

A Low-Cost Multiplatform VLC System Prototype for Indoor Attocell Downlink Communication

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Abstract. *Devices operating in the Radio Frequency (RF) spectrum face capacity limitations due to licensed bandwidth and rapidly growing connectivity demand. Visible Light Communication (VLC) emerges as a complementary alternative, leveraging existing lighting infrastructure for energy-efficient indoor communication. However, for widespread adoption, VLC devices must achieve a cost comparable to established technologies. This work proposes a Plug-and-Play (PnP) USB dongle for VLC data reception based on low-cost hardware, along with a multiplatform interface for reactive data visualization. Our prototype achieves error-free downlink communication in attocell scenarios over distances up to 280 cm under line-of-sight (LOS) conditions.*

1. Introduction

The rapid growth of wireless communication systems, driven by the expansion of mobile networks, Internet of Things (IoT) devices, and data-centric applications, has led to an increasing demand for bandwidth and connectivity. Current wireless technologies are predominantly based on the Radio Frequency (RF) spectrum, which is both finite and heavily regulated. As a result, RF systems face challenges related to spectrum scarcity, interference, and restrictions in sensitive environments such as hospitals, industrial facilities, and classified areas, where electromagnetic emissions may pose safety or security risks [vd Zwaag et al. 2020]. In this context, Visible Light Communication (VLC) has emerged as a promising complementary technology to RF-based systems.

VLC enables data transmission by modulating light emitted by Light-Emitting Diodes (LEDs), leveraging existing lighting infrastructure for communication. This approach offers several advantages, including large unlicensed bandwidth, spatial confinement of signals, reduced electromagnetic interference, and energy efficiency, particularly in indoor environments where lighting systems are already deployed [Badeel et al. 2021]. Despite these advantages, the widespread adoption of VLC technology depends on the

development of accessible, low-cost, and user-friendly solutions that can integrate with existing devices. Most current consumer electronics lack native support for VLC, creating a barrier to practical deployment. Therefore, there is a need for systems that bridge this gap without requiring significant modifications to existing hardware platforms.

This paper presents a multiplatform VLC system based on a plug-and-play (PnP) dongle for data decoding and a web interface for reactive data visualization. The proposed solution enables data reception from modulated light sources using a combination of embedded hardware and software, interfacing with standard computing devices through serial communication. The system is designed to be low-cost, portable, and compatible with multiple platforms, facilitating the adoption of VLC in practical attocell scenarios.

Experimental results indicate the feasibility of the proposed approach, achieving reliable communication under line-of-sight (LOS) conditions in typical indoor environments, where the main sources of interference are known beforehand. The contributions of this work include the design and implementation of the VLC receiver hardware, the development of a corresponding software interface, and the validation of system performance in terms of communication reliability and operational range.

1.1. Motivation

To illustrate the motivation of our contribution, a hospital scenario is considered. Hospitals are environments with strict requirements regarding electromagnetic compatibility and data integrity. In particular, the use of RF communications is often restricted in critical areas such as Intensive Care Units (ICUs) and operating rooms due to the risk of interference with sensitive medical equipment [Periyasam and Dhanasekaran 2013].

In this context, consider a Neonatal Intensive Care Unit (NICU), where multiple patients require continuous monitoring of vital parameters such as heart rate, oxygen saturation, and body temperature. These measurements are acquired by sensors connected to monitoring devices that must reliably transmit data to healthcare professionals. In conventional setups, communication is typically achieved through wired connections or RF-based wireless technologies. However, wired solutions limit mobility and increase infrastructure complexity, while RF-based approaches may suffer from interference, spectrum congestion, and regulatory constraints within hospital environments.

VLC systems provide an alternative communication layer by leveraging the existing lighting infrastructure. In such a scenario, monitoring devices can be integrated into hybrid communication networks, where VLC is employed in regions where RF usage is limited or undesirable. For instance, [Baig et al. 2018] proposes a hybrid architecture combining Power Line Communication (PLC) and VLC for 5G networks. Similarly, [Feng et al. 2016] investigates the use of VLC at the attocell level to enhance indoor coverage and capacity. Despite these advances, the practical deployment of VLC systems remains constrained by the lack of accessible and interoperable reception solutions. In particular, there is a need for low-cost, PnP receivers capable of interfacing with existing devices while supporting real-time data acquisition.

