APPENDICES

Journal

1. **Fatinah Mohd Rahalim**, Juliza Jamaludin, Syarfa Najihah Raisin, Wan Zakiah Wan Ismail, Irneza Ismail, Ruzairi Abdul Rahim & Yasmin Abdul Wahab, (2022). An Application of Charge-Coupled Device (CCD) Tomography System for Gemological Industry - A Review. *Enabling Industry 4.0 through Advances in Mechatronics*. Lecture Notes in Electrical Engineering, vol 900, 31-41. (Published).
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3. **Fatinah Mohd Rahalim**, Juliza Jamaludin, Syarfa Najihah Raisin, (2022). Ruby Stone Light Grade Inspection System Using CCD Linear Sensor-A Review. *Journal of Physics: Conference Series.* (Published)
4. **Fatinah Mohd Rahalim**, Juliza Jamaludin, Syarfa Najihah Raisin, (2022). Non-Invasive Grading Technique for Ruby Gemstone Using Charge-Coupled Device (CCD). *ASEAN Engineering Journal*. (Accepted for Publication)

Conference

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An Application of Charge-Coupled Device (CCD) Tomography System for Gemological Industry - A Review

Fatinah Mohd Rahalim, Juliza Jamaludin, Syarfa Najihah Raisin, Wan Zakiah Wan Ismail, Irneza Ismail, Ruzairi Abdul Rahim, and Yasmin Abdul Wahab

Abstract Charge-Coupled Device (CCD) is a semiconductor chip with a light-sensitive sensor. The CCD has been used in many fields of engineering, including astronomy, medical sciences and processing. CCD is capable to detect light sources and convert this analogue signal into electrical signal. CCD is an integrated circuit that contains a large number of small photo elements with high sensitivity to light energy. The main focus of this research paper is on the review of CCD basic operating principle and construction, CCD characteristic, and the application of CCD in tomography system. The potential use of CCD in the gemological industry is also highlighted in this paper. Gemology is one of the important industries that considered profitable and crucial that deals with precious stones. This industry is in need of standardized grading valuation of gemstones as the current technique is prone to errors. An approach to the standardized grading technique is proposed where CCD tomography is used to detect and analyze the light distribution characteristic in ruby stones.

Keywords Charge-Coupled Device (CCD) · Gemology · Light distribution · Ruby · Tomography

1 Introduction

Since the 1980s, Charge-Coupled Devices (CCDs) have been the most widely used high-performance imaging detector in almost all scientific and industrial imaging

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applications [1]. In today's industries, the CCD sensor is a multipurpose electronic component that is in high demand. This type of sensor is unique in its architecture design, since it is made up of thousands of very small sensors that are very responsive to light sources [2]. It is extensively used in optical imaging, target tracking, and other products due to its wide spectral response, large dynamic range, high sensitivity, low power consumption, shock resistance and anti-electromagnetic interference capabilities. With this special characteristic, CCD is used as core imager components in resource satellite, ocean satellite and also meteorological satellite [3]. CCDs are also utilized in medical applications, particularly in X-ray tomography systems. X-ray tomography systems provide extremely high-resolution image reconstructions, which are critical in the medical industry since a clear and correct image output is important. Nowadays, CCD tomography systems are widely used in process industries for plant monitoring purposes because this system provide a non-intrusive and non-invasive inspection technique. CCD tomography system is also known as a hard-field sensor system because CCD sensor only depends on the change of the light attenuation or absorption. Aside from that, CCD sensors are resistant to electrical noise and interference, have a high resolution, and operate at a high speed. Many studies have been conducted on the analysis and monitoring of multiphase flow, solid contamination, sewerage blockage, and object measurement using CCD tomography systems.

