CHAPTER 1

INTRODUCTION

1.1 Background of the Research

The ruby is a corundum combination (a-Al_2O_3), where a small amount; roughly 1%; of chromium cations (Cr^{3+}) substitute aluminium ions (Al^{3+}) to yield a distinctive crimson colour (Nassau, 2003). Natural rubies are one of the most precious gemstones in the world. It is very rare to acquire large-sized rubies with high clarity. These rubies are even more valuable than the same-sized diamonds. Figure 1.1 provides an image of a ruby stone.

Source: https://www.indiamart.com/proddetail/ruby-stone-17128395773.html

Figure 1.1: Ruby Stone

The commercial value of a ruby is based on its colour, size, appearance, and origin. Historically, rubies have been mined in Asian and African countries like Burma (or Myanmar), Thailand, Sri Lanka, India, Afghanistan, Cambodia, Kenya, Vietnam, Tanzania, and Madagascar, which are the major suppliers of this precious stone.

The region that lay at the border of Thailand and Cambodia also produced high-quality ruby stones from the late 1800s to the 1990s, though this deposit came to light after the 1960s (Tang et al., 1988). In the last few decades, owing to technological advancements, many gemmology tools have been used for determining the optical properties of the synthetic and the non-synthetic rubies, which include a microscope, loupe and a dichroscope (Liao et al., 2017; Mukherjee, 2012). These tools are based on visual assessment and require vast experience. However, since these procedures rely on visual inspection, they are need to be standardized as they can result in inaccurate grading valuation (Liao et al., 2017; Mukherjee, 2012).

Genuine rubies have a deep, intense, almost stoplight-red color, while imitation stones are often dull. Darker red stones are most likely garnets than rubies. There is no such thing as a naturally-occurring clean ruby, as all rubies have what appear to be silk inclusions. They enclose microscopic crystals of other minerals in the form of pale, angular grains, irregularly shaped holes, and patches of lovely needle-like crisscrossing canals that reflect light to create a silky look. A magnifying glass is necessary to identify these patterns, especially if they are not apparent to the naked eye. A gemstone is most likely red glass if no such inclusions are observable, even under high magnification. Furthermore, inclusions are not present in synthetic or imitation rubies. They may, however, exhibit bubble-like inclusions or apparent cracks similar to those found in glass. These cracks have a milky color and are even (Ferns Icon, n.d.).

Many industries like precious stone businesses, manufacturing sectors (drilling and cutting), gemologists, and medicinal and dentistry applications benefit from the standardized optical properties and valuation of the ruby stones. The transparency and imperfections of the ruby stones determine their grading value. Recent technological improvements have led to the use of gemology equipment, such as a binocular microscope loupe and a portable dielectric tune able forensic lens, to analyze the optical qualities of synthetic and non-synthetic ruby stones (Liao et al., 2017; Mukherjee, 2012). These tools magnify the image of the ruby stone structure for visual assessment. However, these visual assessment techniques require gemologists and gemstone traders to have years of experience. It may also lead to inaccurate grading valuations due to human error (Sinkevicius et al., 2013). Figure 1.2 depicts the use of a diamond magnifying loupe to grade gems.

Source: https://www.costerdiamonds.com/blog/the-diamond-loupe/

Figure 1.2: A Diamond Magnifying Loupe

This study aimed to examine the conceptual model of the optical properties valuation of ruby stones using the CCD tomography method. Based on the Australian Bureau of Statistics (2022), quantitative data refer to the data that can be measured by its value and could be counted and usually expressed in numeric variables. Meanwhile, qualitative data is measured of 'types,' and usually, the data is about the categorical variables. This research will focus solely on the ruby stone's clarity. Previous Gemology tools such as the loupe, microscope, and dichroscope, which depend on the human eyes, result in qualitative data. The CCD and tomography structure proposed the optical properties of ruby stone based on the z-axis value of the three-dimensional image produced from the effective pixels value of the rubies. Therefore, the z-axis gives the numeric value, which will ease the classification of the grading of the ruby stone based on its clarity.

