VLC positioning in low data rate for V2V communication

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Abstract

The creation and implementation of a system that bridges visible light communication (VLC) with selected identifiers, envisioned as informational beacons, are outlined. This system is adept at controlling LED panels and orchestrating communication between LED lights and the receiving unit, laying the groundwork for vehicle-to-vehicle (V2V) communication systems tailored for precise positioning. The design and assessment of test-bed requirements cater to the anticipation of future V2V optical wireless communication scenarios. Through analysis, it is demonstrated that commercial outdoor lighting can be effectively utilized for V2V positioning, capable of operating under daylight with a data transmission rate of 100 Kbps. Crucially, the system's ability to accurately detect positioning beacons facilitates the localization of vehicles within designated areas of interest, paving the way for the advancement of V2V communication technologies. This comprehensive approach not only validates the feasibility of using VLC for vehicle positioning but also sets a precedent for future developments in V2V communication systems.

CCS Concepts

• **Hardware** → **Emerging optical and photonic technologies**; *Sensor devices and platforms*; *Signal processing systems*; **Wireless integrated network sensors**; • **Networks** → *Network components*.

Keywords

Visible light communications, vehicular positioning, ITS

ACM Reference Format:

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1 Introduction

In recent years, the widespread adoption of Light Emitting Diodes (LEDs) has revolutionized modern illumination systems, driven by their remarkable energy efficiency and the ability to oscillate between different luminescence levels at optimal speeds [11] [16]. As the demand for efficient and reliable data transmission systems has escalated, Optical Wireless Communications (OWC) technologies have gained prominence, addressing the challenges posed by high occupancy in the Radio-Frequency spectrum [5]. This surge has propelled the exploration of alternative solutions, such as Visible Light Communications (VLC), which facilitates modulated and modifiable illumination for wireless data transmission through pulses of light, operating within the spectrum at approximately 400 THz [17]. VLC presents a promising avenue for indoor communication and navigation, leveraging existing illumination systems [9] [22].

In response to the evolving landscape of VLC, the integration of accurate device localization with high precision, known as Visible Light Positioning (VLP), has emerged as a complementary approach [21]. The synergy between VLC and VLP has paved the way for advancements in embedded systems for transmission, leading to the development of novel technologies within the realm of Intelligent Transport Systems (ITS) and vehicular-to-vehicular (V2V) communications [1] [14]. As the demand for high-speed and reliable data transmission becomes imperative in indoor positioning, researchers are exploring innovative implementation ideas to enhance the performance and reliability of Bit Error Rate (BER) and Signal-to-noise Ratio (SNR) [15][20].

The idea is to present a preliminary design for enabling direct communication of codified messages in ASCII at a specific height [6][12]. We will explore the communication analysis at a height of 1 meter, performing measurements with a built-in photodiode. The proposed setup facilitates multiple data transmissions under different positions, offering a comprehensive analysis of modulations, noise mitigation techniques, and the implementation of LED control systems [12]. The motivation behind this optimal VLC system design for indoor environments stems from the observed effectiveness of visible light in optical communication developments across various domains [8] [13]. Furthermore, the progress of the idea extends to the application of embedded systems generating continuous data, serving as a control signal for DCDC drivers and

LED panels.

Drawing inspiration from the advancements in lighting infrastructure, particularly the increased use of LEDs in road applications, this report aligns with the paradigm shift in street lighting [18]. The incorporation of LED technology for road lighting not only brings advantages such as low power consumption, low voltage, and extended lifespan but also opens avenues for data transfer through optical signals without compromising the primary lighting functionality [10]. Visible light communication technology, encompassing both illumination and communication functionalities simultaneously, has gained significant attention across diverse fields [19]. While various positioning technologies using visible light communication have been actively researched, existing studies predominantly focus on indoor positioning, leaving room for addressing challenges related to positioning accuracy and implementation methods, particularly in outdoor environments and vehicular contexts.

In this order of ideas, we implemented a unidirectional communication system using an Arduino Uno microcontroller. ASCII characters were first grouped into 8-bit segments, each mapped to a unique character according to the ASCII table. This data was then encoded using Manchester encoding, a self-clocking scheme that embeds clock information within the signal itself through mid-bit transitions [3]. The encoded signal was subsequently transmitted via LEDs and ultimately decoded by a photodiode for data retrieval. This approach offers the advantage of reliable clock recovery and a DC-balanced signal, suitable for transmission over various channels. The integration of VLP and VLC, explored in this report, thus contributes to the ongoing efforts to enhance V2V communication and Intelligent Transport Systems.