The primary goal of this research paper is to provide an overview of CCD basic operating principles and construction, CCD performance criteria, and CCD applications in tomography systems. This paper also discusses the potential applications of CCD tomography in the gemological industry. The scientific study of gems is known as gemology [4]. Gemstones are natural inorganic minerals which have been mined and valued since prehistoric times as precious stones in jewelry or adornment [5]. The gemology sector is tremendously profitable, but it is far more complex than many other industries, such as iron, silver, or gold, because the quality of the gems, particularly the high-demand gems such as ruby, diamond, and sapphire, do not depend solely on carat weight or purity. With many artistic, subjective, and cultural factors in grading techniques, the relevance is dependent on a much more complicated quality [6].

2 Basic Operating System of CCD

A CCD is a type of image detector that comprises of an array of pixels that generate potential wells from applied clock signals in order to store and transfer charge packets. The charge packets for most CCDs consist of electrons created by the photoelectric incident photons or the internal dark signal. These pixels are defined by gate structures on the silicon surface. A time variable voltage sequence is supplied to these gates in a certain pattern, which moves the charge physically to a charge-to-voltage converter output amplifier. The output sequence of voltages is converted into a two-dimensional (2D) digital image by external electronics (typically a computer) [1].

Although the CCD's early promise as a memory element has faded, its superior ability to detect light has made it the industry's standard image sensor technology. Its light sensitivity was immediately exploited for imaging applications, resulting in a tremendous revolution, particularly in the field of astronomy [7]. Linear CCDs, in which one row of pixels is transferred to the output, and matrix CCDs, in which the bottom row is always entirely pushed out when all columns are shifted down by one pixel, are the two types of CCD sensors [8].

The underlying principle is based on the movement of electrical charge. A Metal Oxide Semiconductor (MOS) capacitor serves as the sensor for this component. When light strikes the CCD's surface, photon charges attract an electron charge, causing it to depart from its covalence band. The number of electrons created is relative to the quantity of photons reaching the detector's glass. The electrons will then be moved to the next sensor until the last sensor is reached. The data from the last sensor will be sent to the computer, which will process it and create an image reconstruction [2]. The number of electrons produced was proportional to the number of incident photons [2].

There are many types of CCDs invented where every type of CCD has their own function that can suit in certain application. For process industries application, it is usually low cost and comprises two types of sensor: color CCD and monochromatic CCD. Color sensors are typically found in video and photographic cameras, whereas monochromatic sensors are found in facsimile machines and scanners. In 1991, researchers discovered that CCD Linear sensor with color scheme had drawbacks. Because the CCD needs to scan three times for three different colors [2], this color CCD Linear Sensor requires a large memory for output signals.

There are several types of monochromatic CCD sensors, each with its own function that can be used in a specific function. For example, CCD ILX551 and CCD ILX551A are monochromatic CCD sensors. The main features of the CCD sensors ILX551A and ILX511, as shown in Fig. 1, differ slightly. CCD ILX551A has a smaller pixel than CCD ILX511 with 14×14 m area, although having the same number of effective pixels. Moreover, both CCDs have a high efficiency, but the CCD ILX551A has a higher maximum frequency of 5 MHz than the CCD ILX511, which has a maximum frequency of just 2 MHz. As a result, the CCD ILX551A can send and receive more data in less time. Above all, the CCD ILX511 is designed to be used for bar

Fig. 1 CCD sensor ILX551A (left) [11] and ILX511 (right) [12]

code point-of-sale (POS) hand scanner and optical measuring equipment where these devices do not require higher accuracy [9]. While for CCD ILX551A is designed to be used for facsimile, image scanner and optical character recognition (OCR) which obviously need greater accuracy and efficiency [10].

Researchers might explore a variety of criteria in order to improve CCD performance. In general, when it comes to CCD performance, there are seven criteria to consider. Quantum Efficiency (QE), signal noise per ratio, spectrum sensitivity, transfer efficiency, spatial resolution, blooming, and the dark current are the criteria. CCD is considered to have a high fraction of Quantum Efficiency (QE), ranging from 40 to 90% [13], when compared to other optoelectronic sensors. CCD has a typical wavelength range of 400 to 1000 nm. This range encompasses the visible spectrum as well as a major part of the infrared spectrum [14]. In today's market, CCD sensors come in a variety of sizes, each with a different level of spatial resolution. Blooming can occur when CCD is exposed to high-intensity light sources or intense illumination. Another factor that influences CCD performance is dark current. Even if the sensor is positioned in a dark area, dark current will occur when the signal is recognized [13].

