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THESIS

To obtain the degree of

MASTER IN ELECTRICAL ENGINEERING

Speciality: system of telecommunication

Presented by

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Design and Implementation of VLC medical healthcare information system

Supported in 20 Julie 2023 in front of the jury:

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In this work, a wireless communication system based on visible light communication (VLC) for medical information system for healthcare is proposed. The system design consists of two Arduino devices (microcontroller) as transmitter and receiver. The user interface, based on MATLAB programming, is used to control the sending and receiving of data. The proposed system is designed to successfully transmit medical data and biomedical signals (ECG). The transmission quality performance analysis shows the high accuracy of the transmission algorithms even though it is difficult to achieve high data transmission speeds with Arduino.

Keywords: Wireless communication, biomedical signals, VLC, LiFi, ECG

في هذا العمل ، تم اقتراح نظام اتصال لاسلكي يعتمد على اتصال الضوء المرئي (VLC)لنظام المعلومات الطبية للرعاية الصحية. يتكون تصميم النظام من جهازي إردوينو (متحكم دقيق) كجهاز إرسال وجهاز استقبال. تستخدم واجهة المستخدم ، القائمة على برمجة Matlab ، للتحكم في إرسال واستقبال البيانات. تم تصميم النظام المقترح لنقل البيانات الطبية والإشارات الطبية الحيوية ECG بنجاح. يُظهر تحليل أداء جودة الإرسال الدقة العالية لخوارزميات الإرسال على الرغم من صعوبة تحقيق سرعات نقل بيانات عالية باستخدام إردوينو.

الكلمات المفتاحية:
اتصال لاسلكي ، إشارات طبية حيوية ،ECG، Li-Fi، VLC

Dans ce travail, un système de communication sans fil basé sur la communication par lumière visible (VLC) pour le système d'information médicale pour les soins de santé est proposé. La conception du système consiste en deux périphériques Arduino (microcontrôleur) en tant qu'émetteur et récepteur. L'interface utilisateur, basée sur la programmation MATLAB, est utilisée pour contrôler l'envoi et la réception des données. Le système proposé est conçu pour transmettre avec succès des données médicales et des signaux biomédicaux (ECG). L'analyse des performances de la qualité de la transmission montre la grande précision des algorithmes de transmission même s'il est difficile d'atteindre des vitesses de transmission de données élevées avec Arduino.

Mots Clés : Communication sans fil, Signaux biomédicaux, VLC, Li-Fi, ECG

Chapter III. Design of VLC Medical Health Care Information System

Conclusion and perspectives

ADC : Analog Digital Converter
AM : Amplitude modulation
ASCII : American Standard Code for Information Interchange
BER : Bit Error Rate
BPM : beats per minute
CSK : Color Shift Kering
CC : courant continue
CPL : courant porteur en ligne
DAC : DigitalAnalogConverter
DD : Direct Detected
DSP : Digital Signal Processor
EMI : Electro-Magnetic Interférence
ECG : Electrocardiogramme
EEG: Electroencephalogram
EMG: Electromyography
PPG:photoplethysmography
FDM : frequency devision multiplexing
FM : Frequency modulation
IEEE : Institute of Electrical and Electronics Engineers
IoT : Internet of Things
IdO : Internet des Objets
IR : Infra-Red
IrDA : Infrared Data Association
LED : Light Emiting Diode
LLC : Logical Link Control
Los : Line of Sight
LDR : Light Dépendent Résistor
LPF : Low pass filter
LIFI : light fidelity
LTE : Long Term Evolution
MFR : MAC Footer
NRZ : non-return to zéro
OFDM : Orthogonal Frequency Division Multiplexing
OOK : On Off Keying
OWC : Optical Wireless Communications
PD : Photodetector
PIN : Positive Intrinsic Negative
PWM : Pulse Width Modulation
RF : Radio Frequency
RLL : Run Length Limited
RFID : Radio-frequency identification
SCM : Single Carrier Modulation
SDK: Software Development Kit
SHR: Synchronization Header
SINR: Signal to Interference plus Noise Ratio
VLC: Visible Light Communication
VPAN:VLC Personal Area Network
VPPM: Variable Pulse Position Modulation
WDM: Wavelength Division Multiplexing
Wi-Fi : Wireless-Fidelity

Chapter I:Introduction to visible light communication

I.1 Introduction

The fields of Visible Light Communication (VLC) systems, optical sources and receivers based on semiconductors are very exciting areas of research in the design of ultra-fast communications networks, high-security, and highly reliable communications networks using high-frequency pulsed light with very high bandwidth. In this context, LEDs have become the main source of lighting for high-speed secure data transmission systems[1]

In addition to the traditional bi-directional transmissions, we are currently experiencing an increasing development of the Internet of Things (IoT), which has become the main development in our world. In this chapter, we present some basic notions about light and then we will focus our attention on the description of the different components of VLC systems, the advantages, and disadvantages of these systems, and their applications.

I.2 History

In 2011, Harald Haas, a professor at the University of Edinburgh who was focusing on Li-Fi research's since 2004, launched a Li-Fi prototype at the TED Global conference in Edinburgh. During the demonstration, Haas used a table lamp with an LED bulb to transmit a video of blooming flowers, proving that the lamp was the source of incoming data by blocking the light periodically. At the event, Haas achieved a data transmission rate of approximately 10Mbps, similar to a good UK broadband connection. Two months later, Haas achieved a rate of 123Mbps.[2]

Figure I.1:*Dr. Harald Haas: research in 2004*

The idea of using LED light bulbs for wireless communication had been around for a while, as German scientists had created an 800Mbps-capable network using normal red, blue, green, and white LED light bulbs. Several other global teams are also exploring the possibilities of Li-Fi technology.

I.3 Definition of visible light

Visible Light Communication (VLC) is an emerging communication technology for short-range applications. Utilizing the latest advances in VLC development, which emits high-power visible light, it offers an energy-efficient and clean alternative to RF technology.
Enabling the development of wireless optical communication systems using the existing lighting infrastructure. Based on the insights of leading researchers from around the world.
Visible light therefore consists, by definition, of visually perceptible electromagnetic waves. The spectrum covers wavelengths from 400 nm to 800 nm

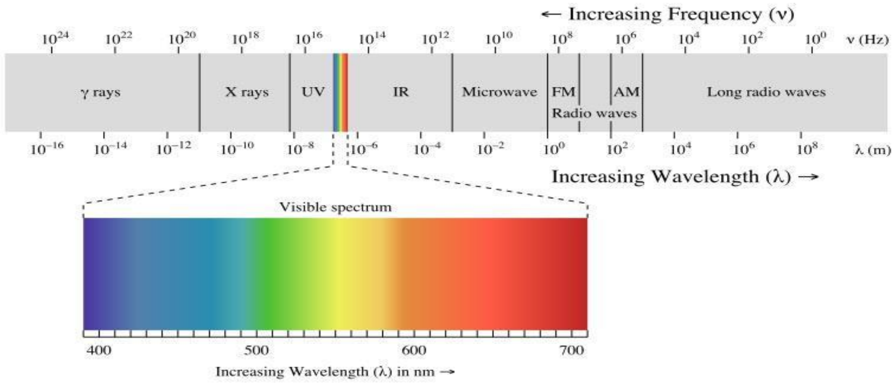


Figure I.2. *Distribution of the electromagnetic spectrum with visible light*

I.4 Working Principle

The Li-Fi technology is implemented with white LED lamps for constant current lighting. However, due to rapid changes in current, the luminous flux can change very quickly. If the LED is on, it sends a digital 1, otherwise it sends a digital 0.[2]
LEDs can be turned on and off quickly to transmit data that the human eye cannot see. So to send data we need LEDs and a controller that encodes data to those LEDs and to receive data we need an image sensor, a photodiode used as a detector
The LED lamp contains a microchip that processes the data. The light intensity can be manipulated to transmit data with small changes in amplitude.
Figure I.3 shows the working principle of Li-Fi system, for data transmission; it can be done by single LED or multi LED. On the receiver side there is a photo detector, which convert this light into electric signals and it will give the electric signals to the device connected to it. Voltage regulator and level shifter circuits are used on both sides to convert or maintain a voltage level between transmitter and receiver.[3]

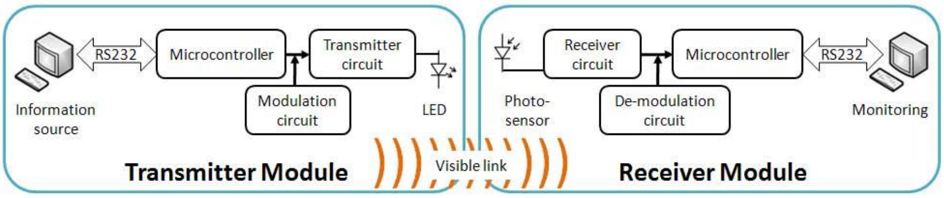


Figure I.3 *The working principle of the Li-Fi*

I.5 Architecture of a VLC system

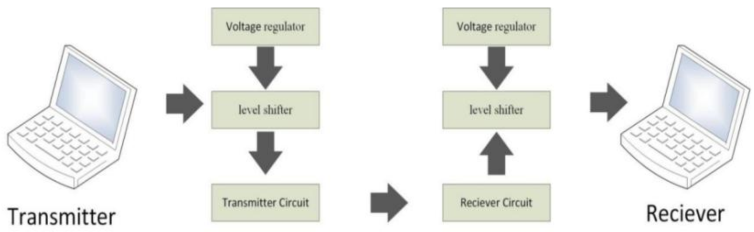


Figure I.4. *General Architecture of Wireless VLC System*

I.5.1Transmitter

A VLC transmitter is an electro-optical transducer device that transmits information using visible light waves over a wireless transmission medium.[4]
The transmitter consists of a digital-to-analog converter (DAC, digital to analog converter) that takes over the modulation of bits of information and converts them into an analog current signal, an amplifier transconductance (TCA, Transconductance Amplifier), low-pass filter (LPF, low-pass filter) and high-speed LEDs.[5]
The LED converts an electrical signal into optical energy providing both illumination and communication. The information is encoded online and modulated by the DAC, then transmitted to the optical signal by modulating the amplitude or other characteristic of the LED.[6]

I.5.2 Receiver

At the receiver, the photodiode converts the received optical power into a signal electrical, which is then amplified, demodulated and decoded by a trans-impedance amplifier (TIA, Trans-impedance Amplifier), followed by a low-pass filter. A converter analog/digital (ADC, Analog to Digital Converter) is used to transform the signal analog current into a digital signal to recover bits from the user's message.[5]

I.6 Modulations in VLC

There are several modulation techniques associated with optical wireless communications. In the context of VLC, the selection of a particular modulation is based on two criteria:

• Lighting requirements

Different activities require different illuminations such as 30-100 lux required for normal visual activities in public places.

There is a non-linear relationship between measured light and perceived light, given by equation (1.1):

$$\text{Perceived light (\%)} = 100 * \sqrt{\frac{\text{(measured light (\%)}}{100}} \qquad (1.1)$$

• Adaptation to flickering effect

Changes in the brightness of the modulated light must be made in such a way as to not cause perceptible fluctuations to the human eye. According to IEEE 802.15.7, switching should be done at a rate faster than 200 Hz to avoid harmful effects.
In the first IEEE 802.15.7 standard, different modulation types are proposed, including On-Off Keying (OOK), Variable Pulse Position Modulation (VPPM), and Color Shift Keying (CSK). However, many studies have shown the benefits of using multi-carrier modulations such as Orthogonal Frequency-Division Multiplexing (OFDM)[8].

The first three modulations are found in the physical layer (PHY) of the IEEE 802.15.7 standard. PHY types I and II are defined for a single light source and support OOK and VPPM technologies, while PHY III uses multiple optical sources at different frequencies (colors) using CSK modulation.

All three systems can coexist, providing attenuation of scintillation and support for dimming, while allowing for a compromise between data rates and dimming ranges.[9]

I.6.1 OOK modulation

As illustrated in Figure I.5, OOK is a simple modulation technique in which a digital "1" is represented by the presence of the signal, corresponding to the "ON" state, while the data "0" is represented by a signal of value equal to zero, or the "OFF" state. The "ON" and "OFF" represent two distinct amplitude levels necessary for communication and do not necessarily imply that the light source is completely turned off.

For OOK modulation, the IEEE 802.15.7 standard mentions the use of the Manchester code to ensure that the positive pulse period is identical to the negative pulse period, but this also doubles the bandwidth required for OOK transmission[10].

Five different bit rates are used, namely 11.67 kbit/s, 24.44 kbit/s, 48.89 kbit/s, 73.3 kbit/s, and 100 kbit/s.[11]
Alternatively, for higher binary rates, a Run Length Limited (RLL) coding technique is used, which is more spectrally efficient. Grading is supported by adding an OOK extension that adjusts the aggregate output to the correct level[12]

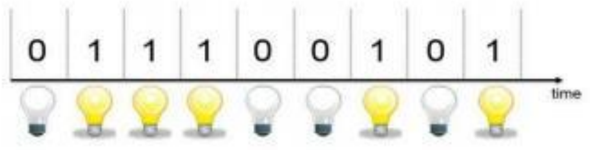


Figure I.5. *OOK modulation scheme*

I.6.2 VPPM modulation

VPPM modulation is a variant of Pulse Position Modulation (PPM), developed specifically for VLC. In PPM modulation, information is represented by the position of the pulse in time. The VPPM variant introduces pulse width variation (PWM, Pulse Width Modulation) based on the level of light intensity . VPPM modulation eliminates the problem of scintillation by removing long strings of "0" symbols, and the PWM technique allows for control of the light intensity. [13]

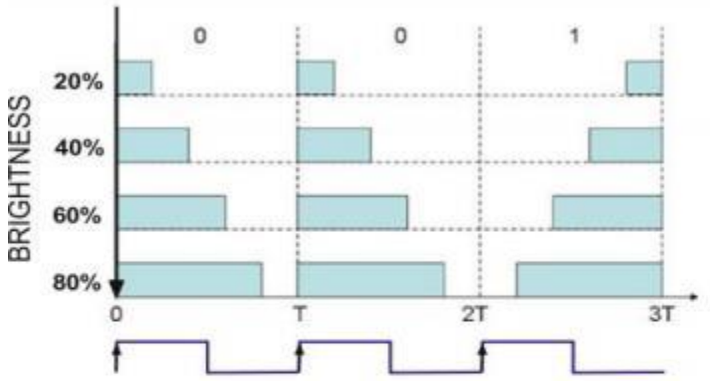
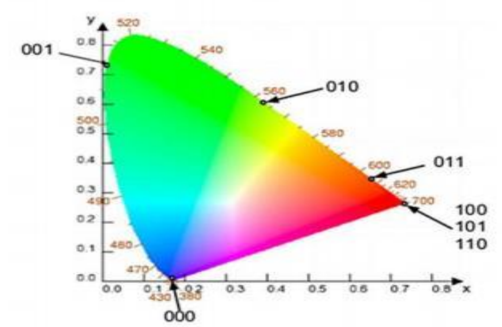


Figure I.6.*VPPMModulation.*

I .6.3 CSK modulation

Like VPPM modulation, "Color-Shift Keying, CSK" modulation is specific to VLC. It was proposed in the IEEE 802.15.7 standard to improve the low data rate in other types of modulation. The switching capacity slows down by producing white light using yellow phosphor and blue LED. Therefore, another way to produce white light is to use three separate LEDs, green, blue, and red. It is specially defined using the intensity of the three colors of an RGB LED (Red Green Blue) source. The CSK modulation depends on the chromaticity diagram of the color space. Unlike other modulations, symbols are selected here so that the light emission remains constant while the different chromatic components associated with each color vary. This modulation maps all colors perceptible to the eye onto two chromaticity parameters such as x and y. Figure I.7 illustrates the seven visible wavelength bands presented in a table with their centers represented on the diagram.[8,13]



Band (nm)	Code	Center (nm)	(x, y)
380–478	000	429	(0.169, 0.007)
478–540	001	509	(0.011, 0.733)
540–588	010	564	(0.402, 0.597)
588–633	011	611	(0.669, 0.331)
633–679	100	656	(0.729, 0.271)
679–726	101	703	(0.734, 0.265)
726–780	110	753	(0.734, 0.265)