2 VLP Setup for V2V scenarios

To verify a transmission from visible light communications, it is necessary to have a setup that allows specific and reliable measurements. The smart street lamp lighting to develop V2V services with VLC technology is the core of this design. To demonstrate the feasibility of deploying positioning and localization V2V services through lightning lamps a laboratory-controlled set-up is designed. The proposed schema uses LED lightning blocks with similar characteristics as commonly used outdoor street lamps in terms of LED elements and drivers. In our proposal, we will use a custom deployment with a rectangular shape where 169 LED elements are placed under a 13 by 13 matrix to build an LED block element. The setup is completed by positioning 4 of those LED matrices under a fixed plane that can vary its height to test and characterize the system performance. These LED blocks were designed by PROEMISA SL, and this LED block adopted a commercial lightning panel used for street lamps to the needs of the laboratory conditions setup.

In the following section, a detailed description of the blocks and their drivers is commented on. It is worth mentioning that as a lightning panel, the high power and current are necessary to reach certain bandwidths necessary to implement the aforementioned V2V services under this proposed set-up.

In the proposed set-up the LED blocks are positioned on a matrix within a distance of 1 meter from each other to improve measurements to maintain a stable centroid on each block when measurements are taken on each panel for future measurements a circular black cardboard was used to shape the LED panels. Numeration of each identifier becomes a goal for the differentiation of data, which leads to the naming of each block with the variable "K". Therefore, block number 1 will be "K1", block number 2, "K2" and so forth.

Figure 1 shows the transmission setup built in the lab with the numbering of each LED block.

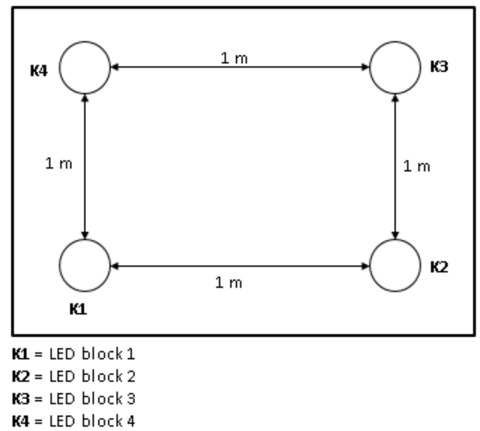

Figure 1: LED block transmission setup.

This redundancy in the transmission path enhances signal robustness and mitigates potential shadowing effects over the communication distance (h). On the receiving end, a single photodiode captured the aggregated light signal, as seen in Figure 2. This centralized detection scheme simplifies alignment requirements while maintaining adequate sensitivity for reliable data reception. To verify optimal communication performance, real-time character transmission and reception were monitored.
Received signals were demodulated and decoded back into ASCII characters, allowing for direct observation of data accuracy throughout the communication link. This setup fosters comprehensive evaluation of transmission fidelity and error rates under varying environmental conditions and distances, thereby validating the effectiveness of the proposed VLP system for robust character transmission in indoor environments.

2.1 LED transmitter driver

An important aspect of the setup and its design was to design an LED driver used for actual street lamp conditions into a controlled indoor environment positioning setup that controls the LED blocks individually. To establish individual control over each LED block, we devised a system where the transmitted sequence from the Arduino directly maps to the corresponding output on the DC-DC LED driver. In our four-channel configuration, the need of individual control over four LED outputs and their associated control signals is crucial. Therefore, the initial experimental stage was dedicated to optimizing key variables, such as power and current to

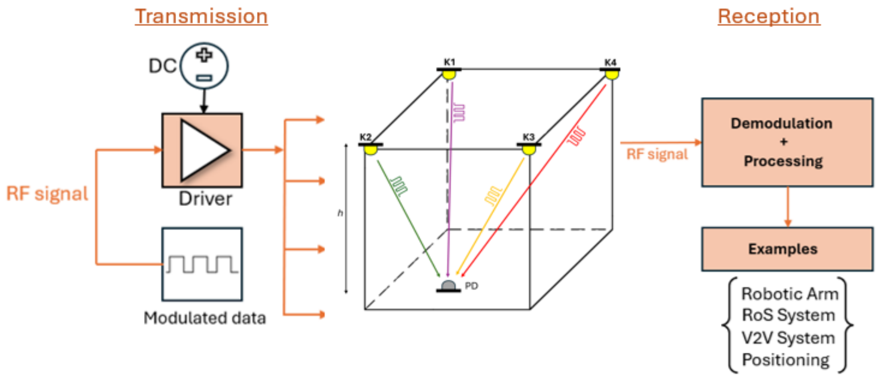

Figure 2: Overview for Visible Light Positioning techniques at low data rate. It presents the general schema for positioning in an indoor environment.