Based on previous literature review, this proposed fundamental research is capable to provide a standardized quantitative grading valuation of gemstones via CCD tomography approach. Light reflection from the gemstone will strikes onto the CCD surfaces. This light source will be converted into an electrical signal which is in voltage output value. The CCD voltage output represents the light intensity value of ruby stone. CCD pixel will collect photon charges received from the light. The more photon charges received by CCD, the higher the transparency of gemstone [15].

3 Applications of CCD

Smith and Boyle, who were the inventor of this sensor, used CCD in solid-state cameras at an early point in its development from 1970 to 1975 [2, 16, 17]. These CCDs were also used in broadcast television [2]. This sensor was first used in the field of astronomy in 1983. Then, several large corporations began to manufacture this type of sensor to meet the needs of astronomy technology [3]. CCD cameras used in astronomy are expensive. To obtain an image of outer space, astronomical engineers typically employed area arrays of CCDs. The greatest CCD size recently recorded is installed on a 6″ wafer size [2]. The application determines the essential principle of detecting an object using a CCD. In the area of astronomy, for example, the area array CCD is used to identify stars, planets, or meteors from millions of miles away via light reflection. So, the actual principle is to detect a bright light spot while the background of the unspotted area is dark. This is how it uses CCD to detect the presence of stars [2]. Then, in 1991, CCD became popular in the photographic world. Many digital cameras using CCD technology that create high-resolution photos have been released. A CCD used in a digital camera is less expensive than one used in a telescope. Furthermore, its pixel properties and sizes differ since they are determined by consumer preferences [2]. CCD guarantees a more compact, high-quality image, and perhaps even more efficient camera [16, 17].

Modern space X-ray astronomy detection techniques have advanced significantly in the direction of low noise, low power, and huge scale. Because it outperforms conventional high-energy particle detectors in terms of both energy and spatial resolutions, the X-ray charge-coupled device (CCD) has a wide range of applications in the X-ray astronomy field [18]. CCD technology is also employed in X-ray Computed Tomography (CT). Since it can provide morphological and physical information about the interior structure of the investigated sample, X-ray CT is one of the most powerful non-destructive testing techniques for full-volume inspection of an object. CCDs are combined with other components to achieve digital radiography for x-ray, such as a CCD camera coupled with a taper for micro-CT, a CCD camera coupled with a fan of coherent optical fiber ribbons (multi-slice linear detector) and a scintillating screen seen by a CCD camera (cone-beam CT) [19]. The recent advancement of CCD based optical Computed Tomography (optical CT) scanners has enabled rapid and low-cost three-dimensional (3D) gel dosimetry for current radiation applications. CCD based optical CT can acquire the entire plane of data at each step and quickly provide a complete 3D dosage distribution [20]. One of the scanners developed is the CCD lasers range scanner (CCD-LRS) method, which is capable of recording both geometric and color information, thus improves scanning and tracking accuracy [21]. CCD scanners are widely used in medical field such as the MRI scanner [22].

The most common application of CCD is as an optical displacement sensor [17, 23], surface detection sensor [25], thickness detection sensor [26] and object detection system [14]. Because CCD cameras have excellent precision for 2D image measurement and lasers have tremendous precision in the axial direction, Z. Fei et al. [13] concluded that the best combination is laser and CCD cameras. According to Yang Ni et al. [13], the combination of CCD and laser has facilitated the development of thickness detecting tools with high sensitivity, exact accuracy, and reading distance stability. These circumstances demonstrated that the best transceivers for opaque object measurement technologies are CCD and laser diode. In comparison to solid items, light may penetrate more through transparent objects. Because light intensities obtained by CCD may not differ considerably, it may be difficult for CCD to detect transparent objects. J. Jamaludin et al. [27, 28] developed the OPT system, which detects moving air bubbles in crystal-clear water. In crystal-clear water, this CCD tomography system can reconstruct a cross-section image of the moving item with multiple low opacities.

