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The RGB Colors Impact Li-Fi Data Transmission in Both Indoor and Outdoor Environments

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Abstract – This study investigates how LED light colors influence Li-Fi data transmission and sound clarity responsiveness. Employing a quantitative experimental design, the research systematically assesses the impact of various color treatments on Li-Fi performance in indoor and outdoor settings. Significant variations are observed in background noise levels and clarity of transmitted sound, with white LED consistently outperforming other colors. In alignment with existing literature, the study contributes valuable insights into Li-Fi connectivity. Despite unexpected results in responsiveness evaluation, proposed future experiments aim to refine understanding and enhance the practical applications of Li-Fi technology. This research comprehensively examines Li-Fi performance under diverse conditions, contributing to the advancement of efficient and adaptable data transmission solutions.

Keywords – Li-Fi, LED Light Colors, Data Transmission, Responsiveness, Indoor, Outdoor

I. INTRODUCTION

Being well-informed is essential to any society, and data communication significantly enhances the speed of information exchange between different locations. An ongoing research initiative on Visible Light Communication (VLC) with an NI LabVIEW SDR-based prototype and commercially available lights was detailed. It delved into experiments on a Phillips indoor ceiling light and an Octavia tail-light under diverse natural conditions, revealing maximal reachable distances, the impact of environmental factors such as fog, and system weak spots. The article emphasized the need to address these weaknesses in future research and suggested custom part upgrades for enhanced performance (Martinek, R. et al. 2019). This synergy between information access and communication speed was vital for societal progress and connectivity.

In the development of Li-Fi technology, as outlined in the study "From Light to Li-Fi: Research Challenges in Modulation, MIMO, Deployment Strategies, and Handover," it was noted that the utilization of diverse Orthogonal Frequency Division Multiplexing (OFDM) techniques in Intensity Modulation/Direct Detection (IM/DD) might introduce computational complexity, yet it simultaneously enabled higher data rates. Furthermore, combining spatial modulation techniques with color domain modulation techniques was identified as a promising approach to achieve improved spectral efficiency and enhance mobility support (Sanket S. et al., 2019).

In the context of Li-Fi data transmission, applications of LED posed potential benefits but faced challenges. External light sources causing interference, LEDs synchronization for illumination and communication, and Li-Fi's reliance on penetrative light in environments with walls or other interception were notable hurdles (Agarwal A. et al., 2022). Addressing these challenges was crucial for optimizing Li-Fi performance.

Furthermore, a specific study in the logistics industry focused on addressing connection failures by deploying an IR-based Li-Fi transceiver. The implemented solution successfully eradicated these failures, pinpointing alignment and distance between transceivers as critical factors affecting connection speed. The study underscored the importance of optimizing the Li-Fi surface area for effective signal transmission and reception, especially in managing positional variations. Leveraging the Six Sigma methodology, the research successfully identified, characterized, and optimized these factors, highlighting Li-Fi's potential to provide secure, interference-free connections in dynamic logistics environments once connection speed challenges were resolved (Sharma & Sharma, 2021).

The researchers aim to bridge a gap in the existing understanding of Li-Fi technology. Despite its potential as a data transmission method, significant unknowns exist concerning how various variables, such as LED light color, affect its performance through sound clarity responsiveness. This knowledge gap carries substantial significance, as it could influence the practical application of Li-Fi in diverse scenarios. The researchers sought to provide valuable findings that may have tangible real-world implications, potentially leading to more efficient and adaptable data transmission solutions in the future.

This study is more than just a test of scientific curiosity; it has a specific goal. Its main objective is to fill a considerable knowledge gap in Li-Fi communication and potentially pave the way for future developments in this fascinating technology. The researchers are dedicated to helping the field of data communication have a brighter and more promising future through the analysis of LED light color in different environments and its impact on data transfer.

II. Materials And Method

This research utilized a quantitative experimental design to evaluate how RGB colors influenced Li-Fi data transmission. The chosen research design included controlling and manipulating conditions to assess how various color treatments affected Li-Fi performance. It adhered to experimental research principles to assess the comparative impact of color treatments on data transmission, considering indoor and outdoor environments.

