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Performance Evaluation of Green and Red Lasers in Long-Distance Optical Sensing Using Light Dependent Resistors

ABSTRACT

This study compares the performance of green (532 nm) and red (650 nm) lasers in optical sensing applications using Light Dependent Resistors (LDRs), focusing on their effectiveness for long-range light intensity detection in environments like bathymetry and surrogate sediment monitoring. The experiment measures resistance changes in LDRs exposed to both wavelengths at incremental distances (1m, 2m, 3m, 4m, and 5m) under controlled laboratory conditions. The key objective is to assess the spectral sensitivity and photoconductivity efficiency of the LDRs with each laser wavelength, providing insights into the optimal laser choice for long-distance sensing systems.

The results indicate that green lasers exhibit superior sensitivity compared to red lasers, as evidenced by consistently lower resistance values at all tested distances. This performance advantage is attributed to green light's higher photon energy and reduced scattering and absorption losses in air and other media, which enhance electron excitation in the semiconductor material of the LDR. These findings align with previous studies suggesting that green light performs better in turbid media, such as sediment-laden water, where precise light transmission and detection are critical for accurate measurements.

This comparison is crucial for the design of optical systems used in environmental monitoring and water resource management, where accurate, long-distance light intensity detection is essential. The research highlights the importance of selecting the appropriate laser wavelength to improve the efficiency and reliability of optical sensing technologies, particularly in challenging aquatic environments. The study's findings provide a foundation for the optimization and calibration of laser-based systems in applications like surrogate sediment monitoring and bathymetric mapping, where maintaining signal strength over long distances is vital. Future work could explore the impact of environmental factors on photodetector efficiency to further advance optical sensing technologies.

Keywords: Optical Sensing, Photodetector sensitivity, Green Laser, Light Dependent Resistor (LDR), Surrogate Sediment Technology, Bathymetry

1. Introduction

Light sensing technologies are central to numerous applications, including communication systems, automation, and environmental monitoring (Hecht, 2001). Among these, lasers have become indispensable due to their unique properties: monochromaticity, coherence, and collimation (Svelto, 2010). The effectiveness of a laser-based system depends significantly on the photodetectors employed and the wavelengths of light used, as these determine the system's sensitivity and accuracy over distance (Davies-Colley & Smith, 2001).

Light Dependent Resistors (LDRs), a widely used class of photodetectors, rely on changes in resistance when exposed to varying light intensities. This property makes them suitable for applications that demand continuous monitoring of light intensity across long distances (Zhang et al., 2018). However, the spectral response of LDRs varies with wavelength due to material properties, particularly in semiconductor-based systems (Horowitz, 2008).

Recent advances in laser technology have enabled the development of systems capable of detecting light intensity with precision over extended distances. Green and red lasers are commonly utilized in such systems, but they exhibit different levels of absorption and scattering in various media (Gordon & McCluney, 1975). Green lasers, with shorter wavelengths, are often preferred for their higher visibility and lower scattering losses (Mertes, 2002). On the other hand, red lasers, with longer wavelengths, are prone to greater attenuation and reduced sensitivity in photodetectors (Postma & Strasser, 2009). Green lasers have also shown significant promise in airborne bathymetry applications, particularly for mapping shallow water and coastal environments. Studies have demonstrated their capability to penetrate clear and shallow water efficiently, making them suitable for high-resolution fluvial and estuarine surveys (Yang et al., 2018). In contrast, red lasers, while less commonly applied in bathymetric contexts, can offer advantages in detecting submerged objects and sediment interfaces under certain environmental conditions (Li et al., 2023).

This study aims to evaluate the performance of green and red lasers in a controlled environment to determine their suitability for long-distance optical sensing. By analyzing resistance changes in LDRs at varying distances, this research contributes to the optimization of wavelength selection in laser-based optical systems.

Literature Review

Several studies have explored the interaction of light with various media and its implications for photodetector performance. Hecht (2001) emphasizes the importance of laser properties such as coherence and monochromaticity in achieving high precision in optical applications. Gordon and McCluney (1975) discussed how wavelength impacts light scattering and absorption, highlighting the advantages of shorter wavelengths in minimizing losses. The efficiency of photodetectors in converting light into electrical signals is another critical factor. Zhang et al. (2018) investigated the spectral response of cadmium sulfide (CdS)-based LDRs, showing that sensitivity varies significantly across different wavelengths. Bilotta and Brazier (2008) examined the role of light attenuation in environmental systems, demonstrating the need for precise calibration of sensors.

