

VLC Technology in Remote Patient Monitoring Systems: A Survey

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Abstract— In the era of connected healthcare, visible light communication (VLC) stands out as a revolutionary technological advancement in the field of remote patient monitoring systems (RPMS). By using LED light to transmit data, VLC offers a solution that is not only fast and efficient, but also secure, eliminating potential interferences related to traditional radio technologies. This innovation enables continuous monitoring of patient health parameters while ensuring reliable data transmission in healthcare environments. This paper aims to provide a comprehensive literature review regarding the use of visible light communication (VLC) in remote patient monitoring systems (RPMS). Therefore, a typical architecture of VLC-based RPMS systems is described. We also explored the different configurations of VLC transceivers, categorized into three categories: static, mobile, and hybrid. Furthermore, we reviewed the main applications of VLC in RPMS, highlighting its potential to improve the quality of care and continuous patient monitoring. Finally, an in-depth analysis of the existing literature, identifying technical challenges and emerging solutions laying the foundations for future work aimed at integrating Deep Learning techniques to optimize these systems.

Keywords— Visible Light Communication (VLC), Remote Patient Monitoring Systems (RPMS), eHealth

I. INTRODUCTION

Remote Patient Monitoring Systems (RPMS) are at the core of modern healthcare strategies, addressing the growing needs of chronic disease management and patient monitoring. Current monitoring systems mainly rely on RF (Radio Frequency) technologies to transmit medical data from wearable devices such as sensors to central processing units [1]. However, the proliferation of sensitive medical data requires robust, secure, and efficient communication systems. RF technologies such as Bluetooth, Zigbee, Wi-Fi, LoRaWAN (Low Range Wide Area Network) are widely used in these systems. These wireless technologies for healthcare monitoring are necessary due to the shortage of doctors and caregivers in a hospital environment, while patient health may vary every minute of the day. However, they have limitations in terms of security, bandwidth, data privacy risks, and strict latency. However, this type of communication is also susceptible to electromagnetic interference (EMI),

compromising the accuracy and reliability of medical equipment [2].

Therefore, visible light communication (VLC) is emerging as a promising technology to overcome some of the limitations of RF technologies. Using visible light to transmit data, VLC leverages light sources such as LEDs (Light Emitting Diodes) to send information to optical receivers. This technology offers unique advantages including very high bandwidth (up to several hundred THz), immunity to electromagnetic interference, and increased security potential due to its directional nature and the limited ability of light to pass through obstacles. VLC is less hazardous to human health and more secure against hacking, as light cannot penetrate through walls. In addition, VLC can be easily integrated into existing lighting infrastructures, thereby reducing implementation costs. However, the security measures built into VLC technology, such as directional light and line-of-sight communication, make it an excellent choice for transmitting sensitive medical information, such as patient records and real-time health monitoring data, without the risk of interception or unauthorized access [3]. However, despite the many advantages of VLC technology, issues such as limited range and coverage due to line-of-sight requirements as well as security and privacy may also arise [4], [5].

Therefore, VLC can be used to implement a wide-area patient monitoring system that leverages visible light to transmit medical data between devices in a healthcare facility. In a healthcare facility, LED transmitters can be installed on various monitoring devices, such as bedside monitors, infusion pumps, and other medical equipment, to collect patient data and transmit it using data transceivers. As shown in Figure 1 below, data from monitoring devices, such as heart rate, blood pressure, and oxygen saturation, can be converted into digital information and encoded onto the light signals emitted by the LED transmitters [6].