Figure I.7.*CSK Modulation*

This technique allows complete freedom from flicker problems. Additionally, since the emitted luminous flux is constant, the command current remains constant as well, greatly reducing the constraints on the sources. The limitation of this modulation is related to the complexity and the necessity in reception to be able to receive each color .[13]

I.6.4 OFDM modulation

For high-speed applications, one quickly faces the problems of source bandwidth limitation as well as IES (Inter-Symbol Interference) generation. To better address these issues, one can use an OFDM modulation.[8]

The principle of this modulation is to consider that data is sent on multiple channels in parallel using different subcarriers. Thus, the time of each symbol corresponding to each subcarrier is much greater than its equivalent for a single carrier, greatly reducing the impact of IES while allowing the bandwidth to be optimized.[14]

I.7 Types of coding

I.7.1 NRZ (Non-Return-to-Zero) formats

The binary data "1" is associated with an optical pulse of duration substantially equal to the symbol time (inverse of the bit rate), and "0" to the absence of a signal. In practice, there is never a total absence of signal since the extinction ratio is never infinite. NRZ coding is used for bit rates below 10 Gbit/s and is used in many 2.5 Gbit/s WDM systems and requires an external modulator .[5]

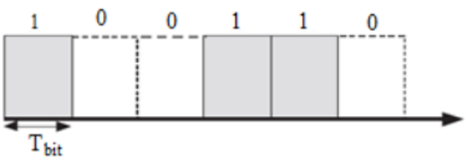


Figure I.8. *NRZ format*

I.7.2 Manchester format

Manchester encoding, also known as biphase encoding, introduces a transition in the middle of each interval, which means that the "1" data will be encoded by a rising edge in the middle of the clock period, and the "0" data by a falling edge in the middle of the clock period. This is achieved by using an exclusive OR (XOR) between the data signal and the clock signal. The use of this coding eliminates the DC component. Figure I.8 represents the coding of data (1 0 0 1 1 0) in Manchester format.[5]

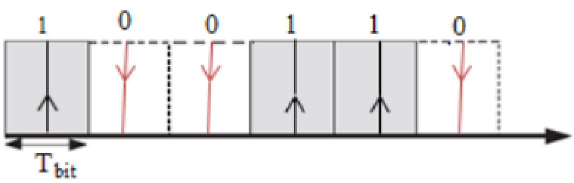


Figure I.9.*Manchester format*

I.8 Li-Fi Applications

The applications of Li-Fi are endless and promising communications on the planet.

- **Underwater Communications:**

Using RF signals is impractical due to strong signal absorption in water. Li-Fi offers a solution for short-distance communication. The submarines could communicate with each other via their searchlights, process the data autonomously and periodically send the results to the surface in remotely operated underwater vehicles (ROVs). Another important point is that Li-Fi can also work underwater, where Wi-Fi completely fails, leaving it open to military operations.[15]

- **Traffic regulation**

Li-Fi can help you better manage traffic and reduce accidents. Traffic lights can communicate with cars and each other to control traffic on the road.
The traffic light can act as a data transmitter and provide the car with information about the road condition or the situation[15,16] of other cars_Cars can also communicate with each other and prevent accidents by exchanging information. For example, LED car lights can warn drivers when other vehicles are too close.[3]

- **Airways**

On airplanes, the cell phones must turned off in order to prevent cell phone signals from interfering with the navigation and control signals used by airplanes. Hence, Li-Fi is more safe to be used on airplanes as it does not interfere with RF[16]. Since data exists where there is light, we can use lights above airplane seats as hotspots[3].

- **Blind interior navigation system**

Indoor navigation is convenient for everyone and especially necessary for the blind. In, the authors have proposed such a navigation system for the blind. The LEDs emit visible light with location data, and an onboard system or smartphone with a visible light receiver receives that data. The built-in system or smartphone calculates the optimal route to the sign and talks to the blind person via headphones[17]

- **In sensitive areas or dangerous environments**

The Li-Fi ensures secure communications in environments such as mines and petrochemical plants as it does not cause electromagnetic interference associated with RF communications. Li-Fi can also be used in oil or chemical plants where other frequencies can be dangerous.[16]
For example, power plants such as nuclear power plants require grid integrity and plant temperature monitoring, which requires interconnected high-speed data systems. WLAN and many other types of radiation damage sensitive areas around power plants. Li-Fi can provide ample secure connectivity for all areas of these hotspots.[15]
Furthermore, this technology also allows us to control plants and their growth without our direct presence.

- **Natural Disaster Management**

The Li-Fi can be used as a powerful means of communication during a natural disaster such as an earthquake or hurricane, for example in locations such as subway stations and tunnels, which are common areas for most emergency calls. Conseqently, Li-Fi can be used as a backup link. [15]

I.9 Advantages and disadvantages of VLC

The VLC comes with the advantages of visible light namely: free high bandwidth with high data rate, license-free spectrum, and safety for the human body and for high precision electronic equipment. VLC is also considered to be safer than RF and data transmission is available, in addition to the lighting function. Besides these advantages, VLC is a technology that is inexpensive and easy to implement .[18]

- High bandwidth

RF communications come with an available spectrum of 300 Giga HZ, which is used for different types of applications such as: AM and FM broadcasting, television broadcasting military applications, or satellite communications. In this case, the exploitation of a certain bandwidth implies to have a license for it. So, it can be stated that VLC comes with a worldwide, license-free and almost unlimited bandwidth with a multi Gb/s data rate compared to RF, which can rarely provide data rates than 100 Mb/s [18]

- Unrestricted technology

RF communication can cause malfunctions in high precision electronic equipment, such as that equipment, such as those found in hospitals or in airplanes, unlike VLC in addition to being safe for the human body.

- Low cost implementation

The table summarizes all the advantages of VLC over RF and IR.

Tableau I.1 : Comparison between VLC, RF and IR[19]

	VLC	**RF**	**IR**
Bandwidth	Unlicensed 400 THZ	Regulated limited <300 GHZ	400 THZ
Interference Electromagnetic	NO	YES	NO
Consumption energy	low	AVERAGE	Low
Mobility	Limit	YES	Limit
Standards	802.15.7	Several	802.11
The cover	narrow	Large	narrow
Risk for health	BLH	Several	Thermal
The cost Implementation	low	low-medium	low-medium

The major disadvantage is that you have to be in the radiation of the light which means that when you leave a room connected via LI-FI, you lose connection.

I.10 VLC Security

Any new technology that promises a bright future raises questions about human and material security. Since Wi-Fi has some flaws in both areas, it is reasonable to wonder if VLC (Visible Light Communication) can also pose such problems.

I.10.1 Human Security

Regarding human security, particularly concerning harmful waves, there don't seem to be any issues with VLC, which uses light waves. Light has existed for years without causing harm to humans.

Some people claim to be hypersensitive to radio frequencies and are looking for an alternative. VLC is a good solution to this problem.[20]

I.10.2. Network Security

From a network security perspective, unlike Wi-Fi, VLC does not penetrate through walls. Any intrusion can only occur within the same room. Moreover, light is directional, making it an interesting technology for sectors and businesses that need to secure their information and communications. However, this can be a disadvantage for public spaces because once someone is not in close proximity to a lamp, the signal is lost.

On the other hand, VLC cannot be disrupted by other spectra, as they can overlap without interference. Therefore, unlike Wi-Fi, even light jammers cannot be used. One of the recent issues with VLC is that if someone turns off the light or if the sensor is obstructed, the internet connection is lost.

Thus, we can conclude that at the moment, there don't appear to be risks in terms of both network and health security. As with any new technology, prolonged use of VLC over time will allow us to identify any potential security problems. For now, VLC remains a viable alternative to the issues encountered with Wi-Fi.

I.11.Conclusion

This chapter provided an overview of Visible Light Communication (VLC), including its working principle, architecture, modulation techniques, coding formats, and applications. The advantages of VLC include its ease of implementation, high bandwidth, unrestricted technology, and low cost implementation. However, it also has some disadvantages such as limited range and susceptibility to interference from ambient light sources. Despite its limitations, VLC technology holds great promise for various communication applications.

Chapter II
Medical data for healthcare

II.1.Introduction

The Visual Light Communication (VLC) system is becoming increasingly popular in hospitals due to its ability to transmit data wirelessly through visible light waves, where the data that are transmitted by light contains information about the patient such as his name, surname, age, and biomedical signals represented by the electrocardiogram (ECG) and electroencephalogram (EEG) signals from the devices in the patient rooms to the medical center and from the medical center to the Doctors mobile device to view the patient's information when visiting him.
One of the main advantages of the VLC system is that it operates in the visible light spectrum, is free of electromagnetic interference, and is more secure than traditional wireless communication technologies such as radio frequency (RF) or Wi-Fi. This makes VLC particularly useful in environments where interference from medical devices can cause signal degradation or data lossand this system is safer because it is unable to penetrate walls.
VLC system also features high-speed data transfer rates, which are critical in medical applications that require real-time data transmission and analysis, such as resuscitation and emergencies. Accurate and timely transmission of biomedical signals can be critical to patient care.
Overall, the VLC system is one of the most promising research areas currently for the transmission of biomedical signals in the hospital environment, providing a reliable, secure, and high-speed communication method for medical devices and systems. With the increasing adoption of VLC-based systems in hospitals, we can expect to see significant improvements in patient care and medical research in the coming years.

II.2.Biomedical signals

Human body consists of different types of cells, tissues, and molecules. Due to the exchange of ions and the electrical potential of cells at resting state and during action, bioelectrical signals are generated. These bioelectrical signals correspond to physiological and anatomical aspects of the human body, and could be detected using electronics, optical, and mechanical sensors and transducers placed on the surface of the body. Given the ease of data collection and the noninvasive nature of data acquisition, understanding and monitoring human health across a broad spectrum of disease states could be achieved by using appropriate signal processing methods and tools. At a higher level, a biomedical signal could be defined as waveforms that contain trends and fluctuations or one which has envelope and oscillations.
A more specific definition of a biomedical signal is one that has amplitude modulation and frequency modulation components. The characteristics of a biomedical signal could be categorized as one that has the following "N" properties: Nonstationarity, Nonlinearity, Non-Gaussian, Near-sparse, and from the data science view point, it could be said as one that has these four "V" properties: Velocity, Variety, Veracity, and Volume [1]. Due to the ubiquitous nature of sensors and the rapid advancements in IoT and ICT technologies, it is important to process and analyze the biomedical signals in a more systematic and robust way. It might be beneficial to review some of the common biomedical signals before we get into the

details of acquisition, preprocessing, analysis, and decision-making aspects of a connected healthcare system.

II.2.1.EEG signal

EEG stands for electroencephalogram in its entire form. It is a graphical depiction of brain electrical activity that was recorded from the scalp using a minimal number of electrodes . The cerebral electrical activity is reflected in the EEG signal.[2]

EEG recording is typically a noninvasive procedure, however occasionally invasive electrodes are employed, as in electrocorticography. The EEG graph is a plot of voltage against time, with time on the x-axis and voltage (usually measured in microvolts) on the y-axis. EEG signals are typically examined to determine whether a person is experiencing seizures, brain damage, a brain tumor, a head injury, sleep disturbances, or any neurodegenerative disease.

The 10-20 EEG system is the most common topography for EEG electrodes. The numbers 10 and 20 relate to the actual separation between neighboring electrodes, which is 10% or 20% of the head's front-to-back or left-to-right distance, respectively.Figure II.2displays a sample EEG recorded while performing a mental arithmetic assignment.Odd number electrodes are on the left side of the head, and even number electrodes are on the right. A typical EEG setup has 64 electrodes or more.

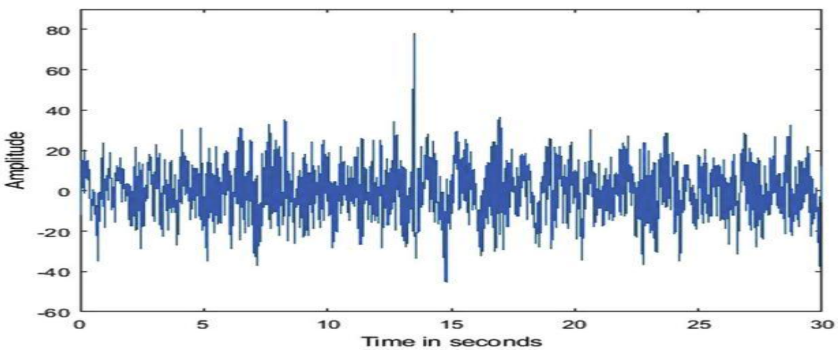


Figure II.2. *A typical EEG signal sampled at 500Hz obtained during a mental arithmetic task[6,8]*

EEG wave types.
The EEG waves are divided into several bands called delta, theta, alpha, beta, and gamma based on their frequency.

Delta: The frequency of this band is 3 Hz or less. These waves are the slowest in the EEG, but they have the highest amplitude, making them the strongest waves. Infants under the age of a year old typically have it, and it can also be found during a few stages of sleep.

Theta: The frequency range of this band is 3.5 to 7.5 Hz.
Another name for it is "slow activity." When found in children up to the age of 13, it is completely normal, but when found in awake adults, it is abnormal.

Alpha: The frequency range of this band is 7.5–13 Hz.
When an adult's eyes are closed, it is frequently recorded. The occipital lobes are where these waves are most prominent.

Beta: has a frequency range that is higher than 13 Hz and is also referred to as "fast activity." Adults who are awake and have their eyes open or closed frequently record it. The frontal and central lobes, which are in charge of conscious thoughts and movements, are where these waves are most pronounced.

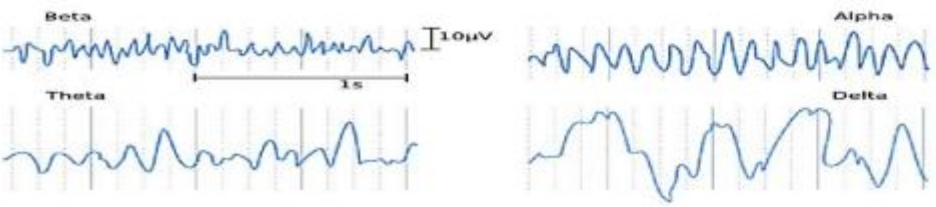


Figure II.3. *The cortical rhythms. [7 , 8]*

The EEG signal only contains a few spikes outside of these main bands. These spikes are brief waves that last less than 80 ms. Slow delta waves may or may not follow. Polyspikes are the name for the series of spikes. To analyze various movements like eye blinking, eye open or close, walking, thinking, imagining a movement, etc., EEG activity is recorded.
The hardest part of analyzing an EEG signal is figuring out where the artifacts are and getting rid of them. The most frequent artifacts are those that relate to the patient, such as movements, perspiration, eye movements, racing thoughts, etc. A few instrumentation artifacts, such as cable movements, interference, and power line frequency (50–60 Hz), may also be present.

II.2.2.EMG signal

The EMG signal, which stands for electromyography, is a technique used to capture the electrical activity generated by the skeletal muscles [3]. The graphical representation of the EMG signal is called an electromyogram. It is commonly used to analyze muscle strength, movement, sports rehabilitation, post-surgery/accident conditions, gait, and posture analysis. The EMG signal can be captured in two ways: surface EMG and intramuscular EMG. Surface EMG involves placing electrodes on the skin to measure the voltage difference between them. In intramuscular EMG, a needle or wire is inserted into the muscle along with a surface electrode as a reference. Sometimes, multiple wires may be inserted with reference to each other. An example of an EMG signal obtained during a sleep study is shown in Figure II.4.

The motor unit is the smallest functional unit that describes the neural control of the muscular contraction process. The EMG captures the contractions of these skeletal muscles, which are controlled by the brain through these motor units. A motor unit consists of muscle fibers twisted to form a cylindrical shape, a motor neuron, and its branches. The activation of each muscle fiber is defined by its action potential. When the action potentials of all the muscle fibers are combined, they form the motor unit action potential (MUAP). An EMG signal is the result of the superposition of these MUAPs, meaning it represents the overlapping MUAPs.