4 Applications of CCD in Gemological Field

The science of gems is known as gemology. People involved in gem analysis, from amateurs to professional gemmologists, such as archaeologists, art historians, conservators, mineralogists, and gem merchants, have a difficult challenge. They must not only comprehend the fundamentals of numerous sciences (mineralogy, crystallography, geology, chemistry, physics, and sometimes biology), but they must also consider economic factors [29]. The study of gems starts from the analysis of their chemical composition, determining whether they are natural or "artificial" (i.e., imitation, or synthetic), screening for enhancing treatments, grading and sometimes determining their geographic origin. In addition, all the information should be gathered by utilizing non-destructive and non-invasive procedures. When such diamonds are placed or inserted in jewels or artworks, their analysis becomes more complicated. Where in collections and museums, the gems and jewels to be tested are conserved, due to their great value, it is frequently not possible to remove them and to prevent any damage, such gems will therefore require in situ identification techniques. As a result, it is critical that the gemmologist handling the stones be professionally trained in the various ways of identification while considering all of the aforementioned scenarios and duties [29].

For an example, ruby depends on the quality and value of the combination; carat, cut, color and clarity. Excluding carat, the other parameters still require the presence of experienced gemmologists [30] in deciding on the value and quality of the ruby stone. This is because these three criteria are incredibly difficult to distinguish by the human vision [31]. Many gemological tools are used to distinguish or measure these characteristics [32]. Haüy (1817) and his colleagues began the development of gemology as a contemporary science. Many gemological instruments like the refractometer and polarizing filters were invented throughout the nineteenth century (at the time, made of gem tourmaline). These two equipment examples remain critical for gemological identification [33].

The International Gem Society claimed that the necessary instruments in the laboratory for gemology include magnifying the gem using a loupe and a microscope, a refractometer for measuring the refraction index, birefringence and the optical sign for gems, a dichroscope, a polariscope and a spectroscope. These instruments are commonly used in conjunction with other tools, such as the eyes, the diamond detector, and hardness sets [32]. Many researchers came out with more advance tools in detecting the grading value of gemstones.

In previous studies, the relevance of ruby stone being graded based on its clarity was emphasized. By capturing them in a fixed setting, the clarity of the various ruby stones was assessed and then each one of them was analyzed based on the acquired image. The authors of in other publications investigated the color of several rubies and analyzed the composition and the components of stones [34]. As the earlier approaches are prone to human error, further advancing techniques such as Raman spectroscopy and photoluminescence (PL) are introduced to identify the color variation of gemstones with better and more dependable findings [35]. The approach of grading is also proposed by Tariwong et. al using the X-ray micro-CT scan in which the interior part of the rubies is analyzed. Synthetic and treated gemstones are often seen in the trading markets as imitating high-quality gemstones, which cause scams and big losses to consumers. However, identifying instruments are generally huge, heavy and costly, while detecting tools require experience and operational expertise in order to prevent misleading results [36]. These tools depend mostly on human vision and are prone to inaccuracy [37]. Moreover, these established measuring instruments cannot perform standardize ruby stone measurements, since the instruments cannot distinguish between different degrees of optical properties (crystal clearness and color).

4.1 Research Background

In this paper, an idea of designing the standardized system for grading the gems specifically on the ruby stone is proposed. The study on the light characteristic of ruby stone is conducted and the concept of the CCD is applied in this research. The light of ruby stone will hit onto the CCD sensor when the laser is transmitted and passes through that ruby stone. The CCD sensor analyses the received light and converts it into to voltage. The system will be designed with the Arduino Nano Microcontroller. The final voltage value will be shown on the computer. The whole process is illustrated in the block diagram in Fig. 2.