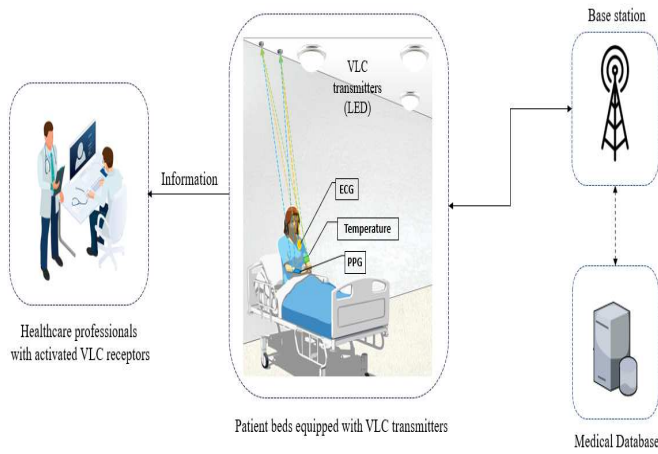


Figure 1. Architecture of a VLC Based RPMS System

The architecture is based on an infrastructure where medical devices communicate via modulated light signals to receivers capable of processing and transmitting this data. Information from patients' beds is transmitted to healthcare professionals via LED lamps that act as VLC transmitters. In addition, patient data is relayed to the medical database for future reference.

The architecture consists of the following elements:

1. Medical sensors placed on or near patients to measure vital data (heart rate, blood pressure, temperature, etc.).
2. VLC transmitter module (an LED integrated into a room lighting unit) that receives data from the sensors and encodes it as light signals.
3. Photodetector that captures variations in light and converts them into digital signals.
4. VLC base station that collects this data from multiple sensors/photodetectors, processes it and transmits it to the central server via a secure channel.
5. Central server that stores patient data and makes it accessible to healthcare professionals remotely.

The main contributions of this article are:

- Comprehensive review summarizing the architecture, applications and different types of VLC transceivers used in RPMS
- To provide a literature overview on the state of the art of remote patient monitoring systems based on VLC technology.
- Overview of challenges in using VLC technology in remote patient monitoring systems and future directions

This paper is structured as follows: Section 2 presents the working principle of VLC. Section 3 reviews the applications, different types of VLC transceivers used in RPMS as well as an overview of the related works of VLC-based RPMS. Section 4 presents the challenges and future perspectives. Finally, Section 5 concludes the paper.

II. OPERATING PRINCIPLE OF THE VLC

It is a wireless communication technology based on the use of visible light emitted by LEDs for data transmission which lies between the violet and red color in the electromagnetic spectrum. VLC concerns only the visible part of the wavelength spectrum between 380 and 750 nm corresponding to a frequency spectrum of 430 THz to 790 THz. It is a protocol that transforms Wi-Fi into VLC via the light of LEDs. While Wi-Fi uses the radio part of the electromagnetic spectrum, VLC uses the optical spectrum and relies on sending data by modulation and according to a well-defined and standardized protocol. A common application of VLC is Li-Fi (Light Fidelity), which works similarly to Wi-Fi but with light. Li-Fi can deliver very high data rates and is seen as a promising technology for environments where radio waves cannot be used or are subject to interference, such as in hospitals [7].

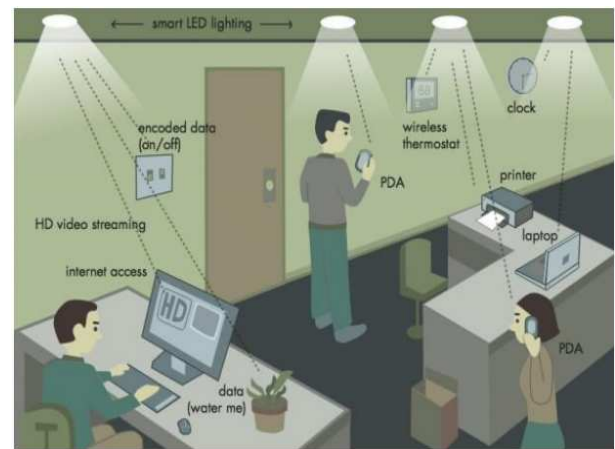


Figure 2. Illustration of applications using VLCs in indoor environments
Source: <https://www.theengineer.co.uk>

VLC works by modulating the light intensity of LEDs to encode the data to be transmitted. The rapid changes in light intensity, although too fast to be perceived by the human eye, are captured by photodetectors which then decode the light signal into digital data [8]. The simplest modulation used is On-Off Keying (OOK), where the light is turned on to represent a "1" and turned off to represent a "0". However, to increase spectral efficiency and signal robustness, more complex techniques such as quadrature amplitude modulation (QAM) and orthogonal frequency-division multiplexing (OFDM) are also employed.