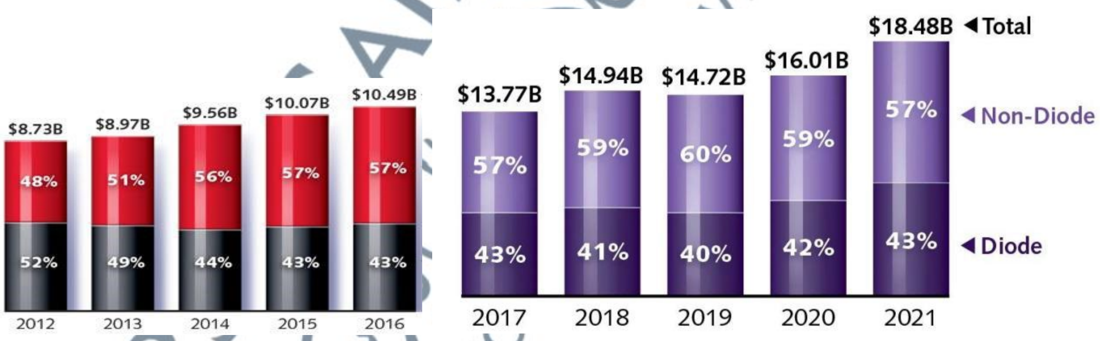
The first objective of this present study was to examine the optical properties of ruby stones. The data would be used to generate a mathematical expression that highlights the relationship between the light intensity received by the CCD after it penetrates the ruby stone. CCD tomography should facilitate the identification of the optical properties of ruby stones. The second objective was to investigate the ruby stone grades outlined in the Gemological Institute of America (GIA) database to facilitate identifying the light intensity values of various grades of ruby stones as commercially classified by the GIA. The third objective of this study was to validate the optical properties of ruby stones using statistical analysis.

The expected output refers to standardized conceptual modeling of the optical properties valuation of the ruby stones based on a CCD tomography method. The conceptual modeling in this research includes how the CCD and tomography system could establish the optical properties of the ruby stone. The concept includes integrating LabVIEW programming software and the statistical engineering analysis of t-tests. The LabVIEW software produced a three-dimensional image consisting of the z-axis. The z-axis represents the effective pixels value which is varied based on the clarity of the ruby stone. Meanwhile, the ruby stone's clarity differs based on the refractive index value, which will be further analyzed in Chapter 4.

Malaysia has the potential to become a global hub for gemstones, and the country can provide Southeast Asian countries with ruby stone-related research and technical expertise. Malaysia can also be a great economic and social partner of Myanmar by becoming a global hub of ruby stone production and appraisals for the high-end luxury market worldwide.

1.2 Problem Statement

The Gem and Jewellery Institute of Thailand (GIT) believes that the gem and jewellery industry grows effectively with the new emerging markets in Asia (Bernatskyi & Khaskin, 2021). Despite the lingering uncertainty due to the COVID-19 pandemic, Allen Nogee, the President of Laser Markets Research, is optimistic about the trend of the laser market in 2021, with the primary use of ruby stones as ruby lasers, according to the data presented in Figure 1.3 (Bernatskyi & Khaskin, 2021).



Source: Holton et al. (2016)

Figure 1.3: Trends in The Laser Market Between (A) 2012 To 2015 And (B) 2017 To 2020 And the Future

Based on the data seen in Figure 1.3, the laser market has nearly doubled. The market has constantly and gradually increased (except 2019), despite many issues like weaker investments, global trade conflicts and COVID-19. All these events negatively affected the global economy and amplified the risk of a long-term economic decline. The percentage of non-diode lasers; including ruby lasers; is much higher than that of diode lasers. Over time, standardisation should create uniformity to develop the gem and jewellery industry (Bernatskyi & Khaskin, 2021) more effectively.

Recent technological improvements have led to the use of many gemology tools, like a binocular microscope loupe and a portable dielectric tune able forensic lens, for analyzing the optical qualities of synthetic and non-synthetic rubies (Clark, 2022). These tools are based on visual judgement, where the gemologist requires vast experience to assess the quality of the gemstones. These methods are not standardized and may lead to inaccurate grading valuations as they depend on pictorial inspections.