Regarding the data gathering procedure, researchers consulted experts to validate the pursuit's self-constructed questionnaire, which had undergone several content and construct validations. Afterward, another set of experts was invited to test themselves on adapting Li-Fi technology and the effectiveness of RGB colors on data transmission for both indoor and outdoor settings.

2.1 Materials

The research employed a prototype, an adaptation of Li-Fi technology, to assess the influence of various light colors on data transmission efficiency in indoor and outdoor environments.

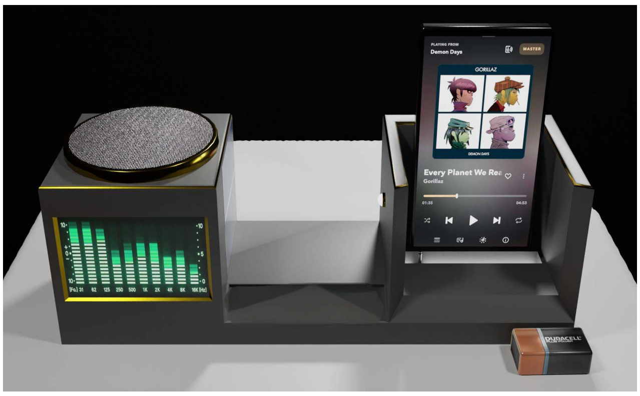


Fig 1. Li-Fi technology prototype

2.2 Li-Fi Technology Screening Test

The comprehensive testing protocol assessed how different colors (RGB and white light) impacted the prototype in indoor and outdoor environments. Indoor testing involved installing transmitters and receivers in a controlled setting and evaluating parameters like distance variations and color treatment (Sanket S. et al., 2019). Outdoor testing was protected from weather conditions and similarly assessed distance variations, color treatments, and outdoor environmental factors. A sound clarity assessment in both settings aimed to identify differences in data transmission quality based on color treatments, providing a comprehensive understanding of Li-Fi's connectivity and responsiveness across diverse environments.

III. Results And Discussions

This pursuit investigated the impact of different colors and environments on Li-Fi data transmission across three trials, concurrently incorporating retest and reliability assessments for the prototype. The examination focused on three pivotal aspects of Li-Fi performance: background noise levels, sound clarity transmitted, and responsiveness evaluations. Each color underwent three distinct trials for evaluations of the prototype. This comprehensive approach aimed to discern how variations in color and environment impacted Li-Fi connectivity and responsiveness consistently across multiple trials, providing a robust assessment of the prototype's reliability in diverse conditions.

3.1 Data Transmission Performance Comparison with RGB and White Light

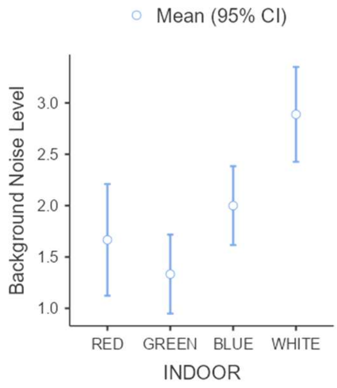
This study aimed to investigate the impact of Background Noise Level, Clarity of Transmitted Sound, and Responsiveness Evaluation on Li-Fi Technology in indoor and outdoor settings. Data transmission evaluations were conducted under four conditions: Red, Green, Blue, and White LED lights. One-way ANOVA was employed to assess potential differences among these conditions.

3.2 Indoor Settings

Table 1. One-Way ANOVA – Indoor Setting

One-way ANOVA (Fisher's)

	F	df1	df2	p
Background Noise Level	11.8	3	32	< .001
Clarity of Transmitted sound	36.9	3	32	< .001
Responsiveness Evaluation	24.7	3	32	< .001