III. VLC TECHNOLOGY IN RPMS

A. Applications of VLC in RPMS

Visible Light Communication (VLC) applications in Remote Patient Monitoring Systems (RPMS) offer several advantages and opportunities, including security, privacy, and efficiency. Specific applications include:

1) Continuous monitoring of vital parameters: VLC can be used for real-time transmission of biometric data, such as heart rate, blood pressure, body temperature, and oxygen saturation. Wearable or implanted sensors on patients can capture this data and transmit it via modulated light signals to a base station or monitoring device. Unlike conventional RF technologies, VLC allows for secure and interference-free transmission, which is crucial in sensitive medical environments [9]. However, in intensive care units (ICUs), where every second can count, communication stability is essential. Thus, VLC offers a reliable solution for continuous patient monitoring, allowing vital parameters to be tracked in real-time without fear of disruptions caused by electromagnetic interference. This guarantees constant and accurate data transmission, helping medical teams to react quickly to changes in the patient's state of health. In addition, hospitals are full of electronic devices often operating on the same frequency bands, which can cause interference and disrupt critical communications. VLC, by using the light spectrum, eliminates this problem by providing a communication channel independent of radio frequencies. This reduces the risk of interference, particularly in environments saturated with medical equipment, and improves the reliability of monitoring systems.

2) Intra-hospital communication: Secure communication between medical devices is crucial to ensure the integrity of healthcare data. VLC can play a key role in enabling secure data transfer between devices, such as bedside monitors and infusion pumps. The directional properties of light help minimize the risk of interception, while ensuring fast and reliable communication. Patient wearables, such as smartwatches or heart rate monitors, can communicate with base stations via VLC. This creates a robust sensor network within the hospital, facilitating the transfer of biometric data in real time. Since VLC is less susceptible to interference, it ensures smooth and continuous data transmission, which is essential for patient monitoring. Furthermore, the development of VLC-based sensor networks in hospitals can revolutionize the way medical data is collected and transferred. These networks can not only improve real-time patient monitoring, but also contribute to better management of hospital resources. By using existing infrastructure, such as street lights, for data transmission, these networks can be deployed cost-effectively and efficiently.

3) Precise geolocation and patient tracking: Precise patient geolocation within hospitals is a key application of VLC. Visible light-based tracking systems can locate patients with high accuracy, which is particularly useful for monitoring the movements of patients with cognitive impairment or those requiring continuous monitoring. The technology can also be used to alert medical staff if a patient leaves a secure area. In addition to patients, VLC can be used to track medical staff and critical equipment within healthcare facilities in real time [10]. This helps improve resource management, ensure equipment availability in emergencies, and coordinate medical

teams more effectively. Integrating VLC into hospital management systems can help optimize workflows. By using technology to track patient and staff movements, hospitals can better manage care and respond more quickly to emergency situations. This not only improves operational efficiency, but also the quality of patient care.

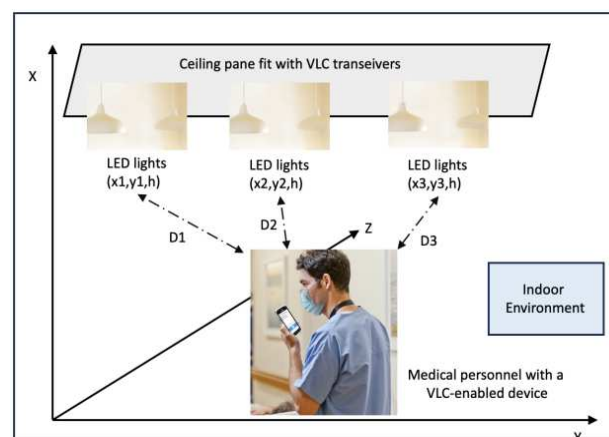


Figure 3. An example of indoor localization by VLC [10]

Figure 3 above illustrates a ceiling equipped with VLC transceivers for locating medical staff wearing a VLC device in an indoor environment.