drive the block as indicated by the manufacturer within both the optical LED block and the DC-DC constant current LED driver and our VLC parameters.

In this case, the DC-DC LED driver, powered dually with a voltage of 24.5 V, and capable of handling up to a maximum of 50 V, plays a crucial role in ensuring the stability and efficiency of the LED blocks. Notably, the decision to set the maximum current through the LEDs to 480 mA for each of the four blocks aligns with the optimal operational parameters. Note that each LED driver is used to drive 5 LED blocks. Once the LED-driven power is stabilized it facilitates the transmission of encoded information from the development board. This granular control over each LED block under one single driver enhances our system's versatility and paves the way for further exploration of optimal VLC configurations.

A snapshot of the physical overview of the industrial LED employed in our setup is presented in Figure 3.

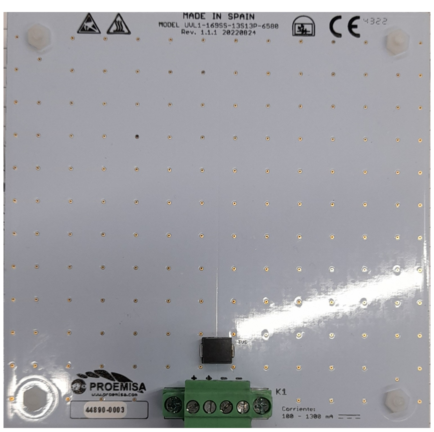

Figure 3: DCDC constant LED block powered by our driver UVL1-TC05-0800A-4800 Rev 1.1.1.

In the realm of positioning, the implementation of a VLC photodiode serves as a key component for detect each data signal transmitted through the light panels, managed by the control board and controlled by the LED driver. The positioning mechanism is crucial, showcasing its significance in determining the optimal height for the quantification of a sequence of data. The photodiode precisely acquires the encoded signals, allowing for accurate localization of the transmitted data, in terms of power detected and signal decoded. This positioning aspect is key to our VLC setup, demonstrating its potential not only in data transmission but also in enhancing the precision of indoor positioning.

2.2 V2V Positioning model

Within the LED grid, individual ASCII characters manifest as a sequence of binary light pulses. To capture and interpret this visual conversation, we designed a photodiode circuit, as depicted in figures 4 and 5, orchestrated by a dedicated Arduino microcontroller. This circuit meticulously decodes the Manchester-encoded light signals, revealing the transmitted characters.

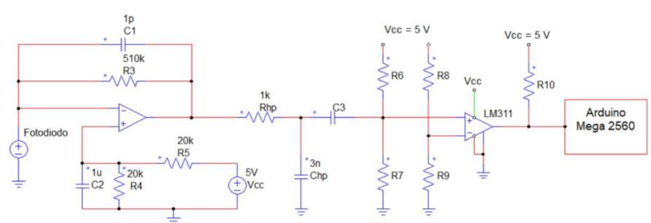

Figure 4: VLP reception system electrical design.

The reception stage of the VLC system focuses on converting the received optical signal into a usable electrical signal for digital processing. This involves three key stages:

1. Photodiode and trans-impedance amplifier: A photodiode converts the incident light signal into a small current. A trans-impedance amplifier (TIA) transforms this current into a voltage for further processing. The TIA provides high gain and impedance matching, maximizing signal strength while minimizing noise. A feedback loop formed by resistor R1 and capacitor C1 stabilizes the amplifier gain and reduces high-frequency noise.

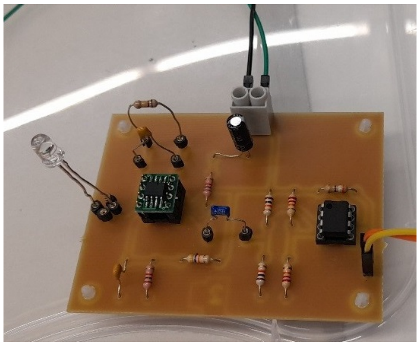

Figure 5: Visible light photodetection board final prototype.