In the case of athletes, the raw surface EMG signals can range between 5000 and -5000 μV, and the frequency content typically ranges between 6 and 500 Hz, with the highest activity observed between 20 and 150 Hz.

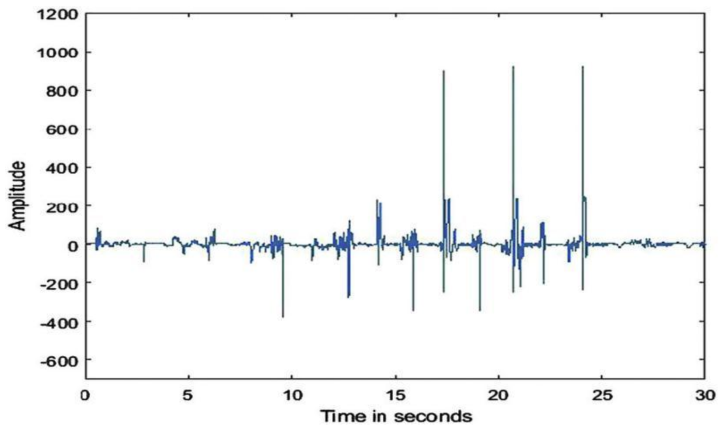


Figure II.4. *A typical EMG signal sampled at 500Hz [16,9]*

II.2.3.PPG signal

The PPG signal, which stands for photoplethysmography, it is a noninvasive optical method used to measure blood volume changes in peripheral circulation [4]. PPG signals are obtained by using a light source, usually an LED, and a detector to capture the reflected or transmitted light. These signals are commonly acquired from the fingertip, wrist, ear lobe, or forehead. Pulsatile signals, corresponding to the blood circulation resulting from the heart's contractile activity, are typically felt at arteries. The PPG signal is acquired by monitoring minor variations in the intensity of light transmitted through or reflected from the tissue. Changes in light intensity are associated with changes in blood flow volume and provide important information about cardiac activity. An example of a PPG signal is shown in Figure II.5. PPG signals consist of two types of waveforms: an alternating current waveform that relates to the heartbeat and a DC waveform that represents tissue structure, venous, and arterial blood volumes.

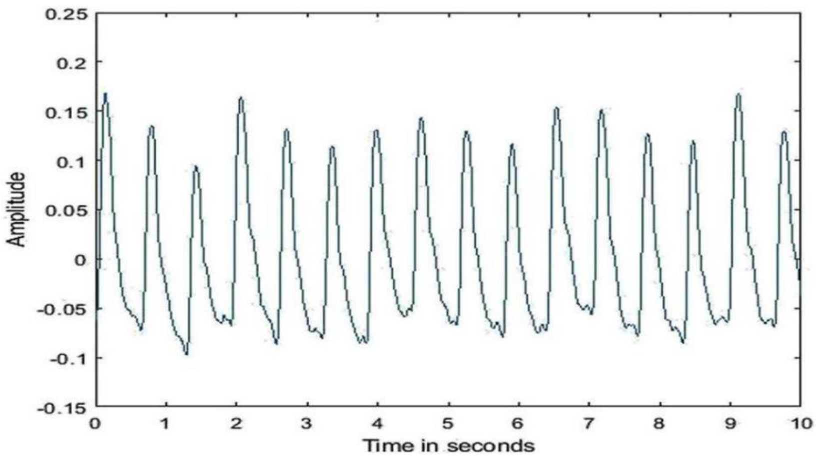


Figure II.5.*A sample PPG signal sampled at 125 Hz [6,10].*

II.2.4.Speech signal

Speech signals are the most convenient means of communication with others. Speech production involves various components such as the brain, throat, tongue, jaw, nose, and vocal tract to produce intelligible speech [5]. The audible range for humans is 20 Hz to 20 kHz, while the speech signal typically varies between 500 Hz and 8 kHz, with most sounds falling within the 2 kHz to 4 kHz band. Music, on the other hand, generally lies above 8 kHz. The diagram below illustrates the muscles involved in speech production. For most speech applications, a sampling frequency of 16 kHz is used, while standard stereo music sampling frequency is 44.1 kHz. An example of a speech signal is shown in Figure II.6.

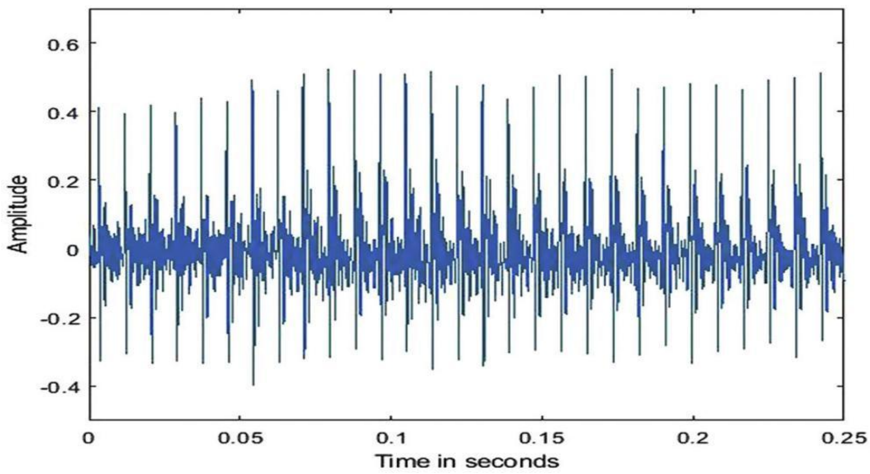


Figure II.6: *A typical speech signal sampled at 8 kHz [6].*

There are several speech disorders, with one common disorder called dysarthria. Dysarthria can be caused by brain stroke, brain tumor, Parkinson's disease, dementia, or other degenerative brain diseases. It is a verbal communication disorder characterized by poor synchronization between the lips and tongue, resulting in ineffective communication of thoughts. Unfortunately, around 170 people out of 100,000 suffer from dysarthria. The severity of dysarthria can vary, with severe cases exhibiting completely unintelligible speech, medium cases having only half of the speech understandable with breathlessness and over-aspiration of certain sounds, and mild cases showing relatively better speech quality except for a few words.

II.3. Electrocardiography

II.3.1. Historical Background

ECG was discovered in 1887 through the work of Wallerf. It was brought to the attention of the medical community in 1901 with the invention of the string galvanometer, which earned its author, Dr. Wilhem Einthoven, recognition in the field of electrocardiography. Since then, electrocardiography has become an essential technique in cardiology practice [11]. Precordial leads were used for medical diagnosis starting from 1932, and unipolar frontal leads were introduced in 1942. These advancements allowed Emanuel Goldberger to create the first 12-lead ECG tracing.

II.3.2. Definition

Electrocardiography (ECG) is the graphical representation of the electrical potential that governs the muscular activity of the heart. This potential is collected by electrodes placed on the surface of the skin [12].

The electrocardiograph generally consists of:
- A set of electrodes intended to be applied in direct contact with the patient.
- A signal amplification system for the signals from the electrodes.
- A recording device.
- A graphical recording system.

Today, electrocardiography is a relatively inexpensive technique that allows for the painless and safe monitoring of the cardiovascular system, particularly for the detection of rhythm disorders and the prevention of myocardial infarction.

II.3.3. Cardio logical Foundations

II.3.3.1. The Heart

The heart is a key component of the cardiovascular system, which is a muscular organ called the myocardium. It has a fist-sized volume and is responsible for pumping blood throughout the human body via blood vessels. In the human body, the heart is located in the mediastinum.
Blood vessels are divided into two major systems: the arterial system and the venous system. The arterial system carries oxygenated blood to the organs, while the venous system returns oxygen-depleted blood back to the heart [12, 13, 14].

II.3.3.2. Anatomy and Muscular Activity of the Heart

The heart is divided into two parts by a septum: the right side and the left side. Each part is further divided into two sections: an upper section composed of two atria and a lower section composed of two ventricles. Figure II.7 illustrates the detailed anatomical structure of the human heart [12,13,14].

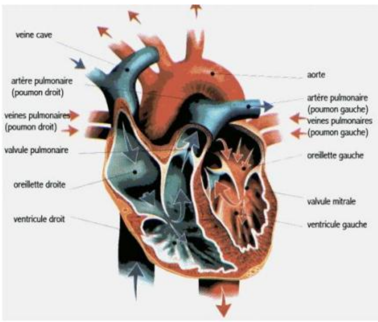


Figure II.7*: The Heart*

The deoxygenated blood arrives at the heart through the superior and inferior vena cava. It enters the right atrium and is then expelled by its contraction called atrial systole, which pushes it into the right ventricle. The ventricular contraction (ventricular systole) propels the blood from the right ventricle to the lungs, where it becomes oxygenated. Upon returning to the heart through the pulmonary veins, the blood accumulates in the left atrium and, during atrial contraction, passes into the left ventricle. During ventricular systole, the blood is sent to the organs through the aorta.

Due to the inherent myogenic nature of the cardiac muscle, rhythmic contractions occur spontaneously and are coordinated by an electrical impulse that stimulates it. In the next paragraph, we will discuss the process of cardiac contraction from an electrical point of view.

II.3.3.3. Cardiac Electrical Activity

The movement of Na+ ions across the cell membranes of cardiac fibers (cell depolarization and repolarization) generates an electrical potential difference that causes the contraction and relaxation, respectively, of the cardiac fiber [12].

In a healthy heart, the depolarization of the cardiac muscle originates in the upper part of the right atrium at the sinoatrial (SA) node (Keith and Flack node). This depolarization occurs autonomously at a rate of 70 to 100 times per minute and spreads through the atria, inducing atrial systole (seeFigure II.7), which is followed by diastole (muscle relaxation). The electrical impulse then reaches the atrioventricular (AV) node after a short pause, allowing blood to enter the ventricles. It then travels through the bundle of His, which consists of two main branches, each branching into a ventricle.
The bundle of His, along with the Purkinje fibers, which have rapid conduction, propagate the electrical impulse to multiple points within the ventricles, enabling almost instantaneous depolarization of the ventricles. This contraction is known as ventricular systole. Following ventricular systole, the ventricles enter ventricular diastole, during which the muscle relaxes. The muscle fibers repolarize, returning to their initial state.

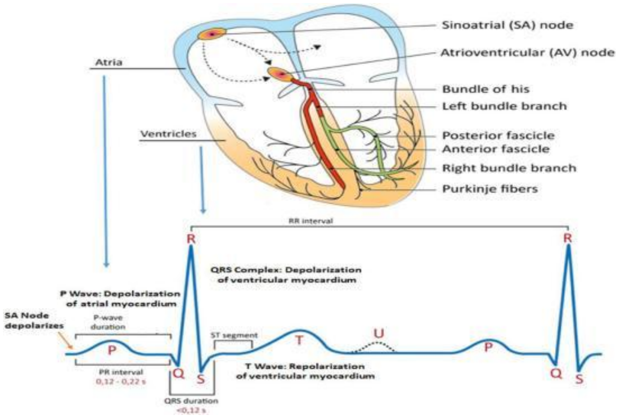


Figure II.7*: Propagation of the Cardiac Stimulus*

II.3.4. Acquisition of the Electrocardiographic Signal

The electrocardiogram (ECG) is the recording obtained through electrocardiography. The acquisition of the electrocardiographic signal is performed using surface electrodes, whose placement on the patient's chest determines the type of lead. The electrode placements on the patient's chest are chosen to explore the entire cardiac electrical field [12,13].

In cardiology, the most commonly performed examination is the 12-lead ECG, where the electrocardiographic signal is visualized in 12 preferred axes:

- 6 axes in the frontal plane, which are:
  - The three bipolar leads I, II, III, known as the Einthoven leads:
    - I: records the electrical potential difference between the right wrist and the left wrist.

- II: records the electrical potential difference between the right wrist and the left leg.
- III: records the electrical potential difference between the left wrist and the left leg.

Additionally, there are the three augmented unipolar leads aVR, aVL, and aVF, known as the Wilson leads:

- aVL (left): placed on the left forearm.
- aVR (right): placed on the right forearm.
- aVF (foot): placed on the left leg.

These 12 leads provide different perspectives and angles for the visualization of the electrical activity of the heart, allowing for a comprehensive assessment of cardiac function and the detection of various abnormalities.

➢ 6 axes in the transverse plane (precordial unipolar leads Vi to V6, known as Kossman leads):
- Vi: 4th right intercostal space, right border of the sternum (parasternal).
- V2: 4th left intercostal space, left border of the sternum (parasternal).
- V3: midway between V2 and V4.
- V4: 5th left intercostal space, on the midclavicular line.
- V5: same horizontal level as V4, anterior axillary line.
- V6: same horizontal level as V4, midaxillary line.

II.3.5. Electrical tracing of the heart

The visualization of the heart's electrical activity for a single heartbeat produces a tracing composed of three successive waves, as shown inFigure II.8 [12,14].

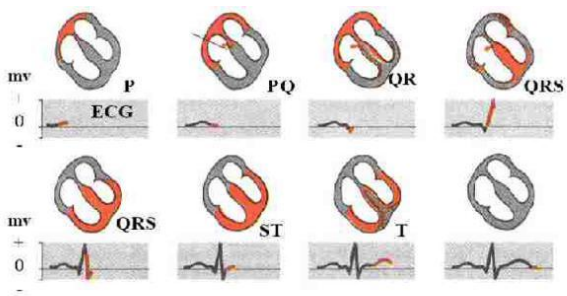


Figure II.8 *The electrical wave of a heartbeat*

□ **The P wave**

During normal sinus rhythm, the depolarization of the atrial myocardium produces a positive wave in leads I and II and a negative wave in aVR. Usually, the P waves are most clearly visible in leads II and VI.

Here are the normal values for P wave parameters:

Duration < 0.11 seconds in lead II.

Amplitude < 0.25 mV (2.5 mm) in lead II.

Orientation in the frontal plane between 0 and +75°.

  The QRS complex

Ventricular depolarization is represented by a polyphasic complex called the QRS complex. The initial negative wave is called the Q wave, and its duration is typically less than 0.04 seconds, with an amplitude rarely exceeding 1 to 2mm. The first positive wave is called the R wave, and the subsequent negative wave is called the S wave.

The T wave

It corresponds to ventricular repolarization. In a normal heart, this wave has a smaller amplitude than the QRS complex and a longer duration.

II.3.6. Temporal Intervals

The analysis of the electrocardiogram includes measuring amplitudes and durations, as well as examining the morphology of the P wave, QRS complex, T wave, PR interval, ST segment, and QT interval. The following normal values, applicable to middle-aged adults, are provided as a reference, but there can be significant overlap between normal and pathological values [12,13,14,15].

 PR Interval

The PR interval, measured from the beginning of the P wave to the beginning of the QRS complex, represents the time of impulse propagation through the atria, atrioventricular node, His bundle, its branches, and the Purkinje network until the start of ventricular activation. The duration of the PR interval ranges from 0.12 to 0.20 seconds depending on the heart rate and age.

 QRS Interval

The duration of this interval represents the time of ventricular depolarization.

 ST Interval

The ST segment is the portion of the trace between the end of the QRS complex and the beginning of the T wave. It corresponds to phase 2, the plateau phase, of the transmembrane action potential. The normal ST segment may be slightly shifted upward at rest or downward during exertion.

 QT Interval

It is the distance between the beginning of the QRS complex and the end of the T wave, encompassing ventricular depolarization and repolarization. The duration of the QT interval varies depending on heart rate, age, and sex.

RR Interval

This interval refers to the time between two successive R waves. The ease of detecting the R wave underscores the importance of this interval, which is used to measure heart rate.

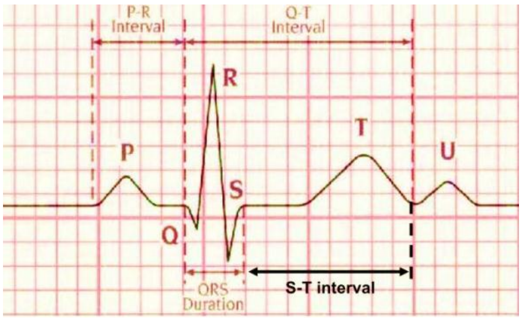


***Figure II.9**. Different Intervals in ECG*

Electrical abnormalities can be the first signs indicating the existence of potentially devastating side effects of certain medications or severe metabolic or electrolyte imbalances.