1.2. Problem Statement

By 2030, it is estimated that around 500 billion devices will be connected to the internet [Yastrebova et al. 2018], raising a critical challenge: the increasing number of devices

communicating over the RF spectrum is expected to saturate the available bandwidth, making it insufficient to meet the growing demand for wireless access. To address this limitation, VLC has emerged as a complementary alternative capable of reducing the burden on RF-based systems, particularly in indoor environments. In such scenarios, the widespread adoption of LEDs for lighting, driven by their low energy consumption and long operational lifetime, creates an opportunity to integrate communication capabilities into existing infrastructure.

Despite its potential, VLC technology still faces significant barriers to broader adoption. Implementation costs remain relatively high, and existing solutions often lack accessibility, interoperability, and ease of use. These limitations restrict the competitiveness of VLC systems when compared to established RF and wired communication technologies, as well as their effective integration into hybrid and heterogeneous networks. Additionally, most contemporary computing devices do not provide native support for VLC, creating a compatibility gap between optical communication systems and conventional hardware platforms. This limitation reduces the practical usability of VLC in real-world applications and slows down its adoption.

Research Objectives

In this context, the problem addressed in this work is the development of a low-cost and user-friendly interface that enables VLC reception on conventional computing devices. The proposed approach focuses on bridging this compatibility gap through the design of a PnP solution capable of interfacing heterogeneous systems without requiring specialized hardware support. Specifically, this work proposes the design and implementation of a VLC receiver prototype composed of a hardware dongle and a web-based application, enabling data acquisition, processing, and decoding across different platforms. Furthermore, the system is evaluated in terms of performance and signal quality to assess its feasibility as a practical VLC solution. Our research objectives are summarized as:

- i) Design and develop a VLC hardware dongle capable of receiving modulated light signals and transmitting the decoded data to a host device via a standard interface;
- ii) Implement a web-based application for real-time data acquisition, processing, and visualization, ensuring compatibility across different operating systems and hardware platforms;
- iii) Develop and integrate signal processing techniques for reliable decoding of VLC signals, including modulation and coding schemes;
- iv) Evaluate the performance of the proposed system in terms of communication reliability, including metrics such as bit error rate (BER) and operational distance.

2. System Model

We consider an indoor downlink communication scenario in an attocell VLC network. There are two main subsystems: (i) a VLC transmitter and (ii) a VLC receiver unit consisting of a PnP hardware dongle integrated with a web-based application.

2.1. Overall Architecture

The end-to-end communication process begins at the transmitter, where input data is collected from a Multiparameter Patient Monitor (MPM), formatted, and encoded into a digital bitstream. This bitstream is modulated using On-Off Keying (OOK) and Manchester

encoding before driving an LED, which converts the electrical signal into an optical signal for propagation over the optical channel. At the receiver, the incident light is captured by a photodetector and converted back to an electrical signal. This signal is then processed to recover the transmitted information. The recovered data are subsequently transmitted to a computer via a Universal Serial Bus (USB) interface and decoded in a web-based application for visualization.

2.2. Transmitter Model and Optical Channel

The transmitter is implemented using an embedded platform capable of generating modulated signals based on input data streams. Data packets are structured according to a custom protocol, consisting of a synchronization sequence, multiple payload segments encoded in IEEE 754 floating-point format, and a parity bit for error detection. After packet formation, the digital signal is encoded using Manchester coding and modulated via OOK, producing a binary waveform suitable for intensity modulation of the LED. This approach ensures compatibility with flicker mitigation and signal detectability.

The communication channel is based on Intensity Modulation and Direct Detection (IM/DD) [Vappangi and Mani 2018], where the transmitted optical power is proportional to the electrical driving signal. LOS is assumed between the transmitter and the receiver. The channel is affected by factors such as distance, ambient light interference, and receiver sensitivity. In indoor environments, ambient light introduces low-frequency noise components that must be mitigated at the receiver stage.

2.3. Receiver Model and Data Processing

The receiver is implemented as a PnP VLC dongle designed to interface with standard computing devices. The reception process begins with a photodetector that converts incident light into an analog electrical signal. This signal undergoes analog conditioning, including low-pass filtering to generate the ambient LED light interference reference signal, followed by a comparator stage that reconstructs a digital waveform from the analog input. The resulting digital signal is sampled by a microcontroller, which performs bit-level processing, synchronization, and packet reconstruction. The system verifies data integrity using a parity check and, upon successful validation, transmits the recovered data through a serial communication interface over USB.