2. Non-inverting Input Biasing: Two additional resistor-capacitor pairs (R2-R3 and C2) at the non-inverting input of the TIA (Figure 1) provide a DC bias voltage greater than 0 V. This reverse biases the photodiode, maximizing its sensitivity and improving signal quality.

3. Voltage Comparator and Digital Output: An LM311 voltage comparator converts the analog signal from the TIA into a digital form. The comparator compares the amplified voltage at the non-inverting input (V+) to a reference voltage at the inverting input (V-). When V+ exceeds V-, the comparator output transistor switches off, and the output voltage rises to Vcc minus the voltage drop across resistor R8. Conversely, when V+ falls below V-, the transistor conducts, and the output falls to GND. This binary output level transition corresponds to the Manchester-encoded data transmitted by the LED grid.

The table 1 outlines the parameters set for the circuit variables. The selection of these values was carefully made with the primary objective of ensuring a consistently stable current, critical for optimizing the performance of the comparator. Additionally, these choices took into account the initial operational frequency of 100 kHz, to accomplish with low-data rate V2V communications environments through VLC as proposed.

Table 1: Reception circuit electrical setup characteristics

R3	510 k Ω
R4, R5	20 k Ω
R6, R7	10 k Ω
R8, R9	22 k Ω
R10	500 Ω
Rhp	1 k
C1	1 pF
C2	1 uF
C3	16 nF
Chp	3 nF

3 Measurements on Data transmission over VLC

Following the experimental design, four optical blocks were carefully positioned 1 meter below the focusing surface of a wooden platform, as seen in Figure 6. Supported by two stable trestles, this configuration maintained optimal spacing and alignment for accurate data collection.

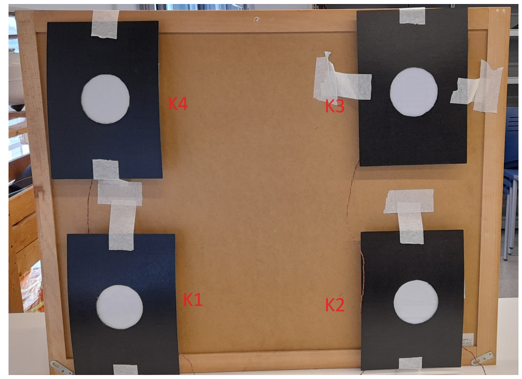

Figure 6: General setup for VLC.

Selecting the optimal method for encoding our message is a crucial consideration. In this instance, we have decided to organize 1's and 0's into 8-bit groups, creating representative characters from the ASCII table. To facilitate this transmission at a low data rate, we will employ Manchester modulation. The anticipated result is establishing a favorable positioning environment within an indoor communication setup, characterized by LED blocks generating a distinct blinking pattern through which the data beacons will be effectively transmitted. As an example check the following ASCII character and its codification under Manchester encoding:

- **ASCII characters in binary**: "a" -> 0 1 1 0 0 0 0 1
- **Manchester encoding**: 01 10 10 01 01 01 01 10

Considering that the LED driver controls the blinking, it is essential to consider the constraints on data transmission, with careful attention to maintaining an observed data rate of around 100 kbps.

3.1 Laboratory setup description

The ensuing table provides a comprehensive overview of the device specifications featured in this paper. It details the essential requirements and characteristics of each device integral to our experimental setup.

Table 2: Main electrical and data setup parameters description

Visible Light Spectrum (400-800 THz)	**LEDs**	**Arduino Mega 2560**	**OPA380 Transimpedance Amplifier**	**LM311 Comparator**
Operational Voltage	1.5-2.2 V	5 V	2.7-5.5 V	3.5-30 V
Operational Current	20-40 mA	20 mA	10 mA	Max. Input Offset Current: 70 nA
		8 kB of SRAM	-40-125 Op. temp. range (°C)	0-70 Op. temp. range (°C)
		4 kB of EEPROM	>1 MHz transimp. bandwidth	165 ns fast response time
		256 kB flash memory	Input vol. noise, f= 0.1-10 Hz	Max. input bias current: 300 nA

3.2 Results and discussion

It is necessary to focus on the objective of validating the viability of conveying verifiable and actionable data via the visible light source employed in our experimental setup. Therefore, this experiment substantiates the efficacy of visible light communication for transmitting a predefined set of characters across a predetermined distance.