4) Communication with implantable devices: VLC can facilitate communication with implanted medical devices, such as pacemakers or sensory implants. These devices can transmit critical data about the patient's health status to an external receiver via visible light, ensuring continuous and discreet monitoring, without the need for invasive connections or bulky batteries. Coordination between wearable and implanted medical devices is crucial for integrated patient monitoring. VLC can synchronize these devices efficiently, ensuring that data transmitted by implants is correctly interpreted by wearable devices, and vice versa. This enables real-time monitoring and improved medical decision-making. Thus, in [11], VLC system designs for wearable patient monitoring devices are presented; this is a bidirectional communication system, in which the downlink communication uses VLC, while the uplink communication uses infrared. Therefore, one of the major advantages of VLC is its energy efficiency, making it an ideal option for implanted medical devices. By using visible light for data transmission, devices can reduce their power consumption, thereby extending the life of their batteries. This minimizes the need for frequent replacement of implants, which is both costly and risky for the patient.

5) Monitoring patients at home: VLC can be integrated into telemonitoring systems for home monitoring of patients, especially those with chronic diseases or in the post-operative phase. By using VLC-equipped home devices, such as smart lighting fixtures, health data can be securely transmitted to healthcare professionals, enabling continuous and proactive

monitoring without the need for frequent hospital visits [12]. VLC, due to its directional nature and inability to pass through walls, offers a more secure communication solution, reducing the risks of data interception. This is particularly important for patients monitored at home, where the confidentiality of medical information must be maintained. VLC enables secure two-way communication between patients and healthcare professionals. This includes not only the transmission of health data, but also the sending of alerts in case of detected anomalies.

B. VLC transceiver in RPMS

Transceivers are devices used in visible light communication (VLC) systems for transmitting and receiving data. Communication via VLC will be possible by static, mobile or hybrid transceivers.

1) Static transceiver: A static VLC transceiver is a device designed for transmitting and receiving data via visible light in configurations where the equipment remains fixed and does not move. For biomedical data transmission and monitoring, a visible light communication method using a commercial white LED display is proposed in [13]. Without the use of a collimating lens, biological data were transmitted at a rate of 56 kbps with a bit error rate (BER) of 106 at a distance of 0.5 meters using the On-Off Keying (OOK) modulation scheme. Their experiments achieved an accuracy of 90% of the rated optical power of the LED transmitter. Multiple sensors have also been used in the literature [14], where data were transmitted as a single combined signal from a VLC transmitter to a receiver. Thin-film corner retroreflectors (TCCRs) were used in passive transmission to modulate and reflect the information measured by the sensors to a central node. The transmitted power and the user position are considered when analyzing the reflected power absorbed at the TCCR and the SNR (signal-to-noise ratio) at the image sensor. LED illumination was used to transmit health data such as patient information and biological signs [15]. In this research, a compact and portable receiver module was developed and attached to a mobile device. Using a single VLC channel, three different types of health data, such as ECG (Electrocardiogram), PPG (Photoplethysmography), and HL7 (Health Level Seven) data, were communicated simultaneously in real time. A reduced packet error rate was achieved by carefully calculating the size of the data packets. In their research, it was possible to perform simultaneous monitoring and evaluation of blood pressure and heart rate.

Therefore, a VLC based uplink data transmission system is proposed in [16], using white LEDs for patient monitoring and sensor data transmission from a static patient in a bed. This model is based on the fact that for downlink, almost all facilities in health centers and hospitals can be easily monitored using LED light. A static model is chosen because the patient under monitoring would be static most of the time. Figure 4 below illustrates the proposed transmission scenario in which a transmit LED is installed for each sensor using a

specific transmit module, pointing upwards towards the ceiling where the photodetectors are installed. The transmit modules placed on the patient are assumed to have the LOS (Line of Sight) connection with the photodetectors on the ceiling. The diversity effect is achieved by using multiple photodetectors. A proper spacing between the photodetectors is required for the robustness of data reception.