On the host side, a web-based application is responsible for acquiring the serial data stream from the USB interface. The application performs decoding, parsing, and visualization of the received data. It operates in a platform-independent manner, enabling compatibility across different operating systems and hardware architectures.

3. Experimental Setup Overview

The experimental setup is illustrated in Figure 1. From left to right, following the Health Level Seven (HL7) standard [Alsafadi et al. 1994], messages are generated by an MPM and transmitted via an Ethernet link to a Raspberry Pi (RPi). At the RPi, the HL7 messages are parsed and converted into a custom communication protocol. The digital bitstream is then encoded using Manchester coding to enable clock recovery and mitigate flicker effects. After encoding, OOK modulation is applied, generating a binary waveform that directly drives the LED. The resulting electrical signal is converted into an optical signal by the LED. The receiver side will be explained in detail in the next subsections.

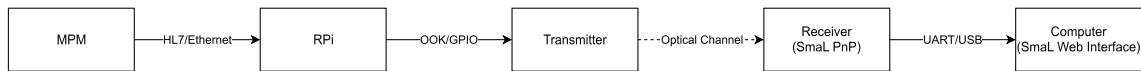


Figure 1. Experimental setup.

Figure 2 shows the transmitter responsible for converting the input data into an optical signal suitable for propagation through the optical channel. The packets generated internally by the RPi, containing information provided via HL7, are used to generate the modulating signal, which is forwarded to the main transmitter board. The control of the RPi General Purpose Input Output (GPIO) is performed using Direct Memory Access (DMA) to avoid processor overload and ensure real-time performance. Subsequently, the transmitter electronics apply a level shift to the RPi output signal by adding a DC component. This shifted signal is then used to modulate the emitted light, enabling the transmitter LED to convey information through free space to the developed receiver.

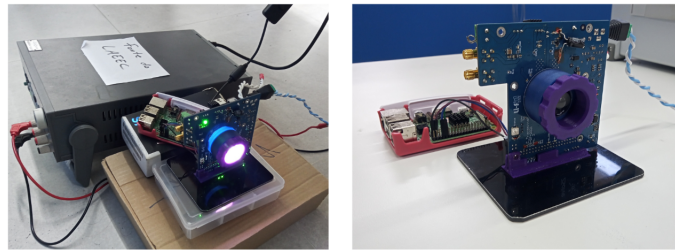


Figure 2. VLC transmitter.

Figure 3 shows our custom protocol, which consists of an 8-bit synchronization header, followed by $32 \cdot N$ bits representing the Electronic Health Information (EHI) extracted from the HL7 messages, encoded in IEEE 754 floating-point (FP) format, where N denotes the number of monitored parameters. Finally, a parity bit is appended for error detection, set to 1 when the number of '1' bits in the payload is even and to 0 otherwise.

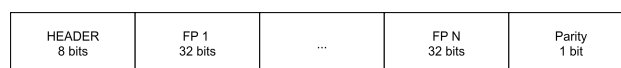


Figure 3. Packet structure.

4. Receiver Electronics

The receiver, shown in Figure 4, is implemented as a PnP hardware dongle interfaced via USB. Its purpose is to capture and reconstruct the transmitted optical signal. We name this device Smart Light (SmaL) PnP.

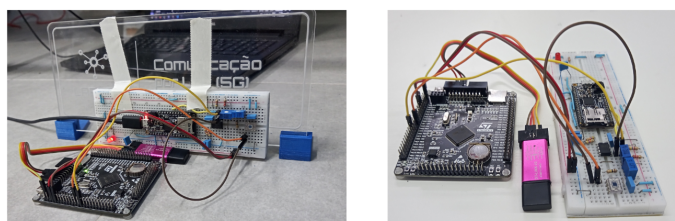


Figure 4. VLC receiver.