The character "A1." was chosen as the initial transmission test message. The Arduino Uno board code developed employed Manchester encoding to convert this sequence, transmitting the message to the LED driver, thereby controlling the blinking sequence of the LED block K1.

At the reception terminal, the detected signal by the proposed photodetector is captured by a digital oscilloscope and a second Arduino board to decode the transmitted light signal. This verification process aims to confirm successful data transmission and recovery of the intended message, as depicted in figure 7.

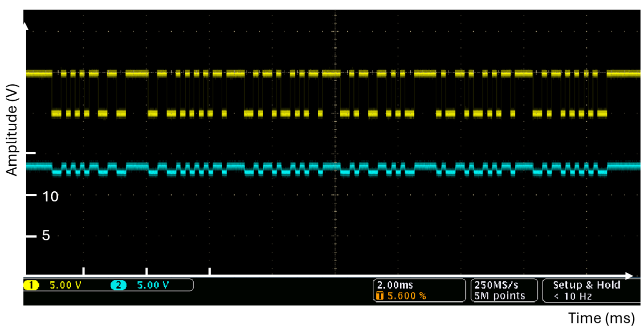

Figure 7: "A1." transmitted message signal (channel 1) and received signal (channel 2) on the oscilloscope. Each step in the oscilloscope is selected in 5 V in amplitude and 2 ms in time.

Transmission of single pulses requires closer proximity between the photodiode and the LED blocks for successful reception. Our experimental setup demonstrated the feasibility of VLP with single-pulse transmissions over a distance of approximately 36 cm.

The analysis of BER and SNR of these measurements are checked in the following table:

Accurate and reliable reception of data transmitted via VLC is crucial for the successful implementation of VLC systems [2]. In this paper, we investigate the reception analysis of VLC systems, focusing on the relationship between signal-to-noise ratio (SNR) and bit error rate (BER), a crucial metric that quantifies the transmission accuracy and determines the proportion of erroneous bits in the received data, as well as the impact of photodiode height and its affectations due to the environment [4].

Table 3: BER and SNR values for Arduino at 36 cm.

K1		K2		K3		K4	
SNR (dB)	BER	SNR (dB)	BER	SNR (dB)	BER	SNR (dB)	BER
6.5072	0.31328	4.5551	0.33607	4.3532	0.37317	7.1771	0.18004

Bassam et al. (2022) demonstrated a strong correlation between SNR and BER in V2V communication systems, indicating that a comparison between SNR for each photo-detector and the average bit error rate (BER) of the experimental data shows a clear result to enhance the analysis of mobile signal detection [1]. This suggests that SNR plays a significant role in determining the accuracy of data transmission in VLC; considering that a higher value of SNR leads to a decrement in BER.

To obtain more comprehensive and reliable results, we conducted a series of experiments by varying the height of the wooden table and the photodiode. It is crucial to note that the photodiode employed in our setup operated at a transmission speed of 100 kbps, ensuring the validity and accuracy of the collected data.

To decode the message and validate the transmission accuracy, we compared the measured received signal on the oscilloscope with the original signal transmitted from the embedded system. To achieve accurate comparison, the signals were first discretized and normalized. This process effectively transformed the analog signals into digital representations, eliminating any inconsistencies due to signal amplitude or phase shifts. The comparison of the results of these signals yielded the bit error rate (BER).

The signal-to-noise ratio (SNR), another essential parameter for evaluating signal quality, was determined through the creation of an eye diagram. The eye diagram provides a visual representation of the received signal, allowing for the assessment of its distortion and noise. The amplitude and standard deviation of the signal levels (1 and 0) in the eye diagram were directly measured to obtain the SNR, as seen in Figure 8. A higher SNR indicates a cleaner signal with less noise, translating to improved transmission quality and a lower BER.

We obtained comprehensive criteria for the received signal quality, including BER and SNR, by comparing the oscilloscope measurements and the eye diagram. This information is crucial for optimizing the VLC system and ensuring reliable data transmission for indoor environments.