The light is moving across a transparent particle with three consequences: absorption, reflectance and dispersion (neglected due to its complex mathematical model and the fact that the particle size of interest is much greater than the wavelength of the incident light) [38]. Energy loss occurs when light passes across an interface of light reflection. The incidence angle of the incident ray increases, reflecting a bigger proportion of light. This reflection reduces the amount of light that is emitted by the particle.

Light attenuation is a process in which light is absorbed and subsequently transformed into energy when travelling through a substance. The output light intensity

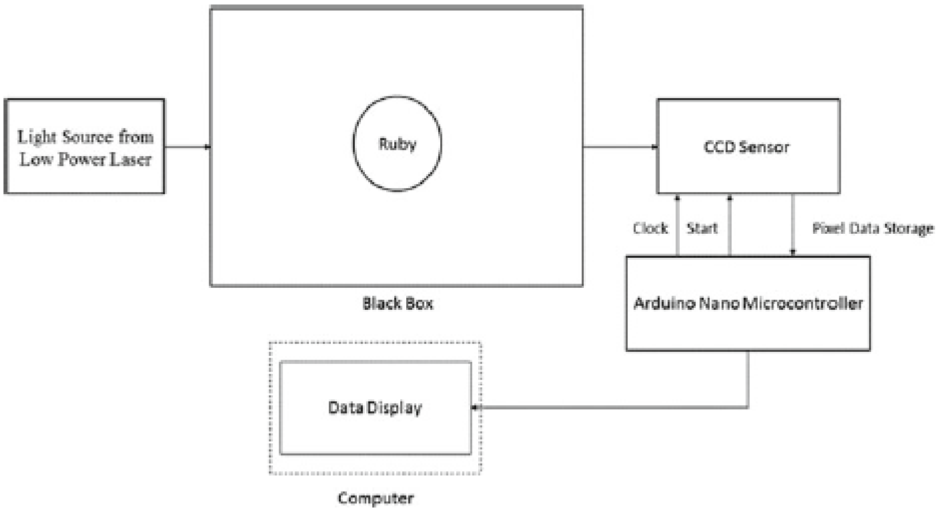

Fig. 2 The overall block diagram of the CCD system

Table 1 CCD voltage output and laser light intensity in off and on mode

Condition of laser	CCD voltage output (V)	Light intensity
Off	4.7419	0
On	1.8142	1

Table 2 CCD voltage output and laser light intensity in different situation of light propagation

Situation of LIGHT PROPAGATION	Light intensity	CCD voltage Output (V)
Air/Ruby	0.8072	2.3787

is attenuated exponentially by the object density along the optical path according to the law of Beer Lambert.

A linear CCD image sensor senses the shadow that falls onto the sensor if a collimated light is sent straight to a CCD linear image sensor. In line with the amount of light in the CCD sensor, the light intensity is transformed into voltage. When there is no object in the system, the saturation voltage is achieved (V_{sat}). In any situation, the reflection on the front of the picture sensor is overlooked [8]. Table 1 shows the theoretical value of CCD voltage output in the laser condition off and on and their respective light intensity. The CCD voltage output is the reference value from the previous research, whereby a clear water pipeline is used to transmit the light [27].

The laser intensity is proportional directly to the output of the CCD voltage. The following equation interprets the relationship between the light intensity and the CCD voltage output.

$$V = -4.5497I + 4.7419 \quad (1)$$

The following table illustrates the theoretical value of the light intensity when the light enters the ruby by the air and the theoretical value of CCD voltage generated. According to Table 2, when a system comprises light intensity and a CCD voltage without a single object, it is demonstrated that the voltage output is higher. The repeated absorption and reflectance process of the laser light results in an increased voltage output [27].

