed to reject both null hypotheses. In conclusions, mean sample for 5 and 10 cent using laser give almost equal value with targeted mean at 95% confidence interval. Modified low intensity laser still gives an accurate data measurement because its monochromatic light source has low distortion, low noise, low angle divergence and high directional beam [15] compared to LED; the chromatic light source. Additionally, low intensity laser also provides less heat affected zone (HAZ) due to the modification proposed.



One-Sample T: LED: 5 cent, Laser: 5 cent

```
Test of mu = 16.22 vs not = 16.22

Variable      N     Mean   StDev  SE Mean          95% CI             T      P
LED: 5 cent   30  15.2624  0.1935   0.0353  (15.1902, 15.3347)  -27.11  0.000
Laser: 5 cent 30  16.2286  0.0470   0.0086  (16.2110, 16.2462)    1.00  0.325
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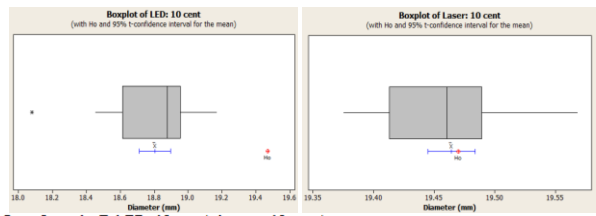
Figure 11 T-test analysis graphs for 5 cent data using LED and laser



One-Sample T: LED: 10 cent, Laser: 10 cent

```
Test of mu = 19.47 vs not = 19.47

Variable        N     Mean   StDev  SE Mean          95% CI             T      P
LED: 10 cent    30  18.8057  0.2462   0.0449  (18.7138, 18.8976)  -14.78  0.000
Laser: 10 cent  30  19.4643  0.0524   0.0096  (19.4447, 19.4838)   -0.60  0.553
```

Figure 12 T-test analysis graphs for 10 cent data using LED and laser

5.0 IMAGE RECONSTRUCTION ANALYSIS

The optical tomography method is another approach that used in this study and investigation for validating the performance of laser diode and LED with CCD linear sensor. Actually, tomography is a method to capture and reconstruct a cross sectional image of internal object for analysis and monitoring purpose. This process is used to reconstruct an image of 5 and 10 cent coins by using single CCD data obtained from LED and laser diode.

Four parallel projections used to reconstruct a circular image of flat coin and several assumptions involved. The assumptions are;

i. All four projections are assumed to have same data values obtained from single CCD experiments (approximately 2000 data per CCD frame using Agilent oscilloscopes)
ii. Each projection is set to have 25 views (CCD data per frame is divided into 25 sections)
iii. Value for each view is equal to CCD mean voltage output value (calculate mean value for each data section)

Octagon shape will be produced when using four pairs of sensors (CCD linear sensor and light source) and it illustration is shown in Figure 13.

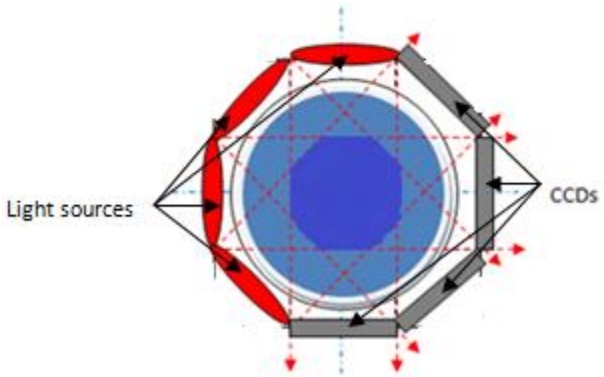


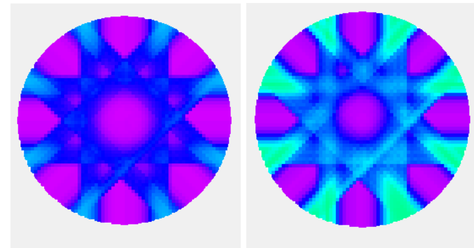
Figure 13 Illustration of sensor orientation for image reconstruction

Available Linear Back Projection (LBP) image reconstruction programming (Visual Basic) done by earlier researchers [24] [25] was used to produce the image reconstruction. The optical modelling method applied in this image reconstruction software was parallel light projection.

LBP image reconstruction generated based on the multiplication of prediction sensitivity map with mean values of CCD voltage output (25 sections=25 mean value of CCD voltage output per projection). Different transmitter gives different quality of image reconstruction due to its voltage output value. Voltage output values between laser and LED, and, the significant different of voltage output values within laser data population and LED data population will affect the image result. Figure 14 and Figure 15 show the image results for 5 and 10 cent using (a) LED and (b) laser diode. Here, the combination of CCD linear sensor and laser diode give clearer image determination compared to LED, although the Lux for laser diode is lower than the Lux of LED. It is because laser gives high voltage output values compared to LED and the voltage output differentiation between its mean populations is large compared to LED.

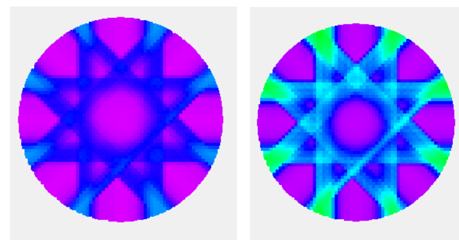
6.0 CONCLUSIONS

Statistical analysis results proved that combination of CCD linear sensor and laser offer good measurement results compared to LED. The dot plot graph can be examined clearly that the data distribution for modified laser within its population and its mean value almost reaches the exact measurement taken from Vernier Caliper. These indicate where the laser gives more precise results compared to LED. Also, image reconstruction analysis help in the investigation to prove that laser diode is the best transmitter for CCD linear sensor. Due to simple laser modification, it provides less HAZ laser with low Lux value and accurate data measurement for the use of future low cost CCD application system.



(a) (b)

Figure 14 Image Reconstruction for 5 cent (a) LED (b) laser diode



(a) (b)

Figure 15 Image Reconstruction for 10 cent (a) LED (b) laser diode

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