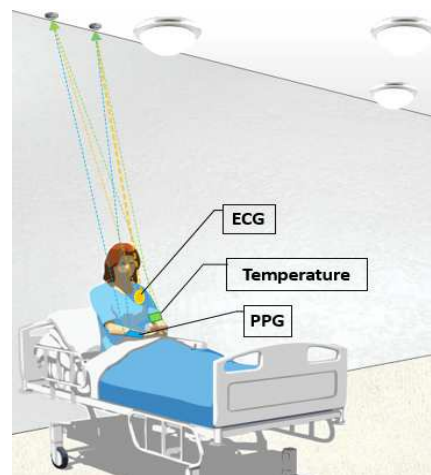


Figure 4. Proposed patient monitoring system [16]

The proposed system uses three preloaded biomedical data for healthcare, namely ECG, body temperature and photoplethysmogram (PPG), which are transmitted through LEDs using OOK modulation. The received data are then demodulated and multiplexed based on the predetermined header. The patient data are provided periodically for monitoring purposes, hence the importance of accuracy and reliability. The proposed monitoring system is implemented to achieve very low bit error rate (BER), e.g., less than, 10^{-5} at reasonable SNR values at the intended locations of the service area.

2) Mobile transceiver: A mobile VLC transceiver is a communication device capable of transmitting and receiving data via visible light while in motion. This type of device is designed to maintain stable and effective communication even when the transmitter or receiver (or both) move, unlike static VLC systems that typically require a fixed direct line of sight. In hospitals, a patient equipped with a portable VLC device can move freely while continuing to transmit real-time biometric data to a fixed base station. Home-based mHealth rehabilitation is facilitated through visible light mobile communication [12]. The proposed strategy uses visible light as a safe communication medium between wearable sensors and a smartphone. Several applications such as home seated exercise, stationary bike, static running machine, etc. could be a possible real-world application of the proposed system. The camera of a smartphone receives clinical data such as PPG, ECG, and respiratory signals through an LED. The smartphone also acts as a local interface to transmit the data to the cloud so that a physician can continue to monitor it. Figure

5 below shows the illustration of the conceptual idea of the proposed home-based mHealth rehabilitation system.

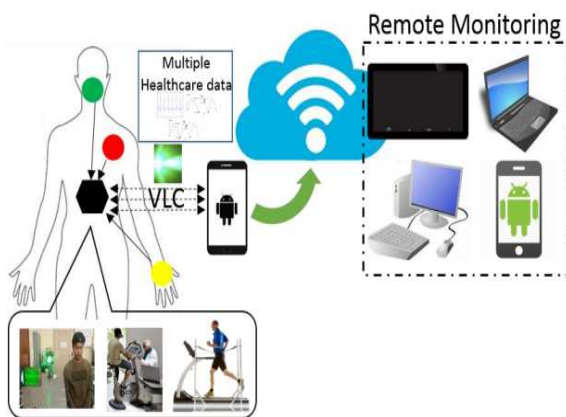


Figure 5. Proposed mobile health system-Home rehabilitation

Clinical data are collected from multiple wearable sensors and then transmitted via a portable LED lamp worn by patients. Therefore, the collected clinical signals were recorded both locally and remotely. For local storage, the authors proposed an Android application that can monitor the history and the monitoring system in real time, while then being backed up to a remote cloud database server so that clinicians, doctors, and other healthcare professionals can analyze the signal remotely via their personal computers (PCs) or mobile devices.

The authors of [17] studied the effect of random receiver orientation on line-of-sight links for mobile users on VLC downlink channels. To achieve this goal, the patient wearing the receiver was made to move around the room and the receiver location axes were distributed uniformly on a 2D plane. They experimented with a uniform distribution used to constrain the random orientation of the receiver based on the patient's movements. It was found that the impact of LOS (Line of Sight) rays on the channel impulse response is greater than that of reflected rays when the orientation angle is zero or perpendicular. It was also learned that for data rates up to 30 Mbps, the effect of receiver orientation does not have a major impact on the performance of the channel model. A site-specific channel modeling approach based on ray tracing was used to characterize the channel parameters of VLC-based mobile body sensor networks (MBSNs) in [9]. A root mean square (RMS) delay spread in an intensive care unit (ICU) and a family-type patient room where three MBSN nodes move along realistic random trajectories was considered in this model. From the simulation results, both the path loss and RMS delay exhibit a linear impact on the communication of the monitoring system.