. Figure 2. Background Noise Level Means in Indoor

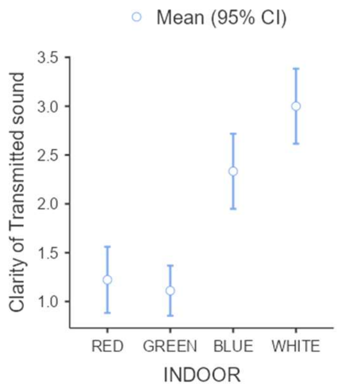


Figure 3. Clarity of Transmitted Sound Means in Indoor

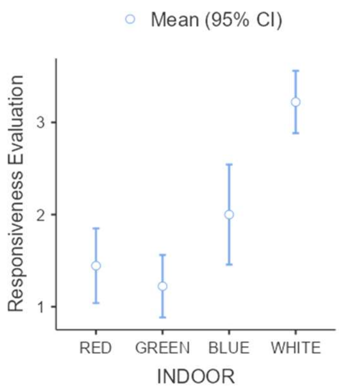


Figure 4. Responsiveness Evaluation Means in Indoor

Table 2. Background Noise Level

Tukey Post-Hoc Test – Background Noise Level

		RED	GREEN	BLUE	WHITE
RED	Mean difference	—	0.333	-0.333	-1.222 ***
	p-value	—	0.624	0.624	< .001
GREEN	Mean difference		—	-0.667	-1.556 ***
	p-value		—	0.093	< .001
BLUE	Mean difference			—	-0.889 *
	p-value			—	0.014
WHITE	Mean difference				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Table 3. Clarity of Transmitted Sound

Tukey Post-Hoc Test – Clarity of Transmitted sound

		RED	GREEN	BLUE	WHITE
RED	Mean difference	—	0.111	-1.11 ***	-1.778 ***
	p-value	—	0.952	< .001	< .001
GREEN	Mean difference		—	-1.22 ***	-1.889 ***
	p-value		—	< .001	< .001
BLUE	Mean difference			—	-0.667 *
	p-value			—	0.018
WHITE	Mean difference				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Table 4. Responsiveness Evaluation

Tukey Post-Hoc Test – Responsiveness Evaluation

		RED	GREEN	BLUE	WHITE
RED	Mean difference	—	0.222	-0.556	-1.78 ***
	p-value	—	0.819	0.150	< .001
GREEN	Mean difference		—	-0.778 *	-2.00 ***
	p-value		—	0.022	< .001
BLUE	Mean difference			—	-1.22 ***
	p-value			—	< .001
WHITE	Mean difference				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Results indicate significant variations in data transmission across the four conditions. Background Noise Level $F(3,32) = 11.8$, p = .001), Clarity of Transmitted Sound $F(3,32) = 36.9$, p = .001), and Responsiveness Evaluation $F(3,32) = 24.7$, p = .001) all demonstrated significant differences *(Table 1)*. Post hoc analysis using Tukey's HSD revealed that the use of White LED light in Li-Fi data transmission resulted in significantly higher scores for Background Noise Level *(Fig.2)* (M = 2.89, s = 0.601), Clarity of Transmitted Sound *(Fig.3)* (M = 3.00, s = 0.500), and Responsiveness Evaluation *(Fig.4)* (M = 3.22, s = 0.441) compared to Red LED light (M = 1.67, s = 0.236), $p < .001$, and Green LED light (M = 1.33, s = 0.500), $p < .001$, for Background Noise Level *(Table 2)*. For Clarity of Transmitted Sound, it was significantly higher than Red LED light (M = 1.22, s = 0.441), $p < .001$, and Green LED light (M = 1.11, s = 0.333), $p < .001$ *(Table 3)*. Additionally, in Responsiveness Evaluation, it scored significantly higher than Red LED light (M = 1.44, s = 0.527), $p < .001$, Green LED light (M = 1.22, s = 0.441), $p < .001$, and Blue LED light (M = 2.00, s = 0.707), $p < .001$ *(Table 4)*.

Furthermore, Blue LED light scored significantly higher in Background Noise Level (M = 2.00, s = 0.500), $p < .05$ *(Table 2),* and Clarity of Transmitted Sound (M = 2.33, s = 0.500) compared to Red and Green LED light, $p < .05$ *(Table 3)*. These findings underscore the significant influence of Red, Green, Blue, and White LED lights on Li-Fi data transmission in Indoor Settings.