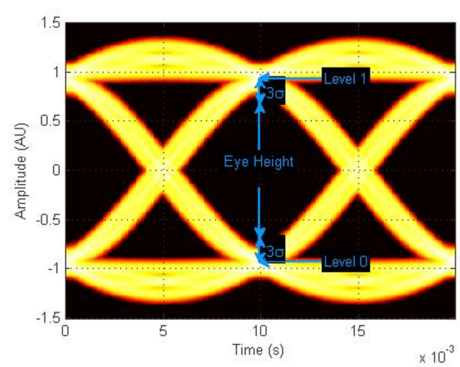

Figure 8: Overview of an eye diagram and its levels. [7]

The following equation shows the measurement for the SNR from an eye diagram plot:

$$\mathrm{SNR} = \frac{L_1 - L_0}{\sigma_1 + \sigma_0} \tag{1}$$

Where L_1 and L_0 represent eye level 1 and 0, respectively, and σ_1 and σ_2 are the standard deviations of eye level 1 and 0, respectively.

A custom MATLAB program was developed to automate the methodological analysis of LED blocks. This program processes analog signals acquired from an oscilloscope, which provides time information on the x-axis and corresponding signal values on the y-axis.

To facilitate comparative analysis and minimize y-axis errors, a numerical model of the original and measured signals will be constructed from the acquired data. This model will be implemented using custom-developed code, enabling normalization between 0 and 1. Subsequently, the normalized analog signal will be discretized through a novel approach, employing established limits that strategically segment the signal at its maxima and minima. This optimized discretization facilitates the accurate determination of the bit error rate (BER) through comparison of the original and measured signals on the horizontal axis.

Following the determination of the bit error rate (BER), the signal-to-noise ratio (SNR) is obtained by constructing and analyzing the corresponding eye diagram. This analysis involves evaluating variables defined in (1).

The data presented in Table 3 indicates that despite facing challenges such as elevated external lightning noise and distance limitations in our setup, resulting in a notable increase in Bit Error Rate (BER), successful localization and data transmission can still be achieved.

To overcome this distance limitation, we propose two potential solutions:

- Focusing the light onto the receiving LED: Employing a lens on the photodiode can significantly enhance light concentration, thereby improving reception sensitivity and extending the communication range. Using a lens on the photodiode achieved the 1m distance height in the communication.
- Modifying the light emission pulse: Using a continuous light emission pulse, instead of a single pulse, can provide a more stable and consistent signal for the photodiode to detect, potentially allowing communication over longer distances.

4 Conclusions

In conclusion, this study presents the development of a setup that establishes a direct link between Visible Light Communication (VLC) and coded identifiers, serving as information data beacons. The system, meticulously designed, not only enables control over LED panels but also incorporates a protocol for efficient communication management between LED luminaries and the receiver. By evaluating and implementing test-bed requirements, we have laid the foundation for potential applications in future Vehicle-to-Vehicle (V2V) optical wireless communications scenarios. The positive outcomes observed in this research underscore the feasibility and promise of integrating VLC into V2V communication systems, highlighting its potential impact on the future landscape of intelligent transport systems and vehicular communication.

The analysis of our results suggests that commercial outdoor luminaries have the potential to be employed in a V2V positioning context, particularly showcasing efficacy at a low data rate of 100 Kbps even under daylight conditions. Furthermore, our study demonstrates the successful detection of positioning beacons, providing a valuable tool for vehicle localization within a defined region of interest.

Visible Light Communication (VLC) and Visible Light Positioning (VLP) offer significant advantages for indoor communication analysis. Their reliable and synchronized transmission and reception, ensured by Manchester coding modulation, enable precise data recovery.

Error detection, noise immunity, and enhanced wireless transmission in complex environments are benefits of employing the visible light spectrum. This not only improves efficiency but also unlocks a range of potential applications capable of replacing traditional RF devices.

The mathematical and methodological analysis verifies the integrity of transmission and validates channel modulations, LED block driver configurations, and control signal generation using development boards. This approach ensures correct and secure behavior regarding Bit Error Rate (BER) and Signal-to-noise Ratio (SNR).

Employing an Arduino Uno provides an intriguing approach to VLP. Preliminary findings reveal the successful development of an initial visible light communication (VLC) system that operates under specific conditions and enables message transmission between designated sender and receiver points across a pre-determined distance.
Signal generation coding guarantees a rapid and consistent response when sending bit patterns in ASCII character light pulses with variable heights.

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