In the context of long-distance sensing, Davies-Colley and Smith (2001) reviewed the effects of wavelength on light transmission, noting that green light often outperforms red light due to lower scattering coefficients. Mertes (2002) supported this conclusion, particularly in turbid media, where shorter wavelengths retain their intensity more effectively. Green LiDAR has been demonstrated as effective in capturing riverbed profiles and sediment patterns in shallow water environments, as explored in studies conducted by the U.S. Geological Survey. However, factors like turbidity and water clarity significantly influence data accuracy, making the calibration of algorithms crucial for such surveys (Paul et al., 2013 and Raju et al., 2024). Amani et al., (2022) shown the utility of bathymetric LiDAR in classifying marine habitats and accurately mapping seafloor sediment types. A study conducted in Bonne Bay, Newfoundland, demonstrated the application of LiDAR intensity data coupled with machine learning to differentiate habitat types. The method showed robust accuracy in identifying sediment types such as eelgrass and fine sediment, which are crucial for environmental monitoring.

Despite extensive research, a direct comparative analysis of green and red lasers for LDR-based systems under identical conditions remains limited. This study fills that gap by providing empirical data on the performance of these wavelengths in a controlled laboratory setting.

2. Materials and Methods

The materials and methods section details the experimental design, the selection of equipment, and the procedures employed to evaluate the suitability of green and red laser light sources for long-distance optical sensing using Light Dependent Resistors (LDRs). The study aimed to assess how these lasers interact with the photodetector material under controlled laboratory conditions and determine which wavelength is more effective for potential applications in bathymetry and surrogate sediment monitoring.

2.1 Materials

2.1.1 Laser Sources

Green Laser (532 nm): A 532 nm laser was selected for its well-documented low scattering and absorption in water and other media, as supported by studies on light penetration in turbid environments (Stern, 1997; Hecht, 2001).

Red Laser (650 nm): The 650 nm laser was chosen for comparison due to its common use in optical experiments and its distinct spectral properties compared to the green laser. More details are shown in table 1.

Table 1. Operating details of the used LASER

Wavelength	532nm (Green) and 650nm (Red)
Power source	18650 rechargeable battery
Output power	1000mW
Start-up time	<10s
Working voltage	DC3.7 Volts

2.1.2 Photodetectors

Light Dependent Resistor (LDR): The LDRs used were based on cadmium sulfide (CdS) semiconductors, which are widely recognized for their sensitivity to visible light. Detailed specifications of the used LDR sensor are given in table 2. The resistance of these LDRs changes with the intensity of the incident light, making them suitable for this comparative analysis (Zhang et al., 2018).

Table 2. Technical specifications of LDR

Operating Ratings:	Maximum Voltage	250 V
	Dark Resistance	> 1M Ohms

	Response Time	30ms
Dimensions:	Sensor Diameter	20mm
	Lead Diameter	0.9mm (0.36″)
	Lead Length	26mm (1″)

2.1.3 Measurement Tools

Digital Multimeter: Resistance measurements from the LDR were recorded using a high-precision digital multimeter to ensure accurate readings.

Calibrated Meter Stick: A calibrated meter stick was used to maintain precise distances between the laser sources and the LDRs during the experiment.

2.2 Experimental Setup

The experiment was conducted in a controlled indoor environment to eliminate external light interference and ensure consistent conditions. Black curtains were used to isolate the setup from ambient light.

2.2.1. Experimental Design

The experiment was designed to simulate the conditions encountered in optical systems used for sediment monitoring and bathymetry, where light needs to traverse considerable distances in challenging environments. The following steps were implemented:

Laser Alignment: The laser source was mounted on a stable platform to maintain a fixed beam direction throughout the experiment.

LDR Placement: The LDR was positioned directly in the path of the laser beam, with the laser-to-LDR distance varying in increments of 1 meter (up to 5 meters).

Intensity Control: Both lasers were adjusted to emit light at the same initial intensity to ensure a fair comparison.

2.2.2. Data Collection

At each distance (1m, 2m, 3m, 4m, and 5m), the resistance of the LDR was recorded for both the green and red lasers as shown in figure 1 and 2. Each measurement was repeated three times to account for variability and ensure reliability.