3) Hybrid transceiver: It is a communication device that combines visible light communication (VLC) technology with another wireless communication technology, usually based on radio frequencies (RF) such as Wi-Fi or Bluetooth. This type of hybrid system aims to leverage the advantages of both

technologies to overcome their respective limitations. A hybrid VLC/RF transceiver in a hospital could transmit critical data via VLC for safety, while ensuring continuous coverage through RF in case of patient movement. It is particularly useful in complex environments where communication conditions may vary and reliability and security are essential. Some recent designs, such as the one in [18], use hybrid channels that use both VLC and RF to meet the needs of MBSN. In this work, Pareto simulated annealing was used to efficiently select a VLC link or an RF link to satisfy the constraints of the underlying system. Compared with the standard VLC system, their hybrid RF/VLC scheme achieved better signal-to-noise ratio (SNR) performance. A hybrid OCC/BLE (Optical Camera Communication/Bluetooth Low Energy) system is proposed in [19] to ensure efficient, remote, and real-time transmission of a patient's electrocardiogram (ECG) signal to a monitor. First, a patch circuit integrating an LED array and a BLE transmitter chip is proposed. The patch collects ECG data based on the patient's health status to minimize the power consumption. A network selection algorithm is developed for a new network access request generated in the patch circuit. Fuzzy logic is used to select an appropriate camera for data reception. Furthermore, a handover mechanism is proposed to ensure efficient network allocation considering the patient's mobility. Finally, simulations are conducted to demonstrate the performance and reliability of the proposed system.

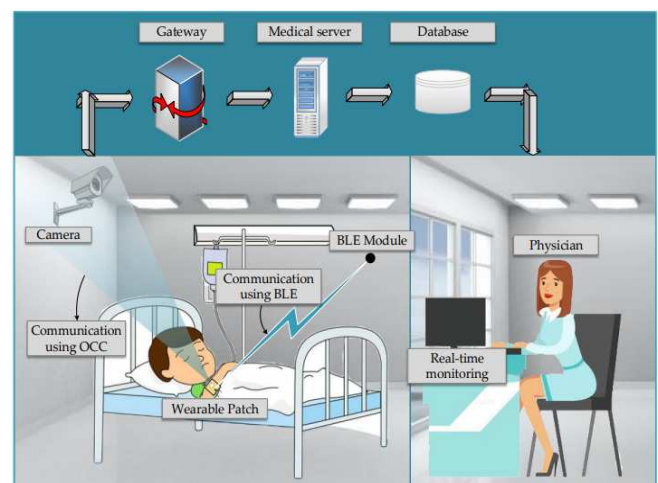


Figure 6. Proposed monitoring system [19]

Therefore, the authors of [20] proposed a hybrid system based on the Internet of Things to monitor the health of mobile workers in an underground mining industry. The wireless body area network (WBAN) placed in the mining workers uses an optical receiver that obtains a cell identifier sent by the infrastructure via an optical cell-based visible light communication (VLC) link, which is used for joint positioning and communication within the mining tunnel and radio frequency (RF) for transmitting primary vital signs to the cloud. Once the data is obtained, a health professional who is located outside the mine can observe and control the previously processed data.