Figure 5 presents the schematic of the electronic reception circuit that composes the *SmaL PnP* dongle. Initially, a photodiode circuit with a transimpedance amplifier can be observed, representing the internal structure of the OPT101 photosensor, which is used as the interface between the optical and electrical domains in the VLC reception circuit. In this first stage, particular attention must be given to the resistor R_f , which provides external feedback to the amplifier. This allows the adjustment of the amplifier gain, which is directly proportional to the value of R_f .

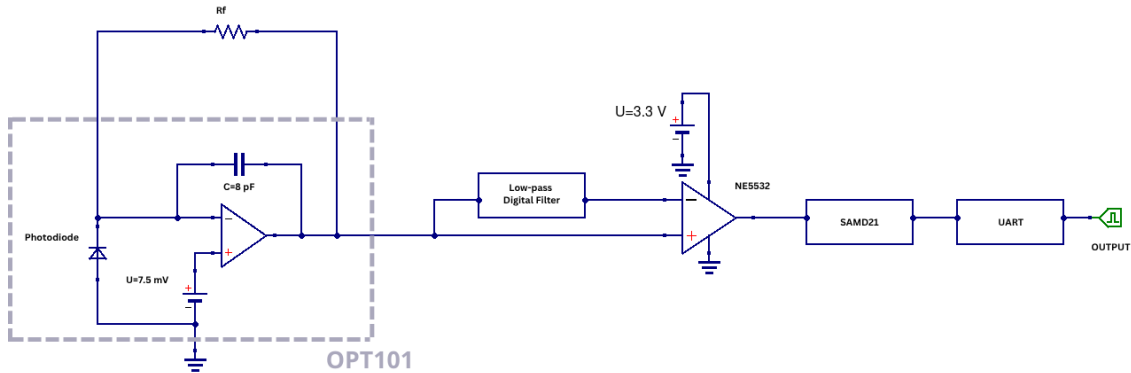


Figure 5. Receiver electronic schematic.

The second stage is a digital filter, which takes as input the output signal from the OPT101 and produces an output containing frequency components below 120 Hz, corresponding to the frequency of ambient LED lighting external to the transmitter.

In the third stage, a comparator circuit is employed. The reference input (inverting input) is connected to the output of the low-pass filter, and the comparator performs a comparison between this signal and the OPT101 output. As a result, a reconstructed signal is obtained, similar to that observed at the output of the transmitter's Raspberry Pi (RPi), consisting only of high and low logic levels according to Manchester encoding.

The fourth stage is composed of a SAMD21 microcontroller, which digitizes the comparator output and processes it by constructing data packets according to the custom protocol previously presented. After validation via parity checking, the decoded data is transmitted to the host device through a serial-over-USB interface.

5. Embedded Software

The SAMD21 was programmed to operate as a decoder for Manchester-encoded messages and to reconstruct data packets into $4 \cdot N$ bytes (N FP values, 4 bytes each) before transmitting them over serial. The operation of this process is briefly described in Algorithm 1. Note that Windows requires specific drivers for this microcontroller¹.

The embedded software running on the microcontroller begins by configuring the serial communication, including the transmission baud rate, as well as setting the input pin mode. Subsequently, an interrupt service routine is defined to be triggered on state

¹Adafruit repository: https://github.com/adafruit/Adafruit_Windows_Drivers/releases/tag/2.5.0.0

changes of this input pin. When triggered, the interrupt routine determines whether a new message is starting or an existing one is ongoing, according to the system's custom protocol. If a message is already in progress, the incoming bits are sequentially stored.

Once a total of $32 \cdot N + 1$ bits has been received, the parity of the stored data is verified, with the last bit corresponding to the packet parity. If the parity check confirms the integrity of the received data, a packet of $4 \cdot N$ bytes is constructed and transmitted via the serial interface to be received and interpreted by the web-based application.

Algorithm 1 Embedded Receiver Flow (SAMd21)

```
1: Configure UART communication (baud rate)
2: Configure GPIO input pin
3: Attach interrupt on GPIO state change
4: Initialize buffer, counters, and state variables
5: while true do                                ▷ Idle loop; reception handled by interrupts
6: end while

7: function ONGPIOINTERRUPT
8:   if transition detected then
9:     if frame not started and invalid start condition then
10:      return
11:    end if
12:    Update timing / synchronization counter
13:    if bit interval completed then
14:      Sample and store received bit
15:      Increment bit counter
16:    end if
17:    if bit counter =  $32N + 1$  then
18:      if parity check valid then
19:        Reconstruct  $4N$  data bytes
20:        Transmit packet via UART
21:      end if
22:      Reset buffer and counters
23:    end if
24:  end if
25: end function
```

6. Web Interface

Once the SAMd21 has validated and transmitted the decoded packet via the USB interface, the data is handed off to the software layer of the proposed system: the *SmaL Web* application. Figure 6 shows the web interface running on a browser, which is responsible for data acquisition, decoding, and visualization of the received physiological parameters.