II.4.The transmission of the biomedical signal

II.4.1 Signal Compression

Signal compression is a technique used to reduce the size or bit rate of a biomedical signal while maintaining its essential information. Biomedical signals and medical images, contain a significant amount of data that can consume storage space and require substantial transmission bandwidth. Signal compression methods aim to efficiently represent these signals using fewer bits, making it easier to store, transmit, and process them.[17]

- **compression using DCT**

The Discrete Cosine Transform (DCT) is a widely used technique for signal compression, particularly in image and video compression algorithms like JPEG. It transforms a signal from the spatial domain to the frequency domain, allowing for the removal of less perceptually significant high-frequency components. The DCT is applied to signal blocks, which are then quantized to reduce precision. The quantized coefficients are encoded and further compressed for efficient storage or transmission. During decompression, the reverse steps are performed to reconstruct the original signal. The level of compression and quality trade-off can be controlled by adjusting parameters such as block size, quantization matrix, and compression algorithms used. Different applications may require different settings to achieve the desired balance between compression ratio and perceived quality[18].

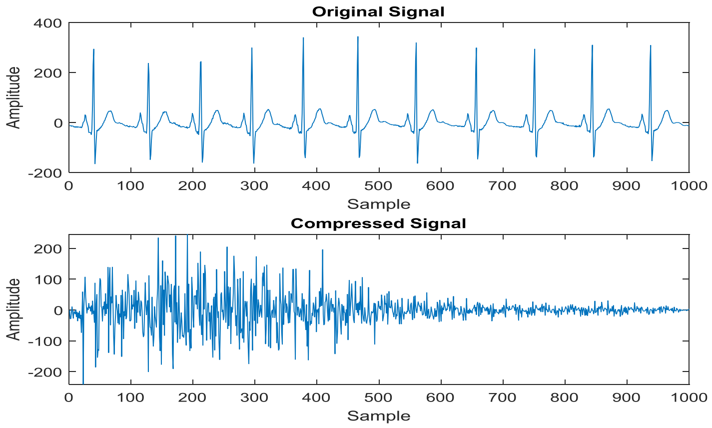


Figure II.10. *The compression of ECG signal using DCT*

II.4.2Analog to digital conversion

The physical world is analog in nature, and the cyber world of Internet is digital. An important bridge between these two domains is the conversion of analog phenomenon as faithfully possible to the digital domain. Analog signals which are continuous-time signals first get converted into a discrete time signal by sampling the signals in the time domain.

The discrete-time signal could then be mapped into a digital signal, which is what the computers understand, by using the process of quantization.

The digital signals obtained could then be subjected to various signal processing operations which could be broadly categorized as digital signal processing (DSP).

wherever it means signal processing, that would be in reference to DSP because that is what happens in the practical world. Figure II.11 shows a sample block diagram of the DSP process.

Figure II.11*.Block diagram of a typical digital signal processing system.*

II.4.2.1. Sampling

Sampling is the initial step in processing biomedical signals, involving the uniform sampling of time-domain signals. The sampling interval should be selected based on the signal's characteristics, with rapidly varying signals requiring a higher sampling rate. The sampling rate should be at least twice the bandwidth of the biomedical signal.

$Fs \geq 2B$

Bandwidth restrictions can be determined based on Table II. 1, which provides the bandwidth of common signals.

Table II.1:the bandwidth of common signals.

signal	B
Geophysical	500 Hz
Biomedical	1 KHz
Mechanical	2 KHz
Speech	4 KHz
Audio	20 KHz

Sampling impacts the frequency spectrum of the signal. Graphical illustrations in both time and frequency domains demonstrate the sampling process and its effect on the signal's spectrum. The time-domain operation involves multiplying the analog signal by a train of equally spaced impulses at a sampling interval of Ts, resulting in a uniformly sampled time-domain signal x(nTs). In the frequency domain, the impulses form another train of impulses with an intersample interval of fs (1/Ts). Convolution in the frequency domain leads to a replicated spectrum of the original signal. Extracting the original signal spectrum requires an ideal low-pass filter.

The consequences of undersampling and oversampling are shown in figure II.12 . Undersampling with fs < 2B leads to aliasing and spectral overlapping, while oversampling with fs > 2B provides a good spread in the frequency domain without aliasing.

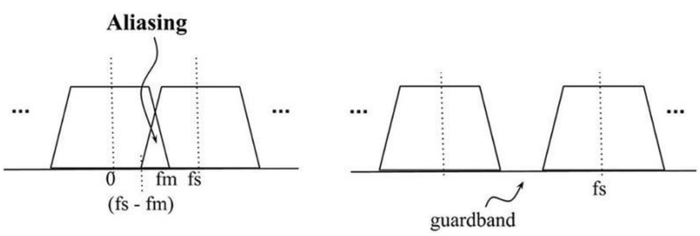


Figure II.12. *Illustration of undersampled and oversampled signal spectra.*

II.4.2.2 Quantization

Quantization involves converting the time-sampled discrete signal into fixed amplitude levels to qualify as a digital signal. Quantization introduces quantization error or noise, which is the difference between the original signal and the digitized version.
Graphical illustrations in figure II.13 depict the quantization process, where the signal's amplitude range is uniformly quantized into L levels. The quantization error exhibits random behavior and can be represented using statistical variables. The power of the quantization error is obtained by computing the second-order statistics of variance. The signal power can also be calculated.

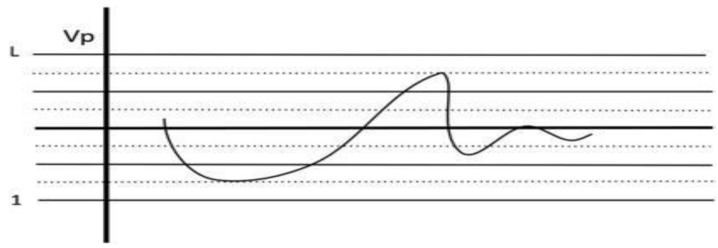


Figure II.13. *Graphical illustration of the quantization process.*

The signal-to-quantization noise ratio (SNR) is an important figure of merit in analog-to-digital conversion. Increasing the number of quantization levels improves the SNR. Each increase in bit size leads to a 6 dB increase in SNR.

$$SNR = \frac{Signal\ power}{Quantization\ Noise\ Power} \quad (I.1)$$

Figure II.14 provides an example of sampling a continuous-time signal with a sampling frequency and quantization levels, demonstrating the calculation of the bit rate for bandwidth and storage requirements.

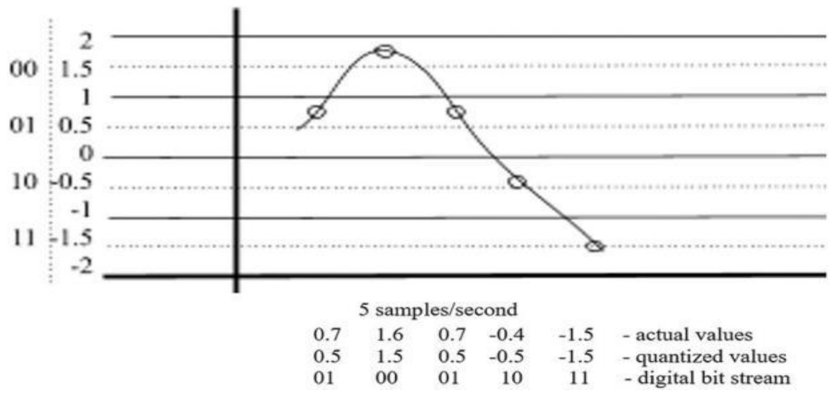


Figure II.14. A simple example showing analog signal to digital bit stream conversion (sampling and quantization processes).

Different extensions of quantization, such as nonuniform quantization and vector quantization, exist beyond uniform scalar quantization. Biomedical signals are typically quantized within a range of 8 to 16 bits/sample, which may need optimization based on bandwidth and storage limitations in a connected healthcare system.

II.5.Data and Software Tools

There are numerous public databases that provide ECG signals, allowing for testing and comparison of processing algorithms. In this course, we will focus on one of these databases, which is a general database of physiological signals called Physionet.

II.5.1Physionet Database

The data used in this course is obtained from the online platform Physionet [19] at

https://physionet.org/.

PhysioNet is a research resource for complex physiological signals, established in 1999 by the National Institute of Health (NIH). PhysioNet's mission is to conduct and catalyze biomedical research and education activities by providing free access to extensive collections of physiological and clinical data and related open-source software. In collaboration with the annual Computing in Cardiology conference, PhysioNet also organizes an annual series of challenges focused on unresolved problems in basic and clinical sciences research.

The PhysioNet platform is managed by members of the MIT Computational Physiology Laboratory.

II.6. Conclusion

In this chapter, we have presented few important medical data necessary to control and supervision the healthcare of patients.
We have explained espacialy the details of ECG signals as well as the procedures for their acquisition. Moreover, the Discrete Cosine Transform (DCT) technique of compression was briefly presented, the compressed ECG signal is also presented. It can be used during transmission ECG signal including sampling and quantization. Further exploration of advanced topics like nonuniform sampling, multirate sampling, and compressive sampling can enhance signal processing capabilities.

Chapter III
Implementation of VLC Medical Health Care information System

III.1 Introduction

In the last few years , the scope of wireless communication in the medical field is increasing. There are numerous devices that operate on Wi-Fi, such as infusion pumps, ventilators, and anesthesia machines. When a doctor is supposed to use both magnetic resonance imaging scanners and Wi-Fi-operated infusion pumps, a frequency problem arises. In fact, the use of new wireless medical devices increases the use of radiofrequency (RF) spectrum, leading to electromagnetic interference (EMI) and potentially dangerous events related to medical equipment operations
Another limitation of Wi-Fi in the hospital system is that patient information needs to be private and secure while remaining accessible to authorized individuals. Hospitals are places where sensitivity to EMI and the security of medical details are issues with the use of Wi-Fi. To address the aforementioned limitations in the healthcare monitoring system, Visible Light Communication (VLC) is used. VLC is a new technology for high-density wireless data coverage that alleviates radio interference in confined areas.

After discussing the characteristics of visible light communication in the previous chapter, the design of such a system will be studied in this chapter. The goal of this project is to create a communication device to facilitate real-time and efficient data exchange between an ECG medical device and another device (such as a smartphone or PC) for monitoring and controlling a patient's health in a hospital. The mode of communication used in the experiments is simplex based on the visible light, allowing a person to transmit and receive data without altering the design of their system.

III.2 Design of VLC based health care information system

Digital transmission systems convey information between the transmitter and the receiver through a medium such as cables, fiber optics, electromagnetic waves, etc. ForVLC/ Li-Fi communication, the transmission medium is light.

The block diagram of a basic digital transmission system is depicted in Figure III.1
The transmitter consists of a source that generates the message to be transmitted. This message is then encoded and modulated to enable its transmission through the channel. At the receiving end, the signal is demodulated and decoded to be deciphered by the recipient.

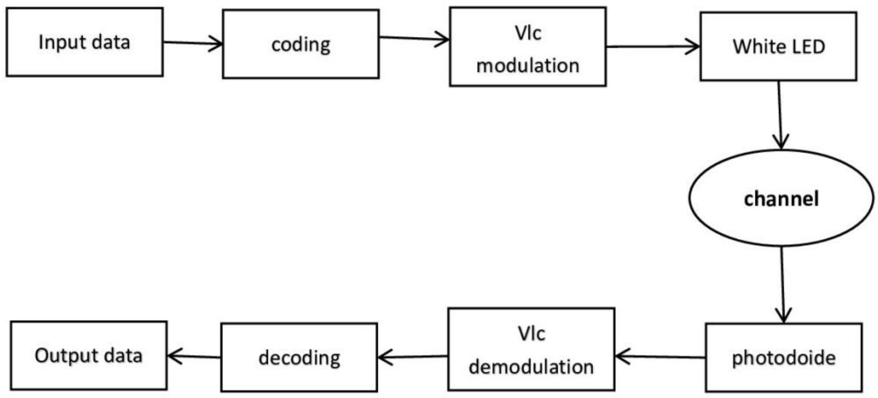


Figure III.1.*Block diagram of a digital transmission system.*

III.3Material , Equipment and programming language

In this section, we will present the hardware, equipment, and programming languages used during the experimentation process of the medical health care information system.

III.3.1 Microcontroller (Arduino Board)

The UNO model from the ARDUINO company is an electronic board whose core is a microcontroller with the reference ATMega328. The ATMega328 is an 8-bit microcontroller from the AVR family, and its programming can be done in the C/C++ language...

We used the Arduino UNO Microcontroller Board (Figure III.2) as the transmitting and receiving module in our system .

Figure III.2*. Arduino UNO board*

III.3.2 LED Module 3W

An electroluminescent diode (LED) is a semiconductor light source with two conductors. It is a PN junction diode that emits light when activated
A high-power LED Module 3W was used for the emission (Figure III.3).

Figure III.3. *LED Module 3W*

The specifications of the used LED Module 3W are as follows:
- Color temperature: warm white 3000-3200K / white 6000-6500K
- Forward current: 700MA
- Luminous flux: White 180-200LM (lumens)
- Forward voltage: 3.3 - 3.6 V
- Reverse voltage: 5V
- Power: 3W
- Viewing angle: 180°

III.3.3 Photodetectors

A photodetector (or photosensitive detector or optical detector or light detector) is a device that converts the light it absorbs into a measurable quantity, usually an electric current or voltage . The most commonly used photodetectors for capturing light are photoresistors, photodiodes, and phototransistors.

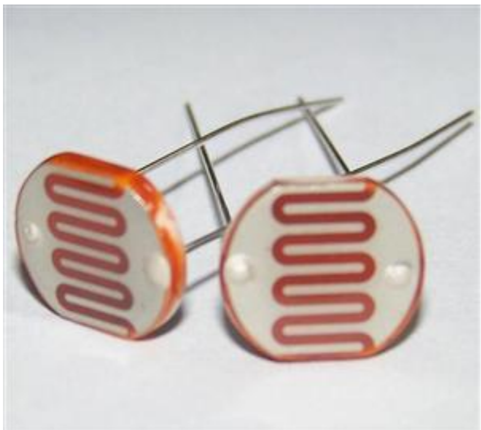


Figure III.4. *photoresistors*

III.3.3.1 Photovoltaic cells

Photovoltaic cells, employed as receiver devices in Visible Light Communication (VLC), play a vital role in converting absorbed light into electrical signals. These cells utilize the energy from photons to excite electrons within the semiconductor material, resulting in the separation of electron-hole pairs. Guided by an internal electric field, the separated charges generate an electric current that varies in response to the modulated light signal. By detecting and processing these current variations, the transmitted data encoded within the visible light signal can be successfully retrieved. The utilization of photovoltaic cells in VLC enables efficient and sustainable communication systems leveraging visible light as a medium for data transmission.[1]

Figure III.5.*Photovoltaic cells*

III.3.4. Equipment Installation

The implemented system (Figure III.6) consists of:
-A transmitter module (Tx),
-A receiver module (Rx), and
- Two user interfaces (two microcomputers).

The transmitter module consists of 3W LED connected to an Arduino board, while the receiver module consists of photovoltaic cells connected to another Arduino board. Both modules are connected to the user interfaces via USB cables.