3.3 Outdoor Settings

Table 5. One-Way ANOVA Outdoor Setting

One-way ANOVA (Fisher's)

	F	df1	df2	p
Background Noise Level	15.82	3	32	< .001
Clarity of Transmitted Sound	6.44	3	32	0.002
Responsiveness Evaluation	2.43	3	32	0.083

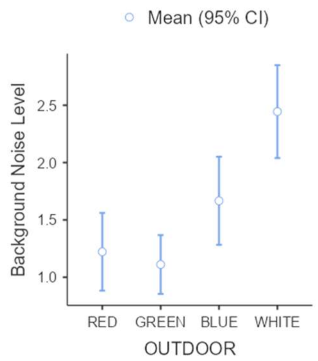


Figure 5. Background Noise Level Means in Outdoor

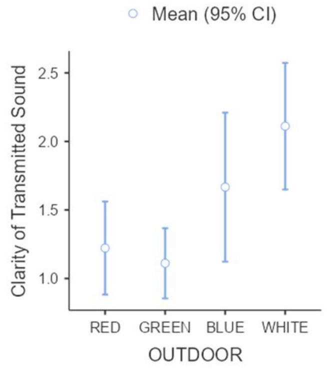


Figure 6. Clarity of Transmitted Sound Means in Outdoor

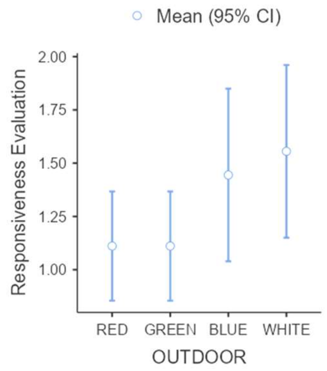


Figure 7. Responsiveness Evaluation Means in Outdoor

Table 6. Background Noise Level

Tukey Post-Hoc Test – Background Noise Level

		RED	GREEN	BLUE	WHITE
RED	Mean difference	—	0.111	-0.444	-1.222 ***
	p-value	—	0.955	0.186	< .001
GREEN	Mean difference		—	-0.556	-1.333 ***
	p-value		—	0.066	< .001
BLUE	Mean difference			—	-0.778 **
	p-value			—	0.005
WHITE	Mean difference				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Table 7. Clarity of Sound Transmitted

Tukey Post-Hoc Test – Clarity of Transmitted Sound

		RED	GREEN	BLUE	WHITE
RED	Mean difference	—	0.111	-0.444	-0.889 **
	p-value	—	0.972	0.318	0.007
GREEN	Mean difference		—	-0.556	-1.000 **
	p-value		—	0.150	0.002
BLUE	Mean difference			—	-0.444
	p-value			—	0.318
WHITE	Mean difference				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Table 8. Responsiveness Evaluation

Tukey Post-Hoc Test – Responsiveness Evaluation

		RED	GREEN	BLUE	WHITE
RED	Mean difference	—	0.00	-0.333	-0.444
	p-value	—	1.000	0.391	0.163
GREEN	Mean difference		—	-0.333	-0.444
	p-value		—	0.391	0.163
BLUE	Mean difference			—	-0.111
	p-value			—	0.950
WHITE	Mean difference				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

The results show notable differences in Background Noise Level and Clarity of Transmitted Sound but no significant variations in Responsiveness Evaluation among the four conditions. Background Noise Level $F(3,32) = 15.8$, p = .001) and Clarity of Transmitted Sound $F(3,32) = 6.44$, p = .002) revealed significant differences, while Responsiveness Evaluation $F(3,32)$ = 2.43, p = .083) did not show significance *(Table 5)*.

Post hoc analysis using Tukey's HSD highlighted that using White LED light for Outdoor Li-Fi data transmission resulted in notably higher scores for Background Noise Level *(Fig. 5)* (M = 2.44, s = 0.527) and Clarity of Transmitted Sound *(Fig. 6)* (M = 2.11, s = 0.601) compared to Red LED light (M = 1.22, s = 0.441), p < .001, and Green LED light (M = 1.11, s = 0.441), p < .001, for Background Noise Level *(Table 6)*. Regarding the Clarity of Transmitted Sound, it was significantly higher than Red LED light (M = 1.22, s = 0.441), p < .01, and Green LED light (M = 1.11, s = 0.333), p < .01 (refer to Table 7). However, Responsiveness Evaluation showed no significant differences in Red LED light (M = 1.11, s = 0.333), Green LED light (M = 1.11, s = 0.333), and Blue LED light (M = 1.44, s = 0.527) compared to White LED light (M = 1.56, s = 0.527) *(Table 8)*.