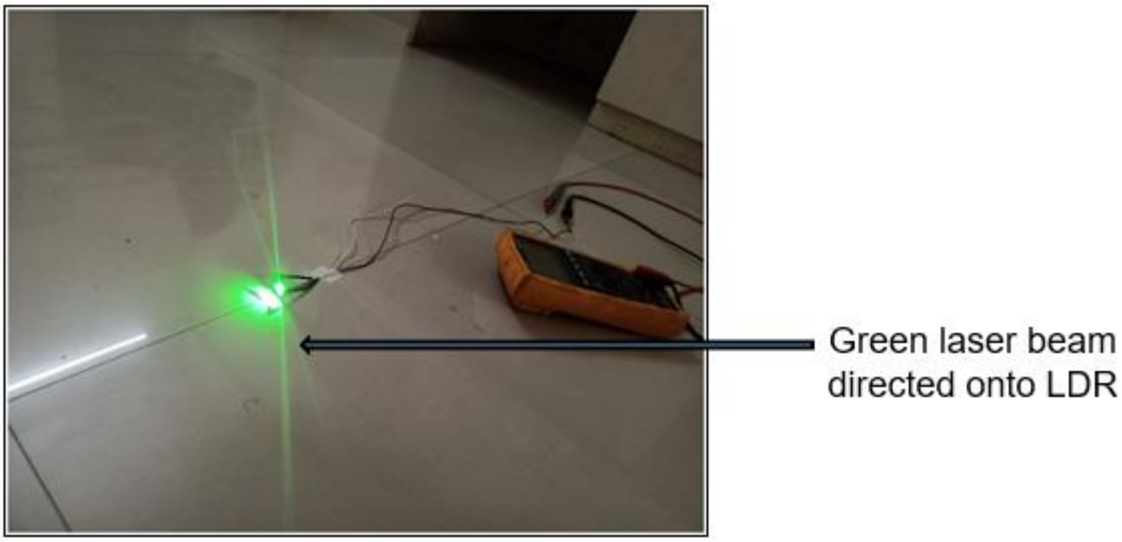

Fig. 1. Green LASER (532 nm) and LDR interaction recorded with multimeter

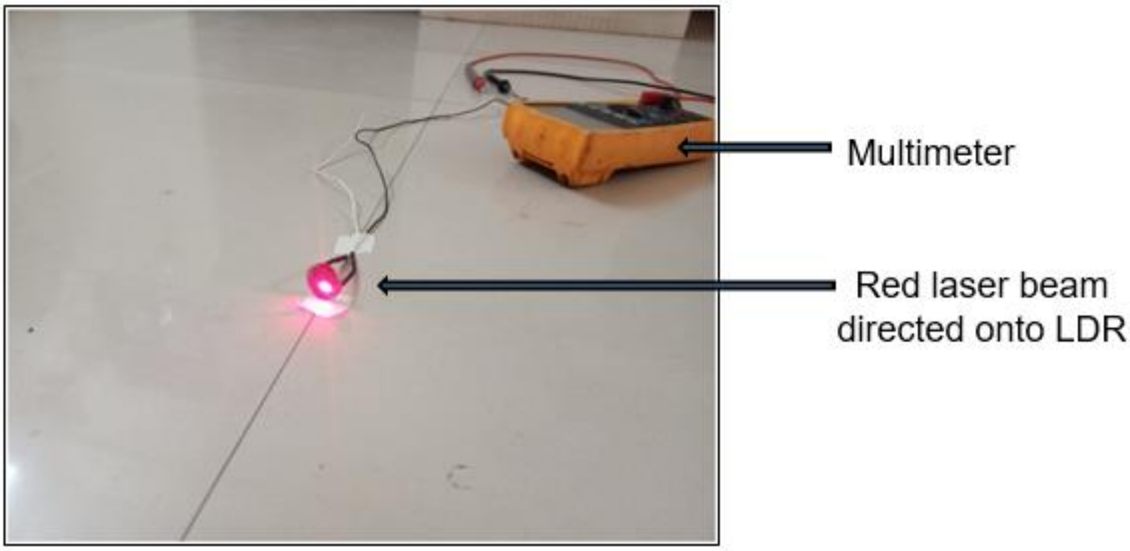

Fig. 2. Red LASER (620 nm) and LDR interaction recorded with multimeter

2.2.3. Analysis of Spectral Sensitivity

The spectral sensitivity of the LDRs to green and red light was analyzed using the resistance readings. According to Gordon and McCluney (1975), light of shorter wavelengths (e.g., green) is generally more effective in penetrating turbid media due to reduced scattering. This principle was used as a theoretical framework for interpreting the data.

2.2.4. Comparative Evaluation

The resistance measurements for both lasers were compared across all distances. The inverse square law, which states that light intensity decreases proportionally to the square of the distance, was applied to interpret the observed changes in LDR resistance (Hecht, 2001).

Additionally, the higher photon energy of green light compared to red light was considered as a factor influencing LDR sensitivity (Svelto, 2010).

2.2.5. Validation

To validate the findings, the setup was tested under slight variations in room temperature to ensure that environmental conditions did not significantly impact the results. Previous research suggests that temperature-induced changes in LDR resistance are minimal within the typical indoor range (Zhu & Zhang, 2019).