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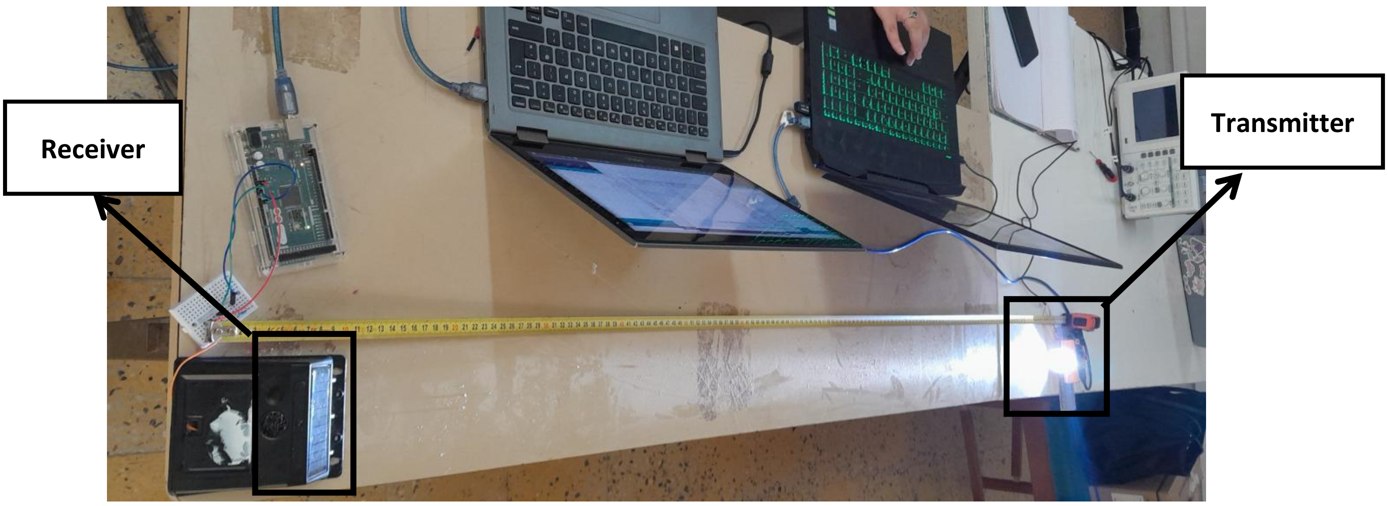

Figure III.6. *VLC Medecial Healthcare information system implementation*

III.3.4.1 Arduino Language (Arduino, C, C++ ...)

The Arduino board is a microcontroller, which is a type of mini-computer that serves as an interface between the environment (actions, measurements of quantities, etc.) and a user. It is programmed natively in a language derived from C called "Arduino Language." The Arduino Language is very similar to C and C++. In the case of figure III.6, we have used the Arduino Language to program both the transmitter and receiver, which are microcontroller boards of the Arduino type.

III.3.4.2 MATLAB Language

Matlab laboratory is a high-level programming language and environment widely used in various fields, including engineering, mathematics, and scientific research. It provides a comprehensive set of tools for numerical computation, data analysis, visualization, and algorithm development. Matlab has a user-friendly syntax and offers a wide range of built-in functions and libraries that simplify complex mathematical operations and facilitate efficient data processing. With its powerful capabilities in linear algebra, signal processing, image and video processing, machine learning, and more, Matlab is a popular choice for academic and industrial applications in scientific computing and data analysis.[2]

III.3.4.3 Arduino/MATLAB Serial Communication

Sometimes, it is necessary to send data in both directions between a computer and an Arduino. Serial communication provides a simple and flexible way to establish communication between an Arduino and a computer or other devices. By connecting the Arduino's serial port to the computer, we can send and receive data using this functionality. It allows for the exchange of data between the Arduino and the computer, enabling seamless communication and data transfer in both directions.

III.3.4.3.a1 Reading Data from Arduino

The Arduino board allows for acquiring an analog signal through a sensor and converting it into a digital signal using its 10-bit Analog-to-Digital Converter (ADC). These data can then be transferred via the serial port to a computer for digital processing using MATLAB.

In essence, we utilize the Arduino programming interface to write a small program that instructs the board on how to perform the acquisition (which is later uploaded to the board through the serial port). We can then retrieve the data through the serial port for further analysis using MATLAB.

III.3.4.3.b Sending Data to Arduino

At the user interface level, with the help of MATLAB, we conduct different encoding process of data, performances analyses and evaluation, data compression. Then, the medical data will be sent from the computer to the Arduino using the serial port. Arduino programming interface is used to write a small program that guides the board on how to manipulate its outputs based on the received data if text or a function of serial medical data

III.3.4.3.c Serial Module

The Serial module in MATLAB facilitates communication with Arduino boards through the serial port. by connecting the Arduino board to the computer, and initializing the serial port in MATLAB using the `s = serialport(port,baudrate)` function, data can be easily sent and received between the two platforms.
This module provides a convenient and efficient way to interact with Arduino boards from MATLAB, enabling seamless data transfer and control.

III.4 System design and transmission protocol

III.4.1 System Design

III.4.1.1 Transmitter Design

The transmitter side of the VLC/Li-Fi system consists of LEDs for transmitting binary data. The transmitter circuit is illustrated in Figure III.7

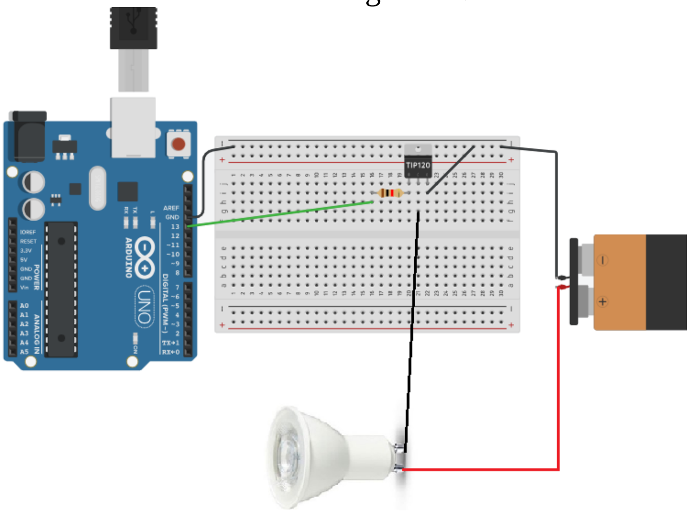

Figure III.7. *Transmitter schema*

III.4.1.2 Receiver Design

The receiver side of this system is composed of photovoltaic cells for receiving binary data. The receiver circuit is illustrated in Figure III.8

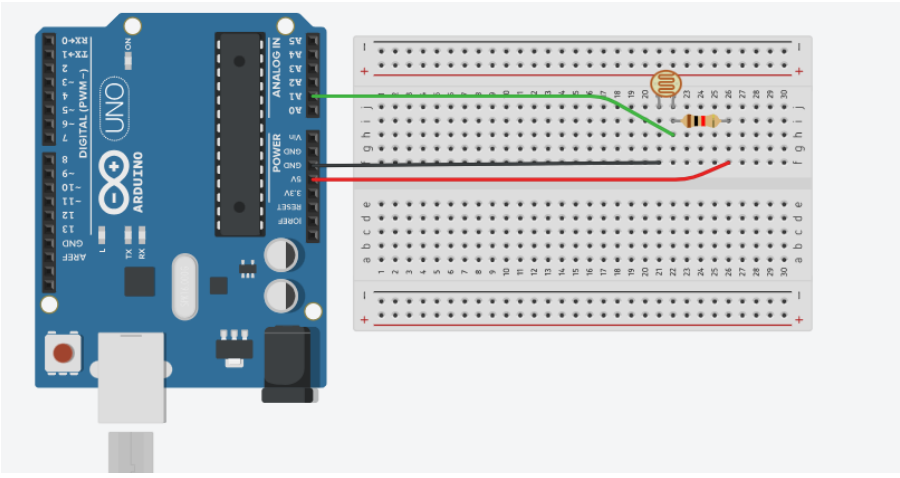

Figure III.8. *Receiver schema*

III.4.2 Data Transmission and Synchronization

III.4.2.1 Data Transmission

Arduino transmits binary data by manipulating the LED (an illuminated LED represents '1' and a non-illuminated LED represents '0'). This custom-designed encoding method is the protocol used to transmit a bit in a single channel. The simplest and naive solution, without considering error correction or other interferences, is to turn on the LED for a duration of t seconds to represent '1', and turn off the LED for a duration of t seconds to represent '0'. For example, if the raw binary data is 100110111100, the LED illumination and extinction diagram is illustrated in Figure III.9.

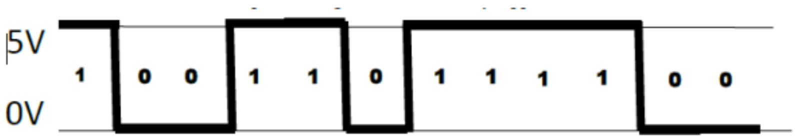

Figure III.9. *LED Illumination and Extinction Diagram*

III.5.2.2 Data synchronization between emitter and receptor

Before starting sending medical data, it's important to identify the level of the bits '1' and '0' corresponding to the received light intensity depending on the environment and especially on ambient light and considering also problem of light fading over time and distance.

Hence, when setting up the receiver in a new environment for a project, it's important to recalibrate the separating threshold corresponding to the bit '1' and bit'o' .

In the project, we have considered that the threshold will represent the average peak voltages (equation 3.1) computed over the received data .

In this project, the threshold is computed using an Arduino program. The Arduino compares the received voltage difference with the threshold value. If the received voltage is higher than the threshold, it's considered a high peak (bit '1'), and if it's lower, it's considered a low peak (bit '0'). By doing this, the Arduino converts the analog data from the received signal into digital data. This process allows the receiver to detect variations in ambient light and convert them into digital information for further processing in the project.

For an automatic and adaptive detection of threshold, the algorithm consists of:

Sending a fixed size sequence of pilot bits each fixed number (N) of sending trams . Then, the threshold is fixed and updated each (N) sending trames.

Calculation of a separation threshold

. On reception side, the maximum value and the minimum value of the received levels are sought. The threshold is then computed according to the following formula:

$$\text{Threshold} = \frac{\text{Maximum Value} + \text{Minimum Value}}{2} \qquad \text{(III.1)}$$

$$\text{Bit} = \begin{cases} 1 \; if\ the\ received\ value \geq Threshold \\ 0 \; if\ the\ received\ value < Threshold \end{cases} \qquad \text{(III.1)}$$

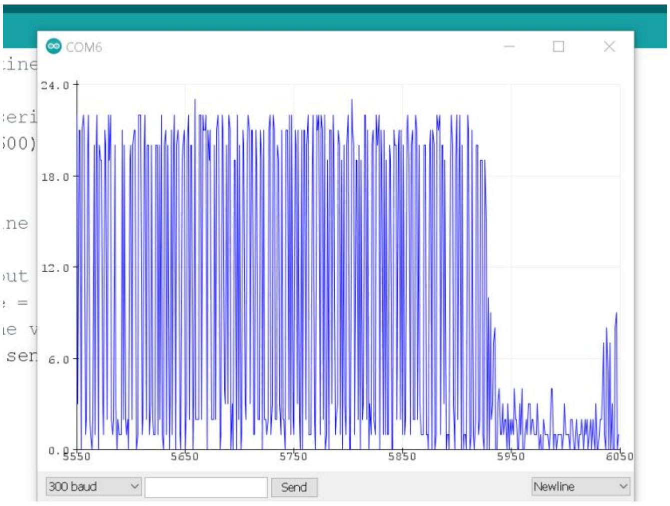

Figure III.10. *Received voltage reading from Arduino*

III.4.3 Manchester encoding

The source encoding in our experience is Manchester encoding. In this encoding, bit 0 is presented by a rising edge and bit 1 is a falling edge. In this case, permanent transitions are created, this will avoid detection errors. However, the frequency of the encoded signal is double of that of the source signal. [3]

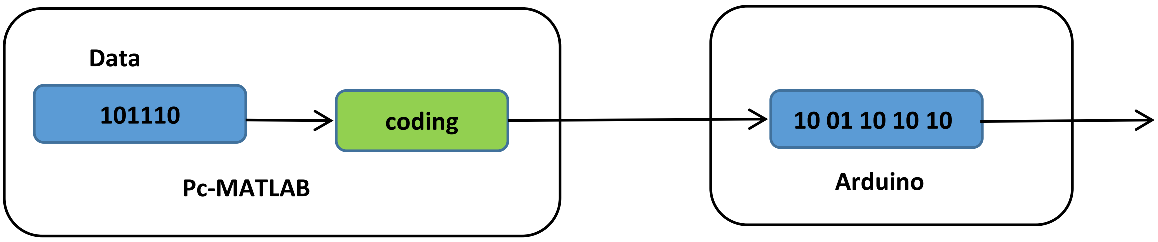

Figure III.11: *Application of Manchester coding*

III.4.4. Transmission Protocol:

Global organigram :