Apart from that, Wang et al. (2006) used high-energy ultraviolet luminescence to process the image of gemstone (Breeding et al., 2006). However, the proposed framework lacked accuracy as it can only be used to determine if gemstones are imitations or originals. Meanwhile, (Leelawatanasuk et al., 2014) stated that the GIT standards that only applied for determining the color code chart for grading the ruby stones and sapphires are based on the system described by ISCC-NBS (Inter-Society Color Council-National Bureau of Standards). Dealers and gemologists would determine if this system can be used as one of the qualitative approaches. However, this method relies heavily on examinations with the human eye, which may lead to errors (Leelawatanasuk et al., 2014).

Thus, it has become clear that a lack of standardized and systematic techniques for quantitatively grading the ruby stones affects its proper appraisal. Hence, this study developed a conceptual model for quantitatively grading the valuation of ruby stones using the CCD tomography technique.

1.3 Research Aim

The research aims to introduce conceptual modeling of optical properties of ruby stone via Charge Coupled Device (CCD) Tomography approach.

1.4 Research Objectives

The aim of this study was achieved using the following objectives:

1. To study the light intensity of the ruby stone based on their theoretical values.
    - Optical properties, such as the absorption attenuation and index refraction, of ruby stones were obtained from Gemology Software Tools. Laboratory Virtual Instrument Engineering Workbench (LabVIEW) programming software was then used to mathematically express the ruby stone's rock intensity
2. To develop conceptual modeling of the CCD tomography technique using the LabVIEW software.
    - Design an octagon orientation concept for CCD and the ruby stone placement for conceptual modeling. This involves dynamic calculation using data from Gemology Tools Professional and real-time experiments.
3. To validate the optical properties of ruby stones based on image reconstruction.
    - The simulated and experimental images constructed were compared and analyzed using statistical and relative error analyses.

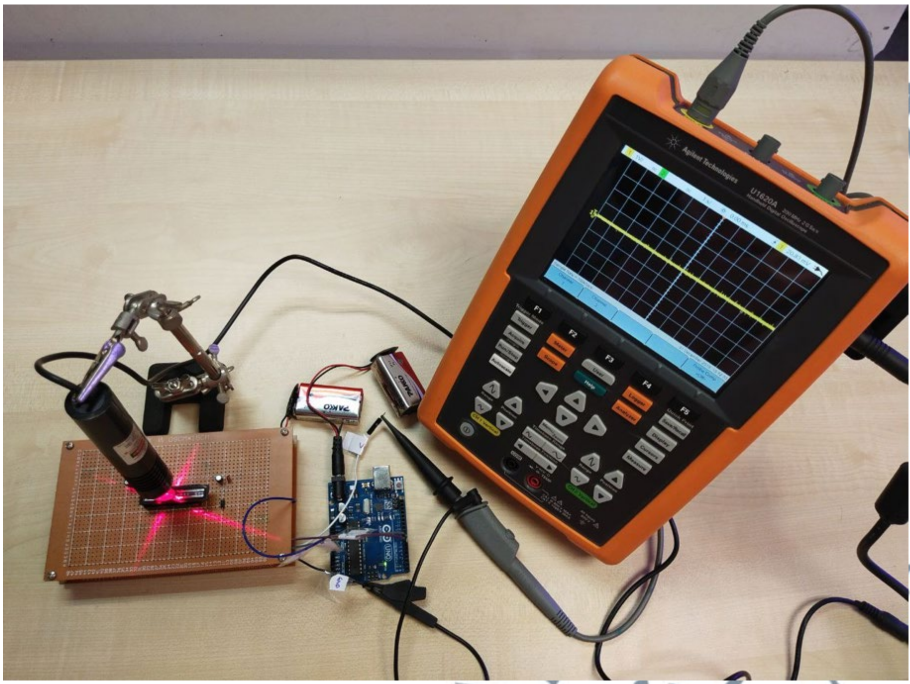
1.5 Scope and Limitations of the Research

This research introduced conceptual modeling of optical properties of the ruby stones using a CCD tomography technique. The scope of this research can be divided into three main parts. This present study emphasized the clarity of a ruby stone in determining the standardized optical properties of this stone. Other characteristics, such as the carat, cut, and color, were negligible due to the main objective of this research is to analyze the optical property of the ruby stone based on its refractive index gained from the Gemology Software Tools (Fuller et al., 2014).