Front-end development techniques and tools were employed to create a responsive web application capable of accessing the USB ports of the computer on which the reception of data packets from the previously presented embedded system is performed. For

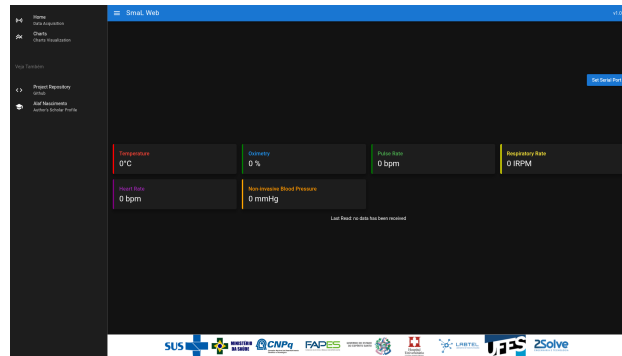


Figure 6. *SmaL Web* interface.

this purpose, a utility-first component framework for Vue.js² was used, namely Quasar³, which is a JavaScript framework based on a single-file component architecture. This framework has been widely adopted for the development of both desktop and mobile applications due to its portability and ease of deployment.

To validate the application in a computational environment before laboratory experiments, an Arduino UNO was used to simulate the VLC dongle prototype. This test device continuously transmits byte packets containing the message “0.75” in order to verify communication and evaluate the implemented application functionalities.

The embedded software running on the SAMD21 is responsible for reconstructing the bitstream received via light and transmitting the resulting data packets through a serial interface. On the receiver side, a computer executes the developed web application, which is responsible for receiving and interpreting the incoming serial data.

For reading and interpreting the transmitted data, the web application accesses the serial interface of the host computer. This communication is implemented using the Web Serial Application Programming Interface (API)⁴, which is supported by Chromium-based browsers (*e.g.*, Chrome, and Edge), enabling multiplatform compatibility. By leveraging web technologies, the interface achieves platform independence and eliminates the need for dedicated software installation. This design simplifies deployment while enabling extensibility for additional features such as data logging and remote monitoring.

On the home screen, there is a button in the upper-right corner to select the serial port. Figure 7(a) shows this button when activated, as well as the pop-up window that appears for selecting *SmaL PnP*. After the serial port is set, if data is received, the “Last Read” status will update to the timestamp of the most recently received message, and the decoded information will be displayed on the interface. If the *SmaL PnP* is unplugged, a message will appear indicating that the device has been disconnected, as shown in Figure 7(b). The application has some other features, but due to page limitations, we will not be presenting everything here.

The operation of the application is described in Algorithm 2. The application

²Available at: <https://vuejs.org/>

³Available at: <https://quasar.dev/>

⁴Available at: https://developer.mozilla.org/en-US/docs/Web/API/Web_Serial_API

communicates with the receiver through the USB serial interface, continuously reading incoming data streams. The received packets are parsed, decoded, and displayed.

Algorithm 2 Web Application Flow

```
1: Initialize application
2: if Web Serial API not supported then
3:   Display incompatibility alert
4:   Stop execution
5: end if
6: while true do
7:   if serial port not available then
8:     Display device disconnected alert
9:     Continue
10:  end if
11:  Prompt user to select serial port
12:  Read serial port
13:  if no data received for 3 seconds then
14:    Display “no data received” alert
15:    Continue
16:  end if
17:  Initialize byte index
18:  while bytes remain in packet do
19:    Group 4 bytes into a 32-bit integer
20:    Convert integer to IEEE 754 FP
21:    if value is a valid real number then
22:      Store value according to its position in the packet
23:    end if
24:  end while
25:  Display values to the user
26: end while
```

7. Performance Evaluation and Results Analysis

The proposed VLC system was experimentally evaluated to assess its feasibility, performance, and robustness under typical indoor conditions. The evaluation focused on communication range, signal integrity, and the effectiveness of the receiver design, particularly in the presence of ambient light interference. Details and a demonstration of how the setup works can be found on YouTube⁵. The algorithms presented are in the project GitHub repository⁶.