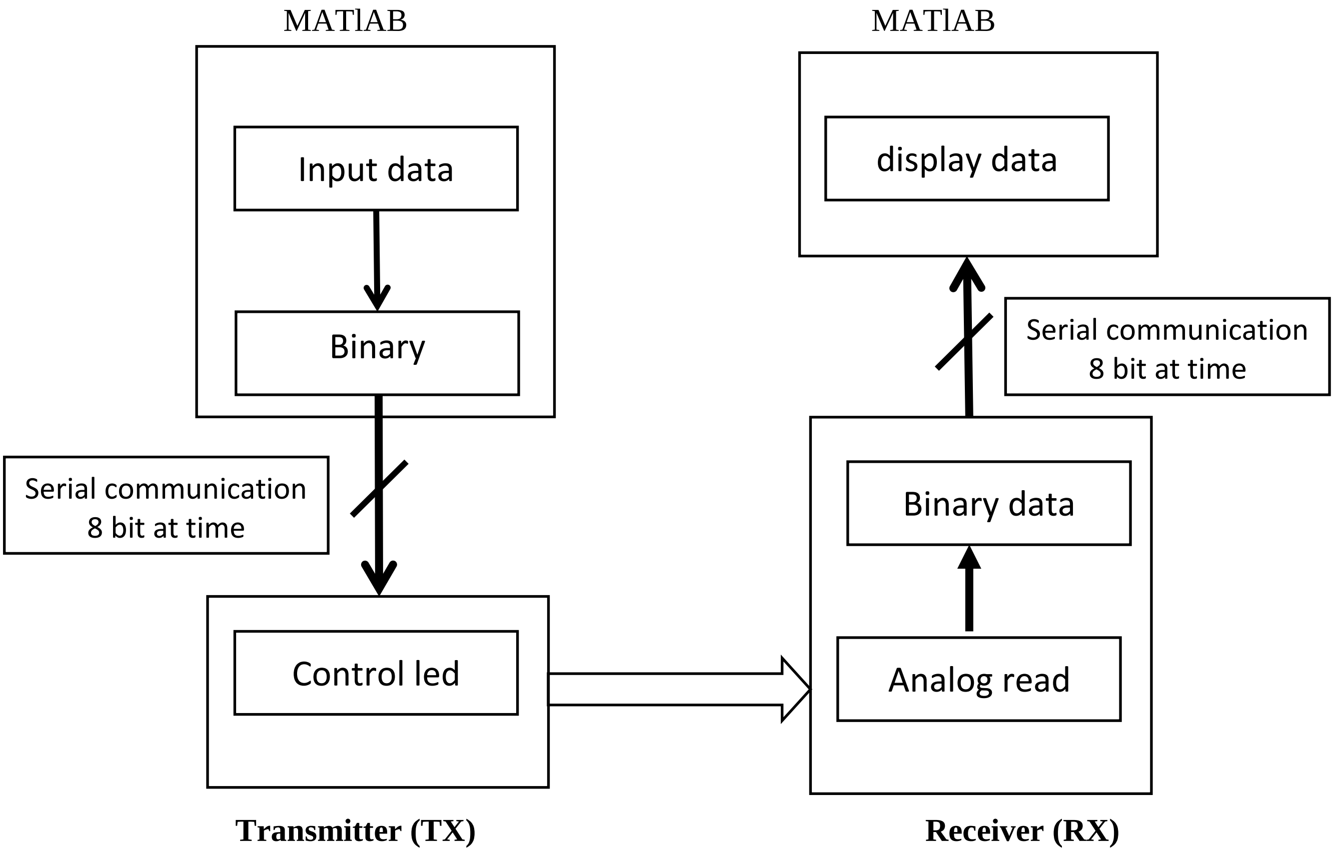

Figure III.12. *Algorithm for transmitting/receiving via visible light*

Transmitter organigrame

Matlab organigram

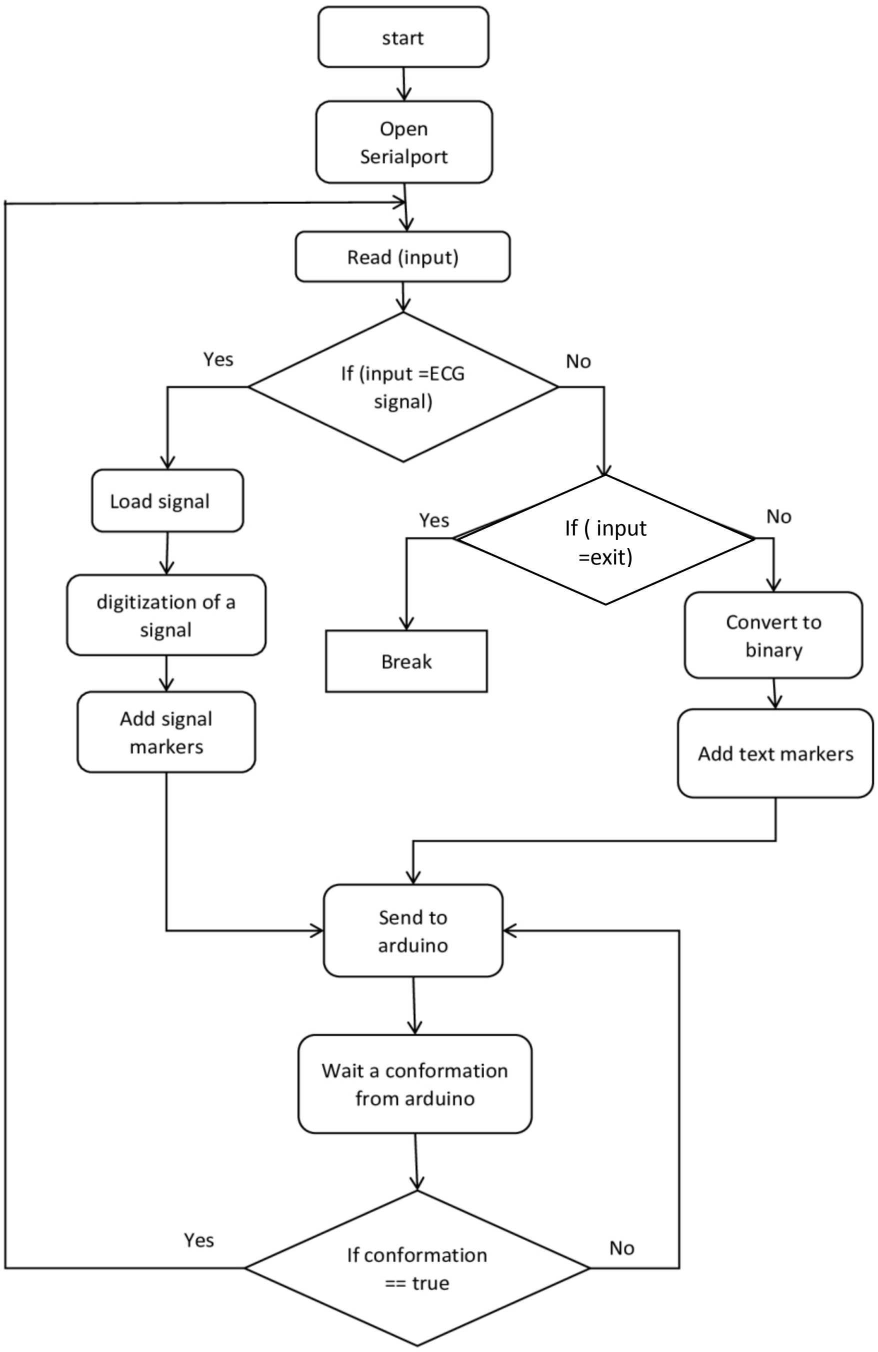

Figure III.13. Algorithm for transmittingtext and signal via visible light in MATLAB

Arduino organigram

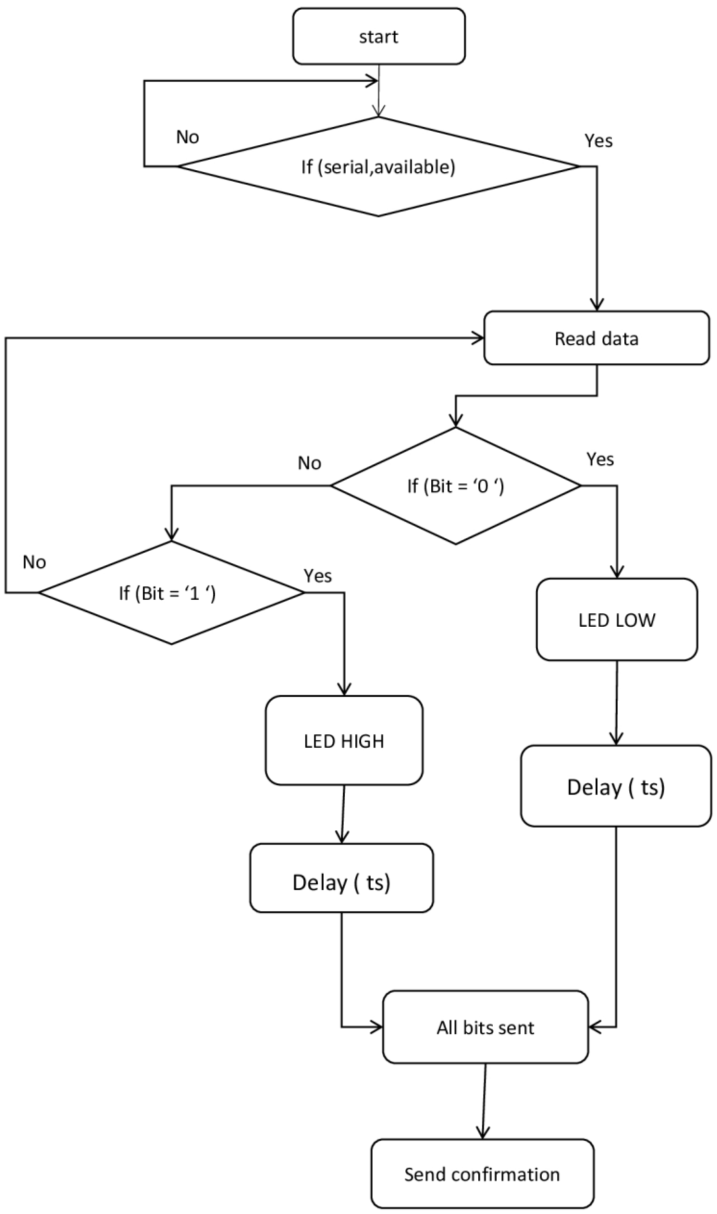

Figure III.14. Algorithm for transmittingtext and signal via visible light in Arduino

Receiver organigram

Arduino organigram

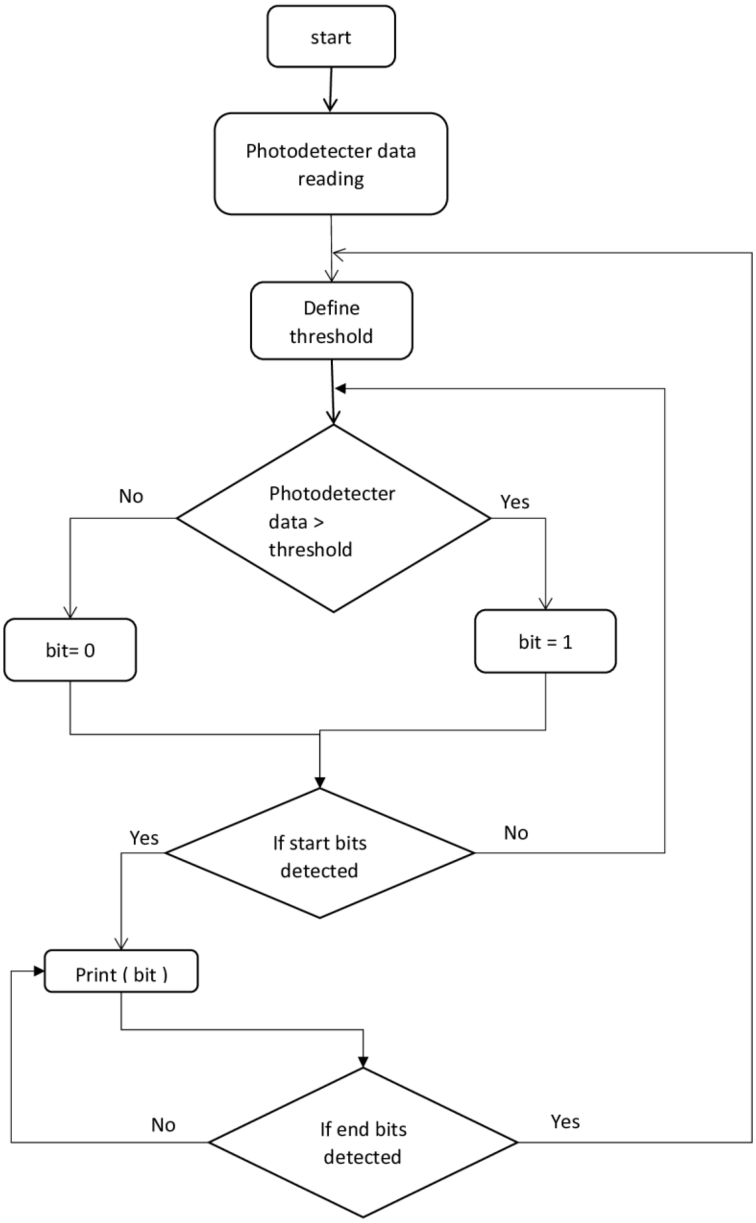

Figure III.15. Algorithm for Receiver via visible light in Arduino

Matlab program :

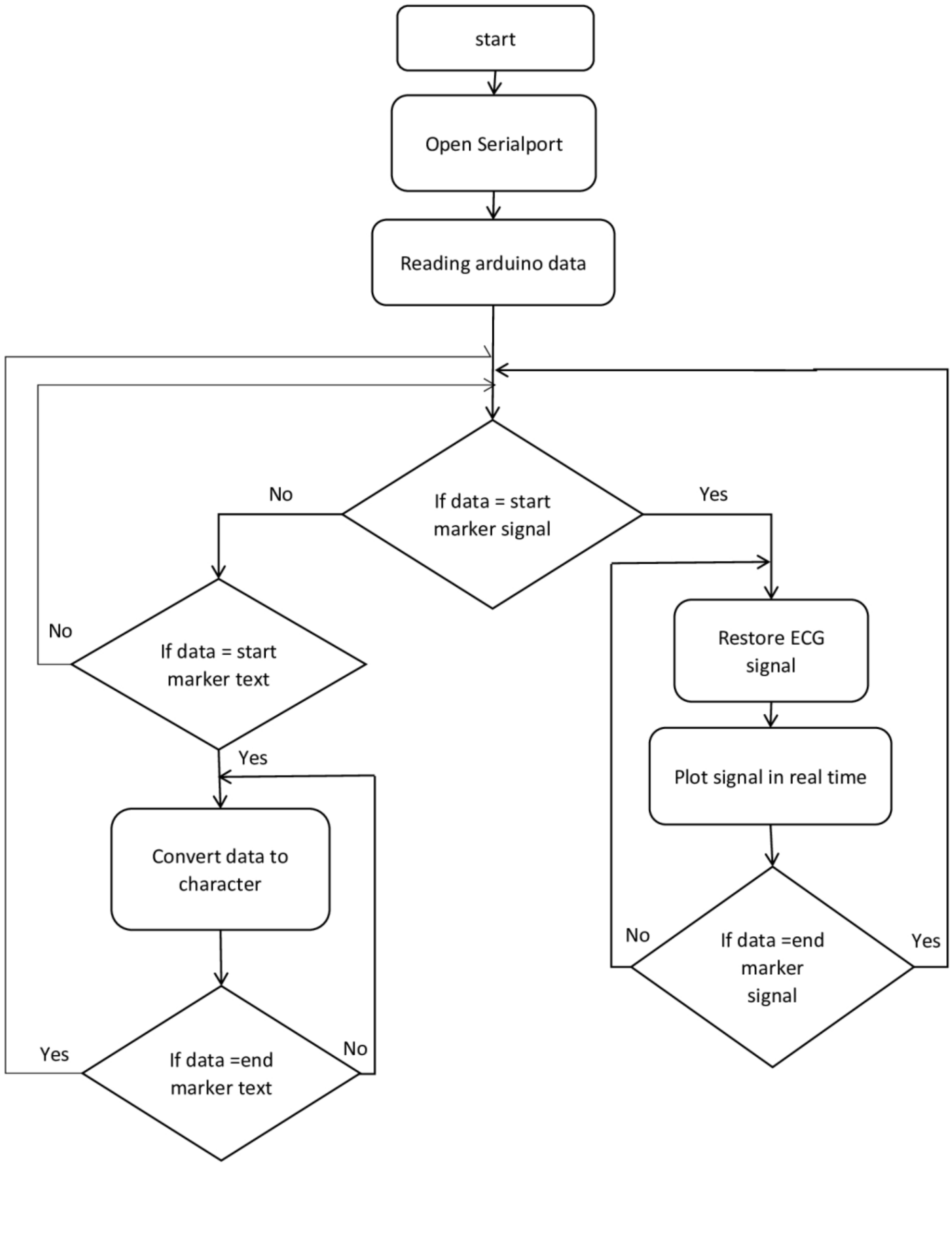

Figure III.16: *Algorithm for Receiver text and signal via visible light in Matlab*

III.5. Performance analyses of the proposed VLC system

III.5.1. Variation in Data Rate

Before starting the health care information VLC tranmission, we have started by compuing the bit rate according to the equipements used in the experimentation.

Firstly, we have fixed one meter as spearting distance between the Transmitter (Tx) and the Receiver (Rx) both on line of sight. Then, we have sent 816 random bits. As shown if table III.1, we have consider 3 delay time during sending binary data.

Based on the obtained results, we can confidently assert that the data transmission speed of 8,13061 b/s achieved by this system represents the maximum rate for ensuring flawless and fault-free data transmission. Consequently, we performed a calculation of the bit error rate to provide additional evidence supporting our conclusion.

Unfortunately, according to the obtained results, we can oberve that the equipments such as the Arduino and different sending and receiving data sensors influence the quality of tranmisssion. In fact, the VLC system are generally used for High speed data transmission.

Table III.1: Transmission Test Results

.

Delay time	Time	BER	Bit rate
50ms	67.653424 s	0.42	12,06147 b/s
70ms	87.476314 s	0.17	9,3282 b/s
100ms	100.361453 s	0	8,13061 b/s

Testing Signal Transmission in the 3 different delay time :

The ECG signal utilized in our transmission was obtained from an individual with a typical cardiac profile. This signal was recorded for a period of 5 seconds to capture relevant data.