C. Overview of the literature

Extensive research has been conducted to determine an efficient data collection and transmission system in the healthcare domain over the last two decades. The developed monitoring systems have implemented different types of VLC systems for the transmission of medical signals. Thus, in [21], optical modulation is based on the hospital lighting network; high brightness LEDs (HB-LEDs) are used in this system as the illumination source so that the general information of the hospital is modulated in the emitted visible light. In [22], there is a static design for monitoring indoor patients using VLC as an uplink suitable for hospital settings; the proposed system is designed to transmit patient data in uplink using VLC via OOK modulation. Al-Qahtani et al. [23] deployed, a non-invasive electroencephalogram (EEG) monitoring system based on visible light communication using a generic microcontroller. In [24], a method that uses VLC technology as a transmission platform and provides real-time monitoring of heart rate and patient information is analyzed; the white LED beam is used as a light source to simultaneously transmit the biomedical signal and the patient's medical record; the OOK modulation technique is used to modulate all the data in the visible light beam. At the other end, a receiving circuit composed of a high-speed photodetector and a demodulation circuit is used to demodulate the data in the visible light beam; the demodulated data is serially transmitted to a personal computer where the biomedical signal, patient information and heart rate can be monitored in real time.

Dhatchayeny et al. In [25] and [26] described a novel strategy for transmitting biomedical EEG (Electroencephalogram) signal using VLC link; the data transmission is performed in line-of-sight (LOS) using OOK modulation and three LED color components: red, green, and blue (RGB). In [27], the focus is on optical transmission of EEG signals that uses LED and PD (Photodiode) to display the information in LabVIEW 2022 software environment. In [28], a time-hopping (TH) VLC system is proposed; the TH scheme is adopted to transmit multiple medical data while maintaining a simple system design. In [29], sparse code multiple access (SCMA) is used to transfer multiple medical data in real time with higher bandwidth efficiency. The received signal, which includes multi-user data, is separated by the message passing algorithm with high reliability and is simultaneously reorganized to be transmitted to a user interface.

In [30] and [31], VLC system designs for portable patient monitoring devices are presented; it is a bidirectional communication system, in which the downlink communication uses VLC, while the uplink communication uses infrared. In [32], an integrated system is proposed via Power Line Communications (PLC) and VLC with orthogonal frequency division modulation (OFDM) for indoor hospital applications. In [33] a hybrid RF and VLC communication system with double hop is modeled to provide a solution to communicate laboratory test results to patients in a short time. Another study proposed a hybrid wireless communication system [34] that combines optical wireless communication

and direct modulation on LED chips. This system is designed for a versatile indoor IoT using a single LED as a transmitter and a combination of photodiodes with the camera as a receiver. The experiment shows that the system can achieve a throughput of up to 100 Mbps for the visible light communication (VLC) link and error-free data transmission for the OCC link. The result is achieved by using direct modulation with different amplitude levels, and optimizing the received optical power can significantly improve the link performance. This research also explored different LED colors and sophisticated modulation techniques (direct modulation). Herfandi et al. [35] presented a novel implementation of the Internet of Medical Things (IoMT) system, which uses OCC for real-time health monitoring and indoor location tracking. The innovative system uses standard closed-circuit television (CCTV) installations, integrating a deep learning-based OCC system to simultaneously monitor multiple patients, each represented by an LED matrix. The effectiveness of the system was demonstrated through two scenarios: the first involves two transmitters and a single camera, emphasizing real-time monitoring of vital health data; the second includes a transmitter with two cameras, emphasizing tracking patient movements across the different camera fields of view. To accurately locate and track the position of the LED arrays in the camera, the system uses YOLO (You Only Look Once). Data is securely transmitted to an edge server and stored using the Representational State Transfer (REST) API, with a web interface providing real-time patient updates.

IV. CHALLENGES AND PROSPECTS OF VLC TECHNOLOGY IN RPMS

A. Challenges

Although visible light communication offers attractive security and bandwidth advantages, it also presents significant challenges in terms of range, integration, and environment.

- **Interference and noise:** Interference and background noise represent significant challenges for Visible Light Communication (VLC), especially in remote patient monitoring systems (RPMS), where the transmission of medical data must be reliable and secure. However, one of the main sources of interference for VLC systems is ambient light from natural (sunlight) or artificial (indoor lighting) sources. These sources can disrupt the VLC signal by changing the light intensity in the environment, making it more difficult to distinguish between the useful signal and the background noise, which can lead to severe signal attenuation resulting in data loss or degradation of the communication signal.
- **Range and coverage:** VLC systems are typically effective over relatively short distances, often limited to a few meters. This can be a problem in medical environments where patients move around or where it is necessary to monitor multiple

patients spread across different areas. The need to maintain a direct line of sight between transmitters and receivers can limit the practical application of VLC in larger or complex environments. Additionally, ambient light sources, such as sunlight or artificial lighting, can create optical noise, which disrupts the reception of light signals. This interference can reduce the reliability and range of communication, requiring adjustments in lighting intensity or the use of filters to attenuate light noise.