7.1. Signal Analysis Along the Reception Chain

The signal behavior along the reception circuit was evaluated at a distance of 30 cm between the transmitter and receiver. The experiment was conducted under typical indoor conditions, with ambient LED lighting introducing interference at 120 Hz. Figure 8(a)

⁵Available at: <https://www.youtube.com/watch?v=HrTFuFJpvJ0>

⁶Available at: <https://github.com/nascimentoIaf/SmaL>

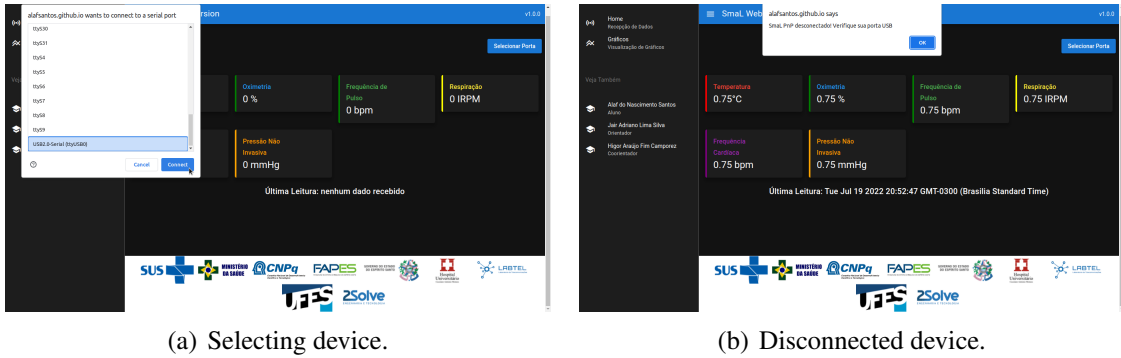


Figure 7. SmaL Web pop-up messages.

presents the output of the photosensor (yellow) and the low-pass filter (blue). The filter effectively extracts the low-frequency component associated with ambient light, which is subsequently used as a reference signal for the comparator. A small phase shift between the input and output of the filter can be observed, which is inherent to the filtering process.

The impact of ambient light interference is illustrated in Figure 8(b). The 120 Hz noise captured by the photosensor results in a square wave at the comparator output due to the phase difference between the filtered signal and the raw signal. This behavior occurs in the absence of data and is a direct consequence of the comparator operation.

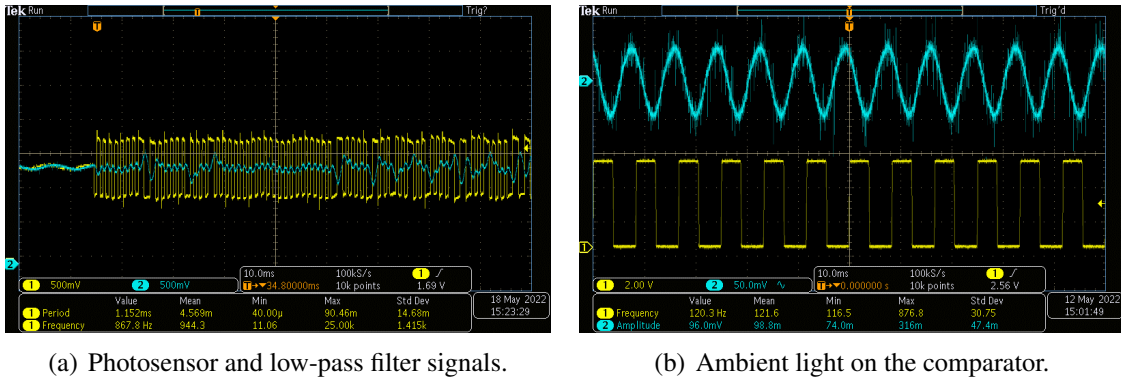


Figure 8. Receiver signal analysis.

