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].

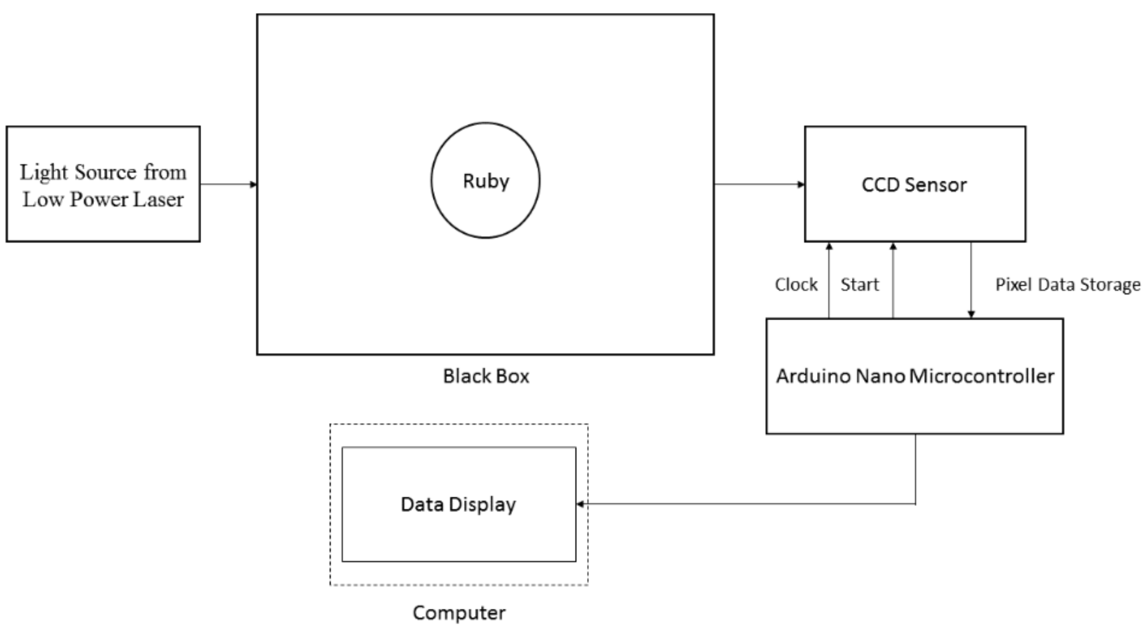

Figure. 1. Block diagram of CCD system to differentiate the clarity of ruby stone

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).

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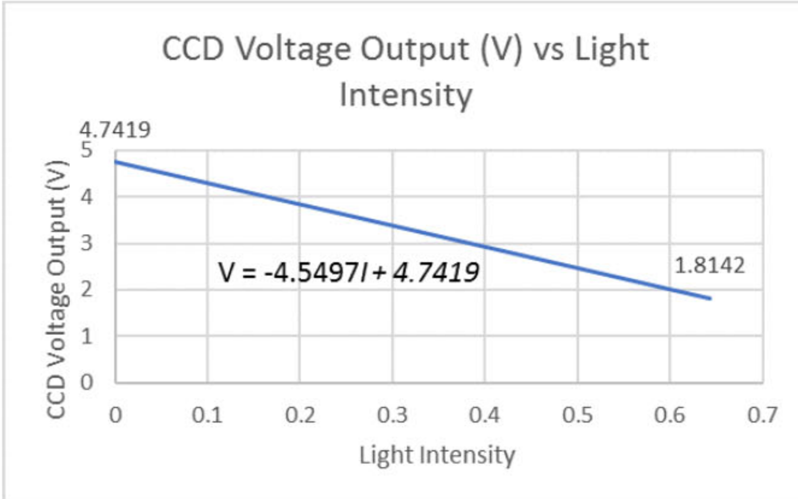

Figure. 2. Graph CCD voltage output versus light intensity

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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