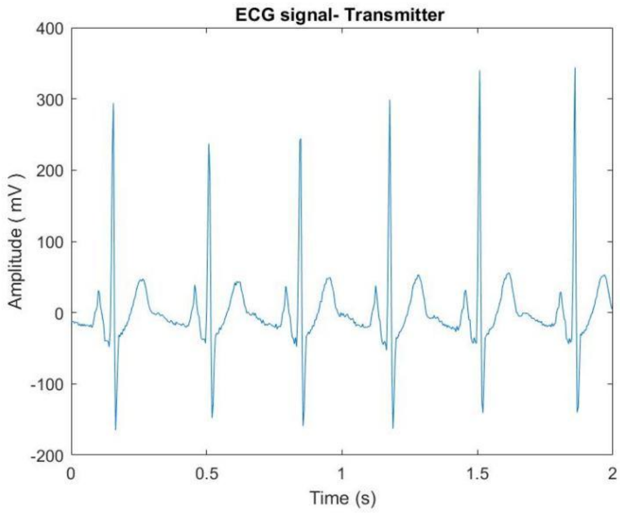

Figure III.17:*The ECG sending signal*

- Delay time = 50 milliseconds

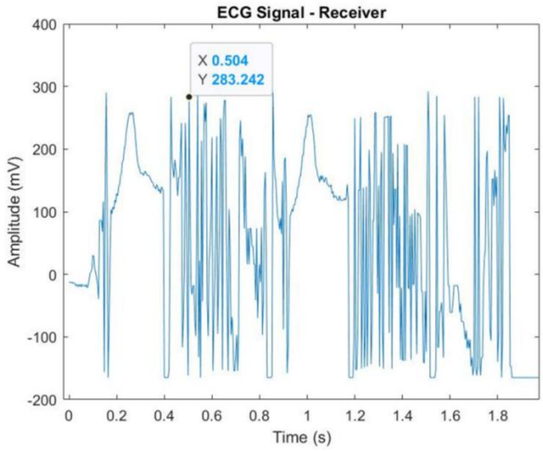

Figure III.18: *ECG Received signal (50ms)*

- Delay time = 70 milliseconds

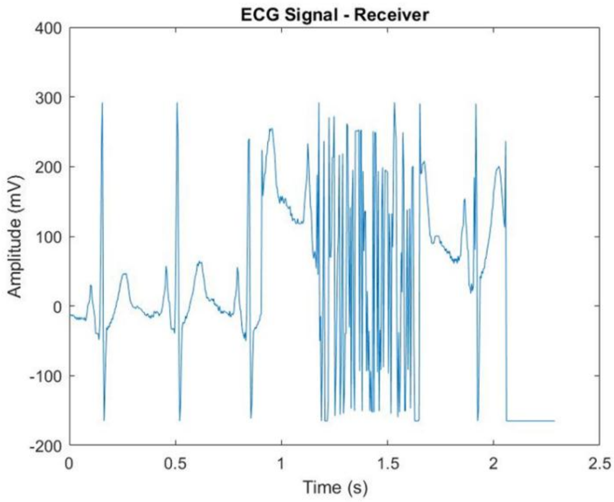

Figure III.19:*ECG Received signal (70ms)*

- Delay time = 100 milliseconds

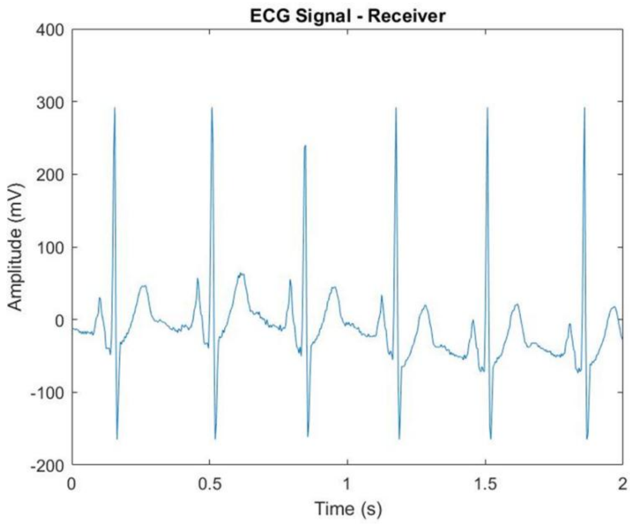

Figure III.20:*The received signal (100ms)*

III.5.2 Text Transmission

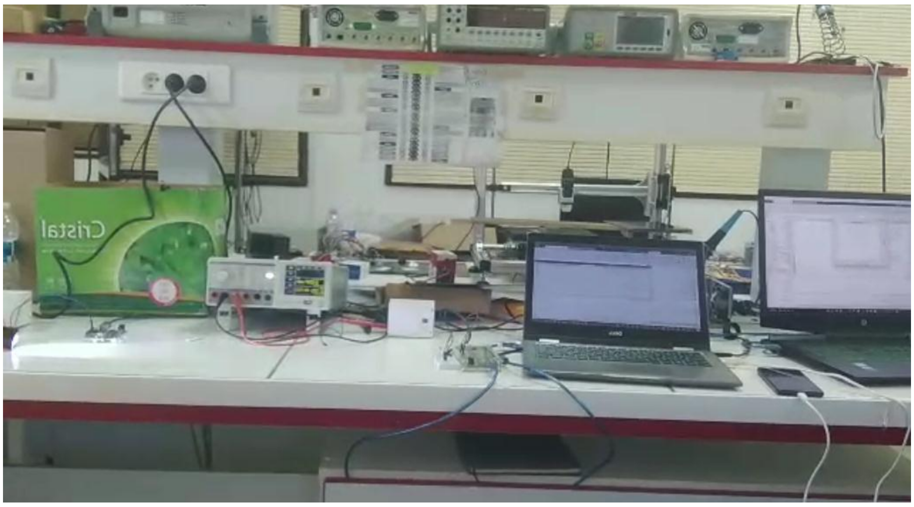

Figure III.21. *Implementation of textS transmission system using visible light.*

When transmitting the text for exemple "**university of mostaganem**" over a distance of 1 meter between the transmitter and receiver, with a bit rate of 8,13061 b/s, the program converts it to binary using ASCII code. This means that each character is represented by 8 bits, resulting in a binary data length of 192 bits. To ensure synchronization and define the content of the binary data, a header of 16 bits and a trailer of 16 bits are added. As a result, the total length of the binary data, including the header and trailer, is 224 bits.

The transmitter requires 23.865228 seconds to send all the bits to the receiver, waiting for confirmation from the Arduino that it has finished processing all the bits. On the other hand, the receiver takes 27.910169 seconds to receive the bits and write the text. The time between the transmitter and receiver, also known as the delay or latency, is 4.044941 seconds.

The delay between the transmitter and receiver, amounting to 4.044941 seconds, is primarily due to the execution of programs and processes involved in transmitting and receiving data. The transmitter takes 23.865228 seconds to convert text to binary, add headers and trailers, send data to Arduino, and await confirmation of processing completion. The receiver requires 27.910169 seconds to receive the bits, retrieve them from Arduino, decode them into text, and perform any necessary processing before generating the final output. This delay encompasses the time required for program executions, indicating the complexity and efficiency of the transmitter and receiver systems.

III.5.2.2 Manchster encoding

In this scenario, the text "**university of mostaganem**" is being sent again, but this time it is encoded using Manchester encoding. Manchester encoding represents '0' as '10' and '1' as '01', resulting in an increased length of the binary data to 384 bits. After adding the header and trailer, the total length of the encoded data becomes 416 bits.

The transmission time for sending this encoded data is 43.61 seconds. This duration includes the time taken for the transmitter to encode the data, add the header and trailer, send the bits to the receiver, receive the data at the receiver's end, decode it, and remove the header and trailer. Additionally, it also takes into account any processing and latency involved in the communication system.

Therefore, in this case, the use of Manchester encoding leads to an increased length of the binary data, resulting in a longer transmission time of 43.61 seconds.

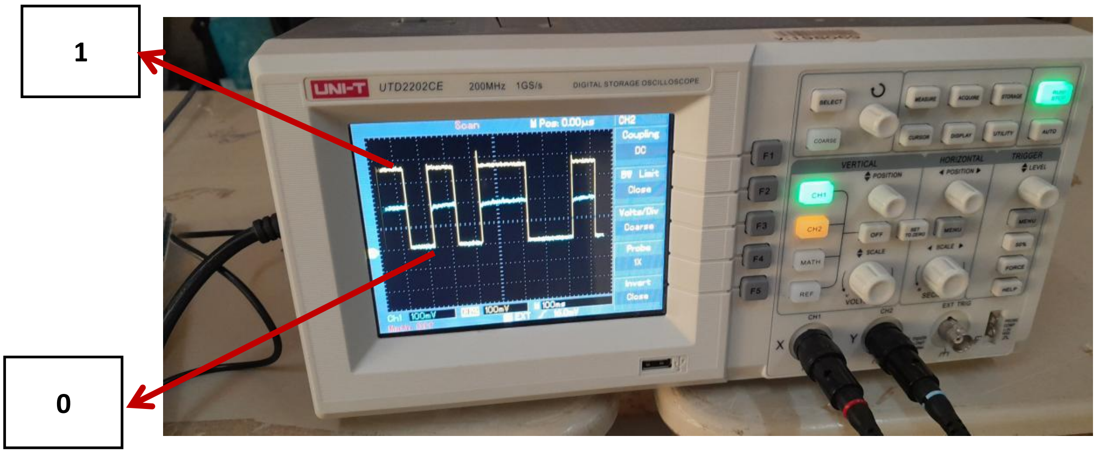

Figure III.22 *Oscilloscope visualization of the emitted signal after Manchester encoding and the received signalfrom the photodetector.*

Table III.2: Performance of the text transmission system via visible light in detected erros.

Word	Emission code	The received code	Detected Errors
hello	10010110011010101001011010 0110 011001011001011010100101100101 10101001011001010101	100101100110101010010110100110 011001011001011010100101100101 10101001011001010101	0
university of mostaganem	100101011001100110010110010101 101001011001101001100101011001 011010010110100110011001010110 100110100101011010010110010110 0110100110010101	100101011001100110010110010101 101001011001101001100101011001 011010010110100110011001010110 100110100101011010010110010110 0110100110010101	0
Vital signs	100110011001011010010110011010 011001010110011010100101101010 100110010110010110101010011010 101010100101011010010110010110 011010011001011010010101100101 10010101101001010110100101 ...	100110011001011010010110011010 011001010110011010100101101010 100110010110010110101010011010 101010100101011010010110010110 011010011001011010010101100101 10010101101001010110100101 ...	0
Body Temperature: 37°C	100110101010011010010110010101 011001011010011010100101010110 100110100110101010101001100110 011010100101101001100110010110 11010101010011010101 00101	100110101010011010010110010101 011001011010011010100101010110 100110100110101010101001100110 011010100101101001100110010110 1101010101001101010100101 ...	0
Heart Rate : 80	100110100110101010010110100110 011001011010101001100101011010 011010010101100110101010011010 101010100110011010011010010110 101010011001010110011010100101 101001100110100110101010101010 010101100110101001101010101010 1001010110101010100101101010 10. ..	100110100110101010010110100110 011001011010101001100101011010 011010010101100110101010011010 101010100110011010011010010110 101010011001010110011010100101 101001100110100110101010101010 010101100110101001101010101010 100101011010101010010110101010. ...	0
Arterial tension 120/80 : systolic =120 diastolic =80	100110101010100110010101101001 101001010110011010100101101001 100110010101101001101001011001 101001100101101010100110010110 010110101010011010101010100101 011001101010010110100110011001 011001010110100101011010010110 010110011010011001011001010101 100101100101011010100110101010 10101001011010 1001...	100110101010100110010101101001 101001010110011010100101101001 100110010101101001101001011001 101001100101101010100110010110 010110101010011010101010100101 011001101010010110100110011001 011001010110100101011010010110 010110011010011001011001010101 100101100101011010100110101010 101010010110101001...	0

III.5.3 VLC Transmission over distance

In this part, the ECG signal is sending over different distances with a bit rate of 8,13061 b/s. The BER is sumerzed in the following table

Table III.3. BER over distance

distance	**BER**
1.5m	0
2m	0
3m	0.036

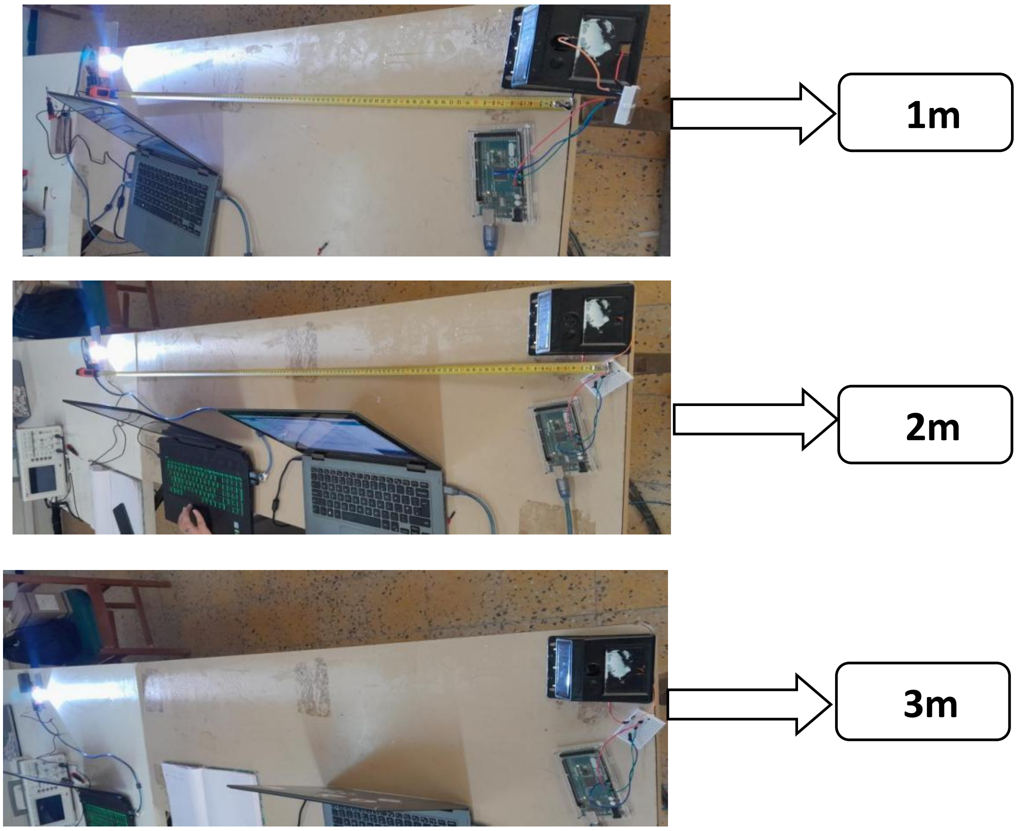

Figure III.23: *Variation of distance*

III.5.4 .Calculate the SNR :

SNR (Signal-to-Noise Ratio) is a measure of the signal strength relative to the background noise in a communication system. In this experiment, we calculate the SNR in two different conditions:

1) in the presence of natural light ambient, and
2) in the presence of interference from a high-power LED.

III.5.4.1 . in the presence of natural light ambient :

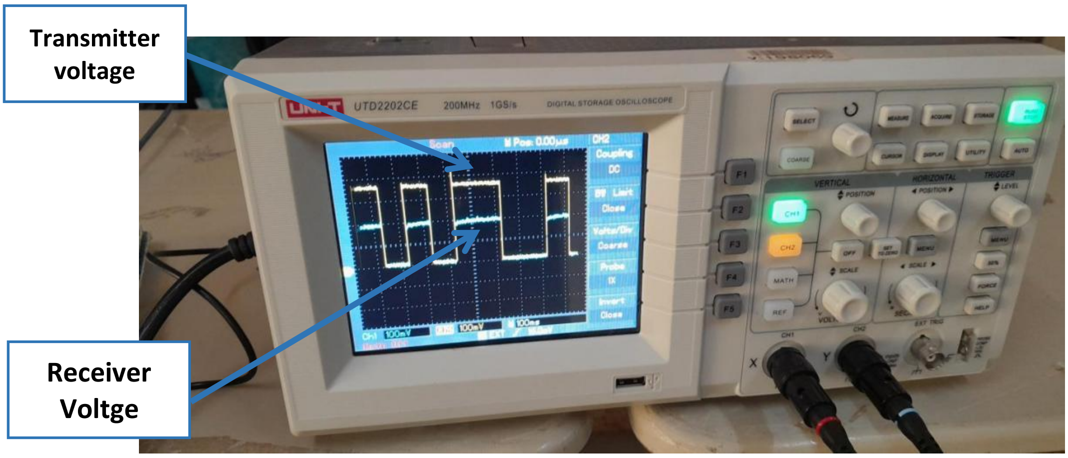

Figure III.24: Oscilloscope visualization in natural light ambient

In the presence of natural light ambient, the SNR (Signal-to-Noise Ratio) is calculated using the formula **SNR =** $\mathbf{20\log(\frac{Vt}{Vn})}$ **(III.3)**
where **Vt** represents the voltage of the signal and **Vn** represents the voltage of the noise.
In this case, the calculation is as follows:

SNR = 8.6024dB (III.4)

This result of 8.6024 dB indicates the ratio of the signal power to the noise power in the presence of natural light ambient. A higher SNR value indicates a stronger signal relative to the background noise, which is desirable for reliable communication.