Figure 9 shows the system behavior when the transmitter is active. The photosensor output (blue) exhibits a 2 kHz modulated signal affected by a 120 Hz envelope caused by ambient light interference. This low-frequency envelope is effectively removed by the comparator, which produces a clean digital signal with only two levels (high and low), closely matching the signal generated at the transmitter side.

Additionally, in periods where no transmission occurs, the comparator output may still exhibit a 120 Hz square wave due to ambient noise and the phase shift introduced by the filter. However, this does not compromise system performance, as the implemented communication protocol allows the receiver to correctly identify valid message intervals and discard spurious signals.

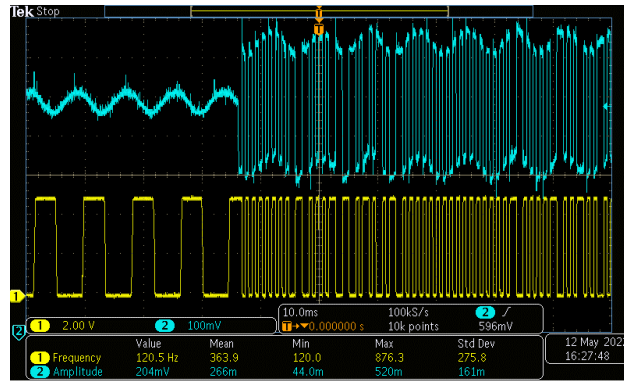


Figure 9. Photosensor and comparator signals

7.2. Error Analysis and System Validation

Initially, a back-to-back validation was performed to verify whether the system could achieve zero error. However, an error rate of approximately 2% was observed, even with a direct electrical connection between the transmitter (Raspberry Pi) and the receiver microcontroller. The error was measured by transmitting 37 kB of known data packets and comparing them at the receiver against the known transmitted data. Oscilloscope analysis revealed brief interruptions in the transmitted signal. The issue was resolved by using Direct Memory Access (DMA) to control the GPIO output, enabling stable transmission and achieving zero error in the back-to-back configuration.

Subsequently, the system was evaluated over a VLC channel. The results demonstrated reliable communication for distances ranging from 25 cm to 280 cm under LOS conditions with normal incidence. Finally, an MPM was integrated into the system to validate a practical application. The device was connected to the transmitter via the HL7 protocol, providing real-time physiological data for transmission and evaluation.

The system operates at a data rate of half of the modulation frequency f_m due to Manchester code. In order to find the goodput, we need to eliminate the header and parity bit. For instance, considering 6 transmitted parameters, Equation 1 computes a goodput of approximately 955.22 bps (*i.e.*, 4.48% of protocol overhead) and a packet rate of around 5 packets per second, which is sufficient for the low-bandwidth requirements of physiological parameter monitoring in the target application (*e.g.*, our setup had the HL7 vital sign parameters updated at rates of 1 Hz). On the one hand, the more parameters we send within a single payload, the more the goodput tends to f_m . On the other hand, intuitively, the reliability of the system tends to decrease because we chose to use a single parity bit to avoid large overheads.

$$\mathcal{G} = \frac{f_m}{2} \cdot \frac{32 \cdot N}{8 + 32 \cdot N + 1} \approx 955.22 \text{ bps} \quad (1)$$

Error measurements were performed under both ambient light conditions and in the absence of external lighting to evaluate the impact of 120 Hz interference and the effectiveness of the low-pass filtering stage. The results showed that, in the absence of ambient light interference, the system achieved zero error across all tested distances, except in saturation conditions (*i.e.*, very short distances or excessive feedback gain). Under

ambient lighting, the error rate increased exponentially with distance. For a high gain configuration ($R_f = 860 \text{ k}\Omega$), near-zero error was achieved up to approximately 290 cm, and a maximum error of 0.27% at 300 cm. However, this configuration led to performance degradation at shorter distances due to sensor saturation.

To extend the operational range, a lower gain ($R_f = 157 \text{ k}\Omega$) was evaluated. This configuration provided stable, near-zero error performance over a wider range of distances (30 cm to approximately 290 cm), but resulted in higher error at longer distances (e.g., 2.450% at 300 cm), confirming the trade-off between sensitivity and saturation.