5 Conclusion

CCD is proven as one of the best imaging detectors that have been used widely in various industries with its ability to detect light and convert it into useful data for image reconstruction. With this important qualification, CCD can detect the internal activity of a system non-intrusively and non-inclusively that will not disturb the internal environment of a system [39]. Gemology industry is a crucial industry that deals with high price and valuable gems and needs a standardized grading technique to determine the gem grades without any error. A research on the grading of ruby gemstone using CCD is proposed based on the characteristic of light distribution in the ruby stone. Based on the theoretical value obtained from the calculation, the voltage value is greater when there is an object in the system compared to when object is absence. Hence, the CCD can possibly be a good choice in building a standardized grading system for gemstones, especially for ruby, based on the light distribution characteristic.

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Analysis on Clarity of Rubies Gemstones Using Charge-Coupled Device (CCD)

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ABSTRACT

Ruby is one of the most precious gemstones on Earth that is always high in demand especially in the jewelry industries. Due to its high value and very expensive, a lot of imitation of ruby has been made. This results in the rising of more complicated issues as gemologists need to perform the grading valuation very carefully and precisely. The current and common grading techniques mostly depend on human vision, which eventually leads to error. This paper aims to analyze the clarity of rubies gemstones using Charge-Coupled Device (CCD). The CCD detects the light intensity and then convert the light intensity value into the voltage value. The CCD sensor is very special in its architecture design, consisting of more than 1000 very small pixels that are sensitive to light sources. Based on the previous research, CCD has high sensitivity to laser light source with wavelength range within 430 nm to 650 nm. This research is going to prove that CCD is able to detect the clarity of various grading of the pink to blood-red ruby stones.

Keywords: Charge-Coupled Device (CCD), voltage, clarity, ruby

1. Introduction

Ruby has the apparent color from pink to blood-red. The red color is primarily caused by the presence of a few percent of the element chromium (Cr) and "pigeon's blood" is considered the brightest and most precious red color of rubies. There are only several places around the globe where rubies can be found as the presence of ruby depends solely on the geographical or geological origin [1]. Among the places that contribute a lot in ruby production is in Myanmar, Thailand, Vietnam and many more [2]. For decades, gems such as diamond, ruby, sapphire and emerald have been recognized as appealing, having excellent value, and are highly admired for their color, transparency, luster and durability [3]. Being one of the most precious gemstones on Earth, the demand for rubies for jewelry is always high. Many jewelers dare to put high investments of money to make this gem theirs. As a result, there is a lot of imitation of rubies developed to supply this demand. The problem arises when the gemologist needs to verify the grading valuation or the quality on the stone. Owing to the growing demand and availability of the natural supply, high quality natural ruby is very rare [4].

The ruby industry is very profitable, but since ruby qualities do not depend only on weight or purity, it is much more complicated than many ore industries, such as iron, silver or gold. With grading methods having many artistic, subjective and cultural elements, the significance depends on a much more complex quality. In addition to the well-known and very detailed diamond trade system developed in the middle of the 20th century on the basis of the 4Cs (color, clarity, cut and carat weight of the gem) [4] with colored stones such as rubies, additional variables are important for market demand value [1]. The colors of gemstones are usually classified depending on three variables:

tone, hue and saturation. The gradient of the pigment, such as dark or pale, is hue. The degree of absorption and reflection of light is called tone. The tone is the primary factor of color intensity. Finally, saturation is how much of the stone's color is composed of the main color. For rubies, the most hunted after are those which are bright and predominantly red [5]. Clarity refers to the presence of inclusions, which may have an effect on clarity and how light is emitted and reflected. Many natural rubies contain inclusions in the vast majority. Highly regarded and immensely rare ones are rubies that have no inclusions. Inclusions influence ruby's light output and color [5].