These findings highlight the considerable impact of Red, Green, Blue, and White LED lights on Li-Fi Technology, particularly concerning Background Noise Level and Clarity of Transmitted Sound. However, no significant differences were observed among the colors in terms of Responsiveness Evaluation in Indoor Settings.

3.4 Environmental Factors' Impact on Connection Responsiveness

Table 9. Spearman's Correlation Matrix

Correlation Matrix

		Indoor	Outdoor
Indoor	Spearman's rho	—	
	df	—	
	p-value	—	
	N	—	
Outdoor	Spearman's rho	0.522	—
	df	10	—
	p-value	0.082	—
	N	12	—

Note. * p < .05, ** p < .01, *** p < .001

The Spearman's correlation matrix provided insights into the relationship between connection responsiveness in both indoor and outdoor settings. In Table 9, the indoor setting was denoted by a dash (—), indicating an inapplicable correlation coefficient within itself. On the other hand, the outdoor setting revealed a Spearman's rho of 0.522, suggesting a moderate positive correlation. However, it is crucial to note that the associated p-value ($p = 0.082$), presented in Table 9, indicated a lack of statistical significance at the conventional threshold, $p < .05$. The table also presented a degree of freedom ($df = 10$) for the outdoor correlation, reflecting the number of pairs of observations considered, and sample size, (N = 12).

Therefore, it became evident that, while a moderate positive correlation was observed in outdoor connection responsiveness, statistical significance was not established based on the provided p-value.

3.5 Potential Light Adjustment Effect in Environmental Shift

Table 10. Spearman's Rank Correlation Matrix

Correlation Matrix

		Indoor	Outdoor
Indoor	Spearman's rho	—	0.302
	df	—	10
	p-value	—	0.341

Correlation Matrix

		Indoor	Outdoor
	N	—	12
Outdoor	Spearman's rho		—
	df		—
	p-value		—
	N		—

Note. * p < .05, ** p < .01, *** p < .001

The Spearman's correlation matrix in Table 10 examines the Potential Light Adjustment Effect in Environmental Shift. In the context of the Potential Light Adjustment Effect in Environmental Shift, the indoor correlation is represented by a dash (—), indicating that the correlation coefficient within the indoor setting is not applicable. Additional details in the table include the degrees of freedom (df), reported as 10 for the outdoor correlation, reflecting the pairs of observations considered. The sample size (N) is indicated as 12. Conversely, the correlation in the outdoor setting demonstrates a Spearman's rho of 0.302, suggesting a modest positive correlation. The associated p-value of 0.341, as noted in the table, indicates a lack of statistical significance at the conventional threshold of 0.05.

IV. Conclusions

In light of the study's findings, the researchers formulated the following conclusions:

The comprehensive investigation into the impact of different colors and environments on Li-Fi data transmission unveiled significant variations in Background Noise Level, Clarity of Transmitted Sound, and Responsiveness Evaluation across conditions. Notably, White LED light consistently outperformed other colors in all evaluated aspects, showcasing its efficacy in Li-Fi data transmission.

The study aligned with the visible light communication systems literature, specifically focusing on Li-Fi performance parameters. The integration with LabVIEW and software-defined radio (SDR) echoed previous attempts, contributing novel insights into the influence of color and environment on Li-Fi connectivity. The researchers noted that their findings complemented prior work by systematically analyzing multiple colors and environments, offering a refined understanding of Li-Fi performance under diverse conditions.

While significant variations were observed in Background Noise Level and Clarity of Transmitted Sound, Responsiveness Evaluation displayed no significant differences among colors and environments. This unexpected result prompted the researchers to consider additional factors influencing Responsiveness Evaluation, such as potential technological constraints or inherent limitations in their experimental setup.

Based on the summary of conclusions, the researchers suggested that future experiments should delve deeper into the factors influencing responsiveness evaluation. Alterations in methods, such as refining the prototype or introducing additional parameters, could enhance the precision of results. Moreover, exploring Li-Fi performance in real-world scenarios beyond controlled environments could provide a more comprehensive understanding of its capabilities and limitations. These avenues for future research aimed to refine the researchers' understanding of Li-Fi technology and contribute to its practical applications.

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