Finally, experiments with manual gain adjustment demonstrated that it is possible to achieve zero error over a given distance range (up to 200 cm) by properly tuning R_f . These results indicate that an automatic gain control (AGC) mechanism would be a suitable enhancement to maintain optimal performance under varying channel conditions.

8. Related Work

VLC has been extensively investigated as a complementary technology to RF. Its integration into future communication architectures, including 5G networks, has been explored in several works. As discussed in [Feng et al. 2016], VLC can be integrated into 5G cellular architectures through the concept of attocells, enabling high-capacity downlink communication in localized indoor environments. In this context, the proposed system can be directly applied as a reception interface within such architectures.

Several studies have also investigated modulation and signal processing techniques for VLC systems. In [vd Zwaag et al. 2020, Santos et al. 2020], the authors explore the use of OOK modulation in medical scenarios, demonstrating the feasibility of VLC-based monitoring systems. Their results also highlight the potential use of smartphones as receivers, although performance is limited by the characteristics of embedded photosensors, which are not optimized for communication purposes.

Different VLC hardware prototypes have been proposed in the literature. In [de Souza et al. 2013], a low-cost system is developed using an LED transmitter operating at 5 V and an OPT101 photosensor as the receiver front-end. The received optical signal is converted into an electrical signal and processed through a comparator circuit, generating a square wave that is sampled by a PIC16F877A microcontroller for data recovery. The system achieves communication over distances of up to 25 cm. Similarly, [Datta et al. 2020] presents a VLC system based on a Raspberry Pi and an LED transmitter, also employing an OPT101. An ambient light cancellation circuit is used, which was developed using ideas from [Pham et al. 2017] and control systems. Their work extends the communication range to approximately 41 cm and provides a detailed analysis of channel efficiency, received optical power, and receiver circuit design.

The present work adopts key elements from these approaches, such as the OPT101 photosensor and comparator-based signal recovery. In addition, an ambient light mitigation strategy is implemented through low-frequency filtering, which enables the reliable reconstruction of the transmitted signal under more realistic attocell conditions. By comparing the low frequencies with the photosensor output, we are able to remove them using the operational amplifier before processing on the microcontroller. Existing works primarily focus on proof-of-concept or application-specific implementations, often relying

on dedicated hardware platforms and lacking interoperability with conventional computing devices. In contrast, we propose a receiver designed for multiplatform compatibility.

9. Future Research Directions

While the system meets the initial design requirements, several directions remain open for future work. On the hardware side, the current manual tuning of the feedback resistor R_f is a practical limitation. This motivates the implementation of an AGC mechanism, which would allow the system to adapt to changing channel conditions without user intervention. Improved noise mitigation strategies and handover mechanisms are also promising directions to increase robustness, mobility support, and scalability.

A systematic comparison with other low-cost VLC prototypes, evaluating end-to-end latency and robustness under different environmental conditions, would strengthen the performance assessment. Scenarios involving receiver mobility, non-LOS propagation, and multipath interference are particularly relevant to characterize practical limitations. For these purposes, the use of Fresnel lenses to increase optical gain at the receiver should be investigated.

Regarding the communication protocol, for more demanding or safety-critical deployments, stronger schemes such as Cyclic Redundancy Check (CRC) or Forward Error Correction (FEC) would offer stronger error detection and correction guarantees. Finally, the web interface currently relies on the Web Serial API, which is supported by Chromium-based browsers; hence, extending compatibility would be a relevant step toward broader deployment.

10. Conclusion

This work presented the development and validation of a VLC system, demonstrating its feasibility as a low-cost, multiplatform solution for data reception. As the RF spectrum becomes increasingly constrained, VLC emerges as a promising complementary technology, particularly for indoor applications that leverage existing lighting infrastructure.

Integration of the dongle with a web application proved to be a practical approach to enable VLC reception on conventional devices. The PnP design allowed seamless interfacing via USB, eliminating the need for specialized hardware support. The web application performed data acquisition, decoding, and visualization satisfactorily. This architecture proved compatible with different operating systems and hardware configurations. The proposed prototype, including the SmaL PnP hardware and SmaL Web software, achieved reliable performance under LOS conditions up to 280 cm. Details and a demonstration of how the setup works can be viewed in an online video on YouTube⁷.

Acknowledgments

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⁷Available at: <https://www.youtube.com/watch?v=HrTFufJpvJ0>

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