Rubies of grade AAA and AA are considered high grade where each grade covered one percent and ten percent of all natural gemstones respectively. These types of ruby are labeled as rare and expensive types of gemstone and they are the best grade used for fine jewelry making [5]. Meanwhile, the rubies of grade A are considered as medium-grade rubies. This type of ruby is of 50-75 percent of natural rubies available and also usually used in fine jewelry [6]. Furthermore, the lowest grade of ruby is the grade B and this type of ruby is mostly found among all natural rubies [5]. This paper will discuss on the early research to prove the capability of CCD to differentiate the ruby stones based on its clarity.

2. Research Methodology

Another tool developed by recent researchers in process tomography is using a CCD [7] [8]. The CCD is a receiver type that is very sensitive to dark areas. With a single line or array CCD, this sensor can provide high resolution of image. It also has low noise and fast detection. A low power laser is used for this project rather than a high power laser to avoid malfunctioning in the CCD since high power laser will result in optical saturation and an increase in the temperature of the CCD sensors [9].

This research will used CCD as a transmitter and atomic laser diode as a receiver. According to previous research, this transceiver is a good combination. The CCD system will be designed with a black box where the CCD sensor is located at one side of the box and a laser is beamed from the opposite side. Figure 1 shows the block diagram of the proposed system. The black box is expected to has a width of 100mm and the ruby with the size of less than 10mm will be placed at the center of the black box. Hence, the distance of the ruby to each side of the box is 45mm. Black box is required to used in this system because it will isolate the system from disturbance by external light that could affect the CCD linear sensors data [10].

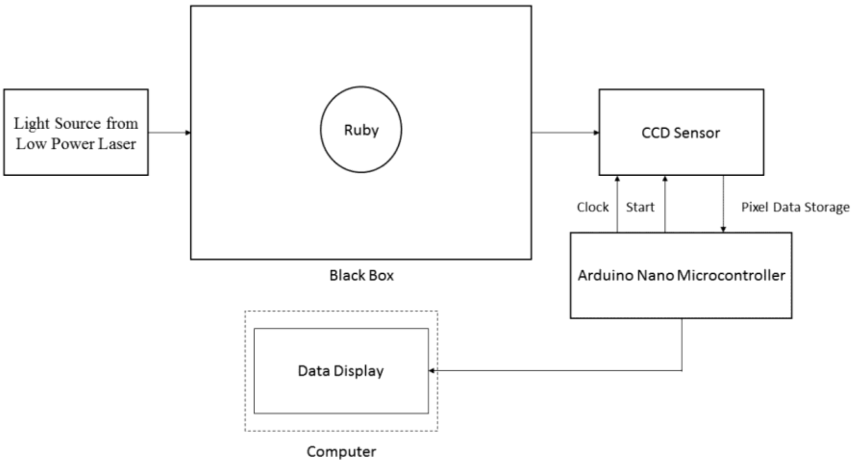

Figure. 1. Block diagram of CCD system to differentiate the clarity of ruby stone

A theoretical value of CCD voltage output is being analyzed to determine the light intensity received from different clarity of rubies which are high, medium and low-grade ruby. Mathematical modeling for the system is intended to simulate the output system behavior. In this research, the mathematical modeling on the effects due to particles is developed using LabVIEW software[8]. There are three consequences as light moves through a transparent particle:

absorbance, reflectance and dispersion (neglected due to its complex mathematical model and the fact that the particle size of interest is much greater than the wavelength of the incident light) [11]. Energy loss happens as light travels through a light reflection interface. The reflection ratio of light in each surface is referred to as reflectance. A greater proportion of light is reflected as the angle of incidence of the incident ray increases. This reflection decreases the amount of light emitted through the particle. The final light reflectance can be obtained by using the Equation (1) below.

$$I_{final\ reflectance} = I_i - \left[I_i \left(\frac{n_2 - n_1}{n_2 + n_1} \right)^2 \right] \quad (1)$$

Where n_1 is the transmitted refractive index and n_2 is the incidence refractive index. Light attenuation is a process where light is attenuated due to absorption and then converted it into energy when passing through a medium. According to the Beer-Lambert Law, the output light intensity is exponentially attenuated by the object density along the optical path.

$$I_{out} = I_{in} e^{-\alpha x} \quad (2)$$

Where α is the linear attenuation coefficient and x is the distance the light traversed. The natural logarithm of the ratio of the incident intensity to the transmitted intensity is equal to the line integral or ray sum of the distribution of linear attenuation coefficients within the object along the path [11].

