CHAPTER 5

CONCLUSION

5.1 Conclusion

This research provides a comprehensive approach to analyzing the light distribution characteristic of the ruby, where the CCD system is proven to be a reliable technique for quantifying the clarity of the ruby in the form of voltage values. The objectives of the research have been achieved well.

The first objective of the research is to design and develop a CCD linear sensor system for inspecting the clarity of rubies. A detailed review of the previous research is conducted to analyze the optical characteristics of rubies that involve the ruby's grading qualification. An analysis of the factors that determine the clarity of the ruby is conducted, where the details on blemishes, inclusions, and others are considered. These factors affect the opacity of the ruby stones, which will also control the light that passes through them. From the optical characteristics of the ruby, the mathematical modeling is developed using the LabVIEW software for light reflection and light attenuation to obtain the theoretical values. The type of laser used as the transmitter, the CCD linear sensor selected as the receiver, and other environmental conditions such as temperature and humidity, are carefully considered to ensure the CCD works well during the experiments.

As a result, the execution of the theories analyzed by the previous research into the experiments using the CCD linear system (single CCD) to detect the clarity of the rubies. The CCD system is set up with the consideration of the optimum condition required by the CCD linear sensor, laser, and rubies to obtain the best possible output from the sensor. The CCD system is set up in a black box that is almost completely dark condition because the CCD is very sensitive to light. Other miscellaneous lights are to be avoided as much as possible to produce the best results.

The second objective is to conduct several experiments for validating the capability of the CCD linear sensor to be used as a clarity inspection system of rubies. Different conditions for the experiments are considered which are in the laser ON and OFF, with and without rubies in the CCD linear sensor system. The experiments validate that the CCD linear sensor produces a better output voltage with less scattered data in the laser ON condition compared to when then laser is OFF.

Similarly, fewer outliers are produced when a laser is used in the system than when there is no laser in the system, apart from the fact that the light detected by the CCD linear sensor is solely from the fluorescent of the ruby. The experiments also confirm the characteristic of the ruby itself—the ability to produce fluorescent light on its own. Moreover, the use of a monochromatic light laser with 650 mm wavelength, which according to previous research and the datasheet, suits the CCD linear sensor condition, also enhances a more accurate voltage value.

The final objective is to perform statistical analysis and reverse mathematical modelling for verifying the efficiency of the CCD linear sensor. Four conditions are evaluated in these experiments, where the first and second situations do not involve the

synthetic ruby in their systems, and the laser is in the OFF and ON mode, respectively. Conversely, the third and fourth conditions require the presence of a synthetic ruby in the system, with the laser in OFF and ON mode, respectively. The t-test is used in analyzing 600 data samples of each condition. The t-test shows that the mean of the CCD voltage output value when the laser is in the OFF condition with the synthetic ruby in the system is less than when the synthetic ruby is not in the system. This proves that the CCD linear sensor detects the presence of the synthetic ruby from only the fluorescence light from the synthetic ruby.

Conversely, when the laser is in the ON condition, the mean value with the synthetic ruby is significantly greater than the mean value without the synthetic ruby. This indicates that the CCD linear sensor can recognize the difference in light intensity, where less light intensity is detected when a synthetic ruby is in the system and vice versa. The experiment is repeated using the natural ruby in the laser ON condition only since the previous test shows that the CCD linear sensor executes a more uniform data compared to when the laser is OFF. The t-test also conducted on the CCD voltage output of the natural ruby. Using the mean value of CCD voltage output from the experiments with the synthetic and natural ruby in the laser ON conditions, the reverse mathematical analysis is done. From the reverse mathematical analysis, the refractive index of each ruby is executed. Then the refractive index value from the calculation is compared to the actual refractive index of each ruby. Finally, the accuracy test where the theoretical refractive index of the natural ruby and synthetic ruby is compared to their actual refractive index also strengthens the reliability of the CCD system with average of 96.90% accuracy.

With all these objectives achieved, the CCD system involving the laser as a transmitter and the CCD linear sensor as the receiver, together with the use of the LabVIEW and MATLAB software to develop the mathematical modeling, is proven to be a reliable system. In particular, this system displays great capability in analyzing the light distribution characteristics of a ruby, specifically the clarity.

5.2 Research Contributions

This research makes several contributions to gemology, particularly in the jewelry industry and specifically in several aspects as listed below:

i. **The application of CCD linear sensors in detecting light intensity quantitatively.**

   The CCD system provides an inspection system that can detect the clarity of ruby and other gemstones as it can distinguish even slight differences in the light intensity of the stones. Thus, the clarity of the ruby and other gemstones can be classified accordingly.

ii. **It introduces a nonintrusive and nondestructive technique for analyzing gemstones**.

   The CCD system administers a system that does not disrupt the internal environment of the ruby physically and chemically. Hence this system helps in maintaining the originality and purity of the gemstones.

iii. **The CCD linear system is a user-friendly system.**

The CCD linear system does not require an expert to operate. This means that anyone unfamiliar or who does not have a lot of experience with rubies can also handle the system and get accurate results.

5.3 Future Recommendations

i. Instead of a CCD linear sensor that only detects linear lights that transmit through it, an area CCD sensor can be used to detect the overall light distribution in the ruby as it has a 100% fill factor and collects light with zero loss (Hamamatsu Photonics, n.d.).

ii. A large number of samples can be applied when a data acquisition system with a higher sampling rate is used to improve the CCD system and provide better accuracy at the same time.