The first scope was to analyze and develop a mathematical expression of the final light intensity ratio of ruby stone toward the CCD sensor. The equations for light reflection, absorption, and refraction were considered at this stage whereas the light scattering and diffraction effects are negligible in this study because the diameter of the object under study is greater than the laser diode wavelength (Idroas, 2004) (Jamaludin, 2016). In this research, the size of ruby z used for analysis is 19.18 mm. Meanwhile, the laser diode which acts as the transmitter in this modeling study is the red laser with 650 nm wavelength. Therefore, the light attenuation due to light scattering and diffraction is imperceptible in this research. The refractive index of ruby stone was obtained from Gemology Software Tools (Fuller et al., 2014). The block diagram of the final mathematical expression was established in LabVIEW.

The conceptual model of the CCD tomography was demonstrated in three-dimensional images in LabVIEW, which involved the simulation setup in this research. The arrangement of three-dimensional graphical code diagrams has been made up in the LabVIEW programming software. From the three-dimensional image reconstruction, the z-axis will be analyzed and compared between the simulation and experimental data, which involve two CCD tomography image reconstruction systems to be analyzed. The first system used a laser as a transmitter or light source, while the other system did not use a laser as a transmitter. This stage aimed to determine which condition can work effectively and distinguish between two different levels of ruby stone grading indicated by a different refractive index value. Data from Gemology Software Tools was used where this software consists of gathered data from gemstones from around the world, including the refractive index value of the ruby stone. From the different values of the refractive index, modeling of grading valuation could be achieved, represented by the z-axis value of the reconstructed three-dimensional images.

In the final evaluation stage, several experiments were conducted by my colleague using a sample of ruby stone (Mohd Rahalim et al., 2022).The refractive index of this ruby stone is unknown. The experiment was conducted using a SONY™ ILX551A CCD Linear Sensor and laser diodes. Figure 1.4 below shows the experimental setup (Mohd Rahalim et al., 2022). The data obtained from the experiments are used to reconstruct the image of ruby stone using LabVIEW programming. Further analysis on the image reconstructions is conducted. The data was analyzed using Minitab statistical analysis software and a statistical engineering analysis technique.



Source: Mohd Rahalim et al. (2022)

Figure 1.4: Experimental Setup of Ruby Stone With SONY™ ILX551A CCD Linear Sensor and Laser Diode

1.6 Research Methodology Summary

This present study attempted to develop image reconstruction using a CCD tomography system with a SONY™ ILX551A CCD and laser diodes arranged in an octagon to cover a large region of the ruby stone. Two different software programs were used in this study, i.e., image reconstruction with laser (System A) and without laser as a transmitter/source of light (System B). Both image reconstruction systems were objectively compared to determine which system more effectively evaluated the optical properties of ruby stones before a real-time image reconstruction was conducted. The modeling was developed using LabVIEW, and the linear back-projection (LBP) algorithm was used during real-time image reconstruction.

The ability of the CCD tomography system to detect and differentiate between the different clarity levels of the ruby stones is based on the refractive index value determined using the Gemology Software Tools, which was investigated after a few experiments. The acquired data was then analyzed and examined using Minitab software and a statistical engineering analysis technique.

1.7 Structure of Thesis

This thesis is divided into six chapters, which are listed below.

i. Chapter 1 briefly summarizes the research background, objectives, problem statements, scope, and contributions.
ii. Chapter 2 presents a literature review of the ruby stones, their industrial applications, their characteristics, various Gemology tools used for grading valuation, and the conceptual framework used in the CCD tomography system.
iii. Chapter 3 describes the research methodology based on the CCD tomography system model and the LabVIEW program used in the technique.
iv. Chapter 4 presents the results of the CCD tomography image reconstruction system based on different refractive index values. The research also presented a detailed analysis and discussed the conceptual modeling of the optical properties for ruby stones.
v. Finally, Chapter 5 presents the research conclusions and recommendations for further work.