3. Result and Discussion

When a collimated light is directed directly to a CCD linear image sensor, a CCD linear image sensor senses the shadow an object casts on the sensor. The intensity of the light is converted into voltage in accordance with the amount of light on the CCD sensor. The saturation voltage is obtained when there is no object in the system (V_{sat}). The reflection on the front of the CCD linear image sensor is in any case, overlooked [8]. Table 1 shows the theoretical value of CCD voltage output in the laser condition off and on and their respective light intensity. The CCD voltage output value is the reference value taken from the previous research done by J. Jamaludin [9] where the condition is the light propagates through crystal clear water on a pipeline [9].

Table 1. CCD voltage output and laser light intensity in off and on mode [9]

Condition of Laser	CCD Voltage Output (V)	Light Intensity
Off	4.7419	0
On	1.8142	1

According to J. Jamaludin [9], the laser intensity is directly proportional to the CCD voltage output. Figure 2 shows the graph of the CCD voltage output versus the laser intensity. Based on the graph, it can be concluded that the CCD voltage output is inversely proportional to the laser intensity with the gradient of -4.5497 and interception value of 4.7419 when the light intensity is at zero. The equation below interprets the relationship between the CCD voltage output and the light intensity.

$$V = -4.5497I + 4.7419 \quad (3)$$

For this research study, there will be two conditions that use different mathematical expressions in each condition. The first condition is when the light enters the ruby stone. This situation involves the ratio of refractive index between air and ruby as the light travels from air into the ruby. The incoming light intensity (/,) is reduced at the first surface of the ruby due to the reflection at the air/ruby interface. The second situation is when light propagates from ruby to the air or ruby/air interface. Table 2 shows the theoretical value of the light intensity in each situation and their respective theoretical CCD voltage output gained by using the Equation in (1), (2) and (3).

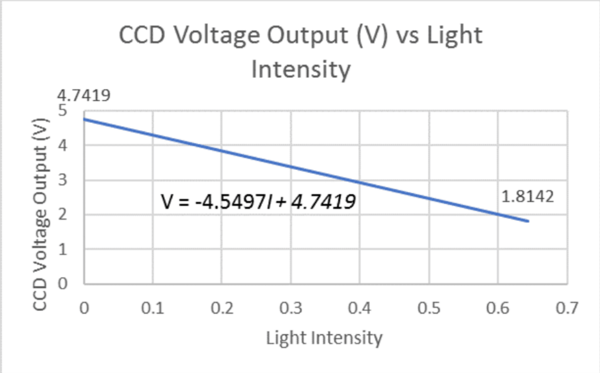

Figure. 2. Graph CCD voltage output versus light intensity

Table 2. CCD voltage output and laser light intensity in different situation of light propagation

Situation of light propagation	Light Intensity	CCD Voltage Output (V)
Air/Ruby	0.8072	2.3787
Ruby/Air	0.8072	2.3787

According to Table 2, it is shown that the voltage output will be higher when an object is present in the system with the light intensity and CCD voltage value without any object is used as control. The repetition of the laser ray absorption and reflection process results in a higher voltage output [9].

4. Conclusion

From the theoretical value above, it can be concluded that CCD is capable to differentiate the clarity of ruby stones. Different ruby grades will produce different light intensity and voltage value. This simulation proves that the aim of this research can be achieved by analyzing the ruby stone characteristic for grading valuation and identifying the light properties of ruby stone. The mathematical equation which is the final light intensity reflects the light properties of the ruby stone which is then detected by the CCD. CCD then converts the light intensity value into voltage value. A higher voltage value is detected in the situations where an object is present in the system compared to when there is no object in the system.

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