- **Patient mobility and positioning:** Unlike radio communication technologies that can pass through obstacles, visible light signals are directly affected by objects that block or absorb light. In a healthcare environment, where equipment, walls, and other structures are common, this can result in signal loss or limited coverage. As a result, patients may move around their room or between rooms, which can interrupt communication if the VLC sensor is unable to track their movement. Monitoring devices must therefore be designed to accommodate these movements, either by using multiple transmitters and receivers or by integrating complementary technologies to ensure continuous coverage.
- **Security and Privacy Issues:** Light leakage and transparent partitions pose unique security challenges for visible light communication (VLC) systems, particularly in critical environments such as remote patient monitoring systems (RPMS). These challenges can compromise the privacy and security of transmitted medical data [37]. Unlike radio waves, visible light does not pass through walls, but it can propagate through openings or windows allowing an outside observer to intercept the data. This light leakage can lead to unauthorized interceptions if the VLC system is operating in a poorly insulated space. However, medical monitoring systems often rely on continuous transmissions of sensitive data, such as real-time health measurements. Transparent partitions could therefore compromise the confidentiality of this information, even in supposedly secure environments, such as consulting rooms or patient rooms.

B. Perspectives

However, the future security outlook for visible light communication (VLC) in remote patient monitoring systems (RPMS) presents unique opportunities and challenges. As an emerging technology for data transmission, VLC offers advantages in physical security and interference resistance, but also requires robust solutions to protect sensitive medical information in a healthcare setting. Some of the key security outlooks for VLC in RPMS include:

- Integrating deep learning techniques for intrusion and anomaly detection can also be applied to VLC. AI systems could monitor the behavior of VLC communications in real time and identify interception attempts or attacks such as denial of service (dos) attacks. These systems would learn from normal data traffic patterns to quickly identify suspicious behavior and neutralize potential threats.
- In hybrid systems combining RF and VLC, secure management of both types of channels becomes essential. VLC can be used for sensitive data transmission, while RF is used to provide network coverage in areas without direct lighting. It is therefore crucial to implement secure switching policies between these two types of communications, ensuring that sensitive data is always transmitted over the most secure channel. Encryption and key management protocols should also adapt to dynamic changes between RF and VLC channels. Deep learning algorithms can strengthen encryption mechanisms in hybrid RF/VLC networks by dynamically adjusting encryption protocols based on detected threats. For example, if a threat is detected in the RF channel, the system can increase the encryption level or switch to the VLC channel, which is considered more secure in terms of limited physical propagation. In addition, deep learning can be used to monitor RF and VLC communications in real time and identify intrusions or anomalies. Convolutional neural networks (CNNs) and recurrent neural networks (RNNs) can learn from normal data patterns to detect abnormal behavior, such as signal interception attempts or denial of service (DoS) attacks on either channel [36].

V. CONCLUSION

The integration of visible light communication (VLC) into remote patient monitoring systems (RPMS) represents a significant advancement in improving the safety, privacy, and efficiency of remote medical care. With its ability to provide fast and secure data transmission, VLC overcomes some limitations of conventional RF technologies, including electromagnetic interference and security of sensitive patient data. In addition, the use of existing lighting infrastructure for communication offers a cost-effective and environmentally friendly solution, while reducing energy consumption. However, some limitations remain, including the reliance on line-of-sight for data transmission, which could restrict its application in some clinical environments. In this study, the use of VLC technology in RPMS was presented and analyzed in the areas of interest of applications and devices used. The challenges faced by VLC in RPMS as well as solutions to these challenges were presented.

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