2.2.6. Data Interpretation

The experimental results were analyzed to assess the efficiency of converting light into electrical conductivity (photoconductivity efficiency) of the LDR under different wavelengths. The implications of these findings for applications such as bathymetry and surrogate sediment monitoring were discussed in the results section, in light of prior studies on light scattering and absorption in turbid environments (Davies-Colley & Smith, 2001; Gray & Gartner, 2009).

3. Results and Discussion

The objective of this study was to assess the relative effectiveness of green (532 nm) and red (650 nm) lasers in optical sensing applications using Light Dependent Resistors (LDRs). The experiment measured the resistance changes in the LDR as a result of exposure to both laser wavelengths at varying distances from 1 meter to 5 meters. The resistance readings (in kilo Ohm) obtained for the LDR under green and red laser light across different distances are summarized in table 3. The results showed that both laser wavelengths followed the inverse square law, where the intensity of light decreased with increasing distance, leading to higher resistance in the LDR. However, the key observation was that the LDR exhibited significantly lower resistance under green light than under red light at all distances.

Table 3. Resistance of LDR for different LASER Wavelengths at varying distances

Distance (m)	Resistance under Green Laser (532 nm)	Resistance under Red Laser (650 nm)
1	1.13 kΩ	1.60 kΩ
2	1.14 kΩ	1.68 kΩ
3	1.40 kΩ	1.80 kΩ
4	1.58 kΩ	2.06 kΩ
5	1.70 kΩ	2.68 kΩ

The data clearly indicates that the resistance under red laser light increases more rapidly as distance increases, suggesting that the red laser is less efficient in maintaining its intensity over distance compared to the green laser. This is consistent with the known behavior of light in different wavelengths. Green light, with a shorter wavelength and higher photon energy, is less affected by scattering and absorption losses in air and other media, making it more suitable for long-distance optical sensing applications (Hecht, 2001; Davies-Colley & Smith, 2001).

The superior performance of the green laser can be explained by its higher photoconductivity efficiency in LDRs. The LDR, typically made from cadmium sulfide (CdS), responds better to green light due to the material's spectral sensitivity, which maximizes electron excitation at shorter wavelengths (Zhang et al., 2018). The red laser, on the other hand, due to its longer wavelength, results in a less effective photoconductivity response in the LDR material, leading to higher resistance at longer distances.

These results are significant for applications such as bathymetry and surrogate sediment monitoring systems. In water with varying turbidity, the ability of green laser light to maintain signal strength over longer distances allows for more accurate measurements of suspended sediment concentration and light attenuation. The higher sensitivity of the LDR to green light ensures more reliable detection, even in environments with substantial turbidity, making green lasers the preferred choice for such systems (Stern, 1997; Gordon & McCluney, 1975).

4. Conclusion

In conclusion, the study successfully demonstrated that green lasers (532 nm) outperform red lasers (650 nm) in terms of optical sensing using Light Dependent Resistors (LDRs). The green laser produced lower resistance values across all distances tested, indicating greater sensitivity and efficiency in light transmission. This finding is consistent with the known properties of green light, such as higher photon energy and reduced scattering and absorption losses compared to red light. The superior performance of the green laser suggests its suitability for applications where long-distance light detection is essential, particularly in environments with turbidity, such as water bodies undergoing sediment transport or bathymetric surveys.

The study contributes to the growing body of research on optical sensing technologies, particularly in the context of surrogate sediment monitoring and bathymetric applications. The ability of green lasers to provide more reliable and accurate measurements in turbid environments opens new avenues for improving monitoring systems in environmental sciences and water resource management.

5. Recommendations

Based on the findings, future optical sensing systems, especially for water quality and sediment monitoring, should prioritize the use of green laser wavelengths. These systems can benefit from enhanced signal strength and better detection accuracy in water with varying levels of turbidity. While this study was conducted under controlled laboratory conditions, further testing in real-world environments is necessary. Future work should investigate the performance of green lasers and LDRs under varying environmental conditions, such as different water depths, sediment concentrations, and temperature variations, to ensure the robustness of these systems in the field. To further enhance the performance of optical sensing systems, it is recommended to explore alternative photodetectors with improved spectral sensitivity, such as photodiodes or phototransistors. These devices may offer better efficiency and a wider range of applications than LDRs, particularly in harsh environmental conditions. Field trials in real-world conditions would further validate the findings, while improvements in system calibration and automated adjustments could optimize long-term performance. Machine learning techniques could also be leveraged for real-time data processing and more precise environmental monitoring. Given the superior performance of green lasers in turbid media, their integration into surrogate sediment monitoring technologies is strongly recommended. This will improve the accuracy of suspended sediment concentration measurements, contributing to better water quality management and soil conservation efforts.

By incorporating these recommendations, future research can continue to refine optical sensing technologies and their applications in environmental monitoring, water quality assessment, and resource management.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

6. References

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