III.5.4.2 .In the presence of interference from a high-power LED

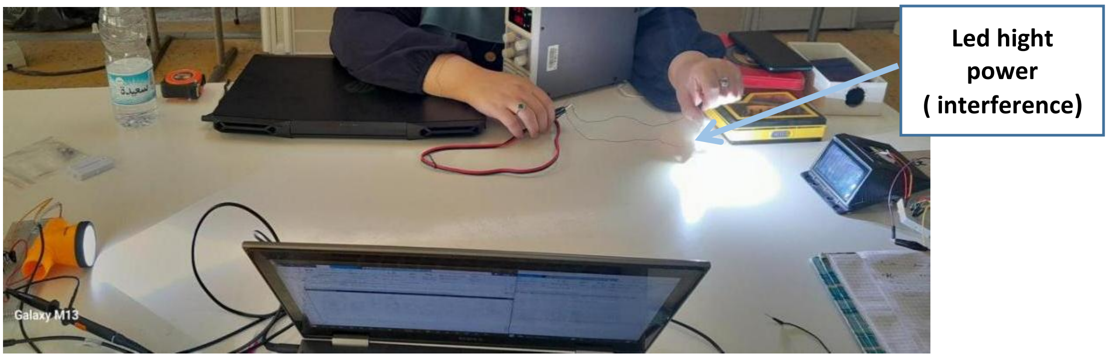

Figure III.25:*the presence of interference from a high-power LED*

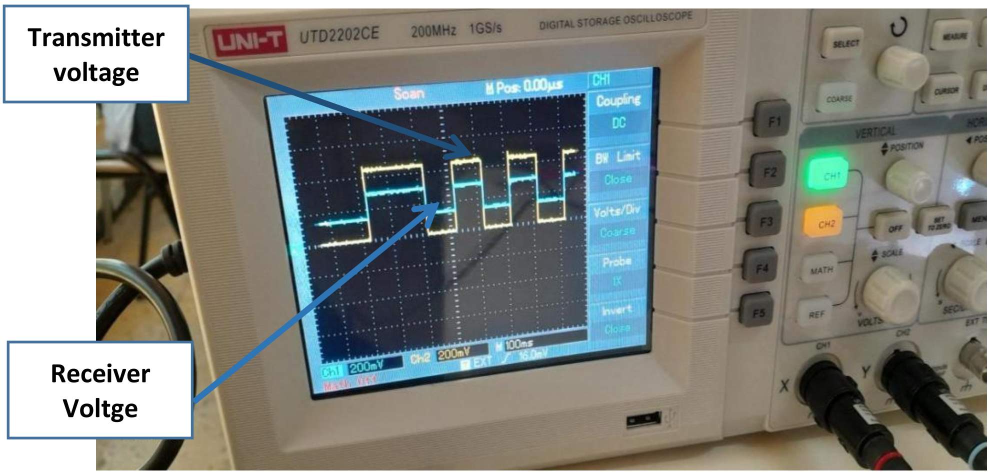

Figure III.26: Oscilloscope visualization in the presence of interference

In the presence of interference from a high-power LED, the SNR (Signal-to-Noise Ratio) is calculated using the formula

$$\mathbf{SNR} = 20\log\left(\frac{Vt}{Vn}\right) \qquad \textbf{(III.5)}$$

where Vt represents the voltage of the signal and Vn represents the voltage of the noise.

In this case, the calculation is as follows:

$$\mathbf{SNR = 2.922dB} \qquad \textbf{(III.6)}$$

The result of 2.922 dB indicates the ratio of the signal voltage to the noise voltage in the presence of interference from a high-power LED. A higher SNR value suggests a stronger signal relative to the background noise, which is desirable for reliable communication. However, a lower SNR, in this case, suggests that the interference from the high-power LED has increased the noise level, making it more challenging to discern the signal from the noise.

III.5.5 Impact of obstacle on VLC System:

Placing a hand between the transmitter and receiver in a VLC system interrupts the transmission of light, leading to a disruption in the ECG signal. The hand acts as an obstacle, blocking the path of the modulated light signals that carry the ECG information. Consequently, the receiver cannot accurately detect or receive the light signals, resulting in a disturbance or loss of the ECG signal (Figure III.28).

It is important to emphasize that VLC systems rely on direct line-of-sight communication, where uninterrupted light transmission is crucial for successful data transmission. Any obstruction, whether it is a hand or any other object, can interfere with the signal and cause disruptions.

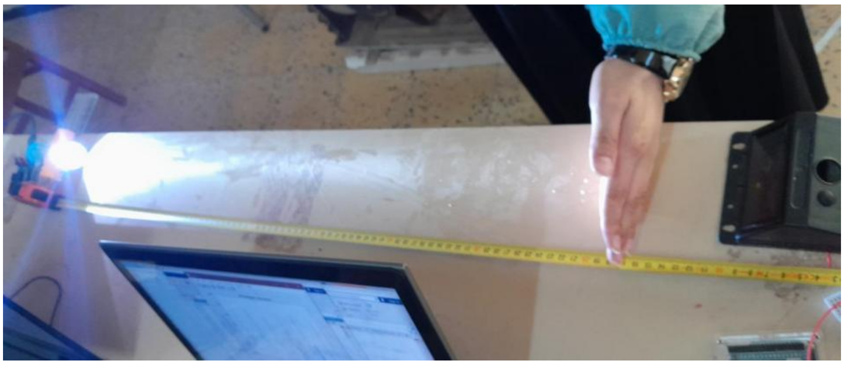

Figure III.27:*Placing a obstacle between the transmitter and receiver*

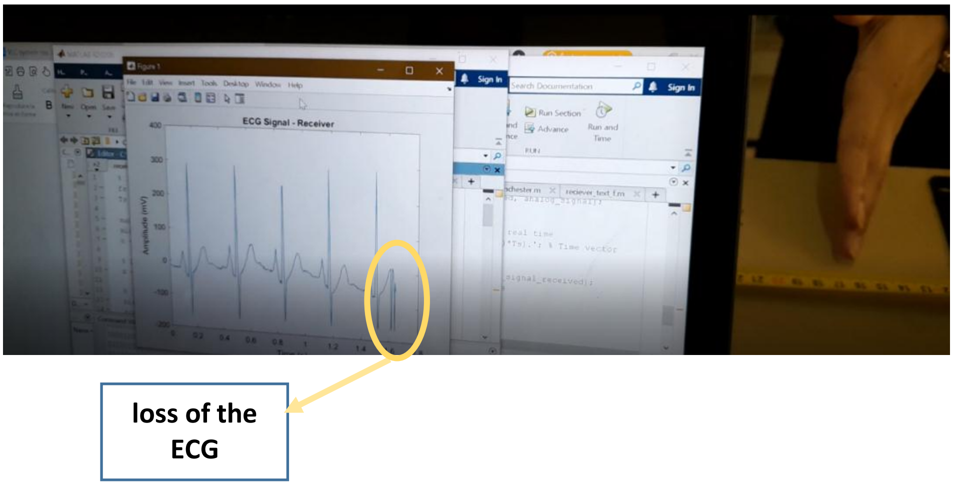

Figure III.28: *the result of a disturbance or loss in the ECG signal*

III.5.6. signal Transmission:

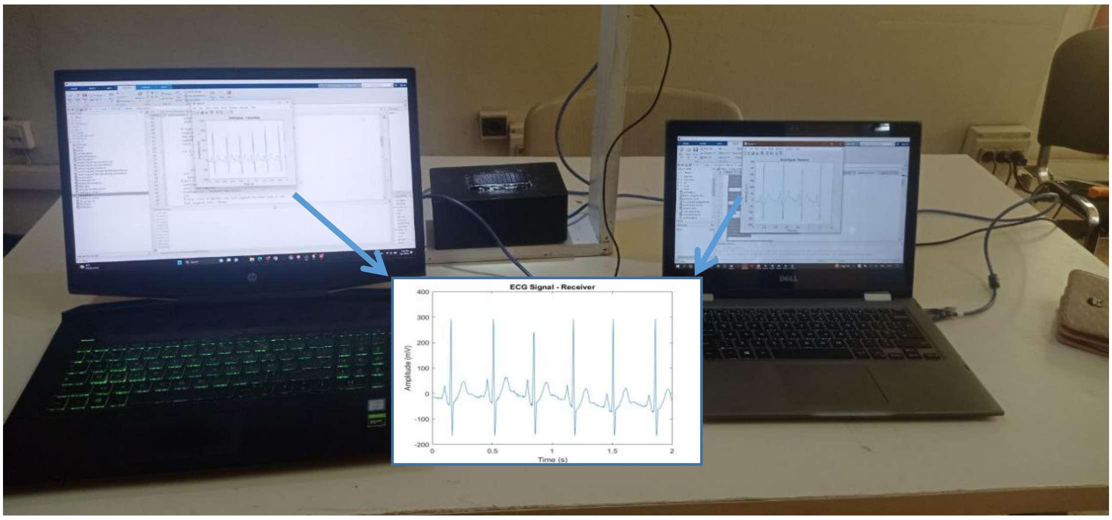

Figure III.29:*signal Transmission*

We utilize a VLC (Visible Light Communication) system to transmit ECG signals. Before the transmission, we process the signals using MATLAB, employing DCT (Discrete Cosine Transform) compression. This choice of compression method was made for several reasons:

Efficient representation: DCT compression offers an effective means of reducing the signal size while retaining significant information. It focuses on capturing the most essential components of the signal, allowing for efficient transmission and storage.
Energy compaction: DCT tends to concentrate the signal energy into fewer coefficients, enabling better energy compaction. This property makes it suitable for applications with limited bandwidth or storage capacity.

To accommodate the limitations of the Arduino's buffer, which can only handle 2 kilobits, while the binary data length of the signal is 16 kilobits, we devised a solution involving segmentation and sequential transmission. The steps involved are as follows:
Segmentation: The signal is divided into smaller segments, each with a size that can fit within the Arduino's buffer. This ensures that all portions of the signal can be transmitted.
Sequential transmission: Each segmented signal is transmitted individually, one at a time, to the Arduino. After the Arduino processes each segment, it sends a confirmation back to MATLAB.
MATLAB-controlled transmission: MATLAB waits for the confirmation from the Arduino before transmitting the next segment. This approach guarantees that all segments of the signal are transmitted successfully.
By implementing this segmentation and confirmation-based transmission scheme, we overcome the limitations of the Arduino's buffer and ensure the complete transmission of the ECG signal.

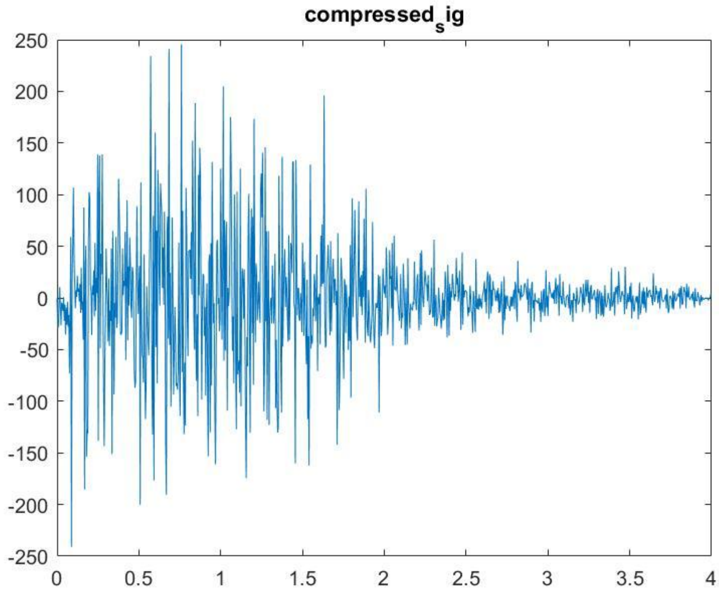

Figure III.30:*DCT compression*

- transmission time of signal without compression is 1 003,61453 seconds
- transmission time of signal with compression is 515,807265 seconds

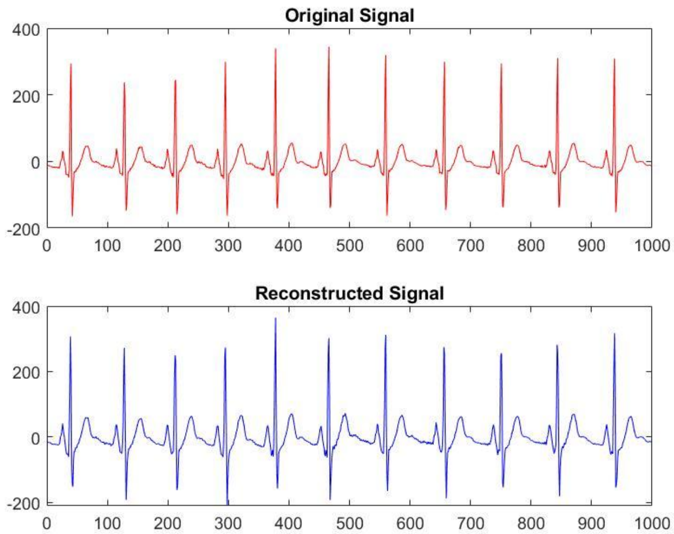

Figure III.31:*Original and decompressed signal using DCT*

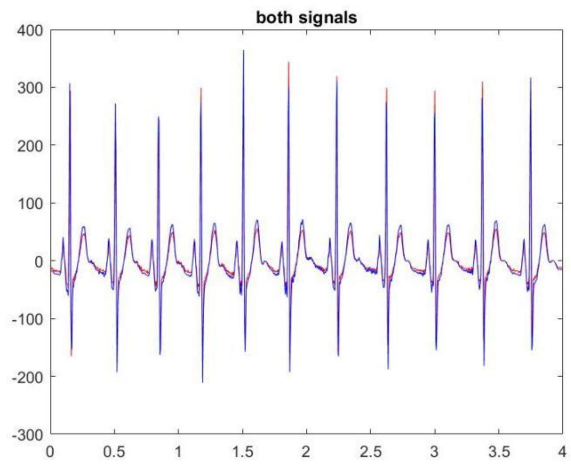

Figure III.32:*Compare the two signals*

III.5.6.1Calculate RMSE :

RMSE (Root Mean Square Error) is a statistical measure that represents the square root of the average squared difference between the original and decompressed signal.

- RMSE point by point:

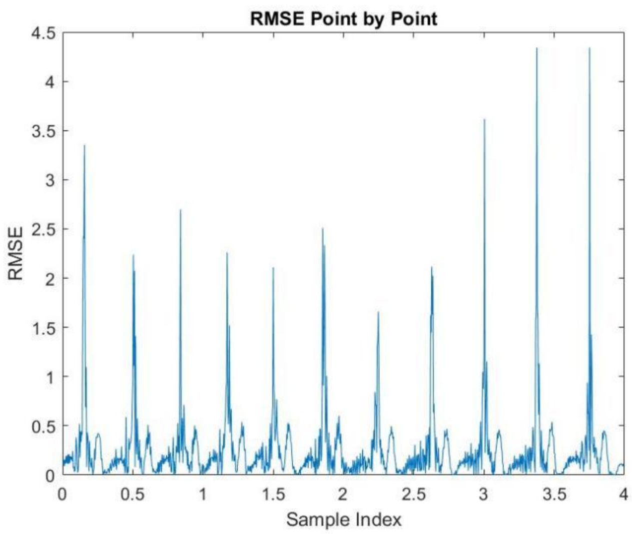

Figure III.33: *The RMSE point by point*

- the overall RMSE is 21,66.

It is important to note that the compressed ECG signals showed a shorter transmission time compared to the original signals. However, despite the reduced transmission time, the high RMSE value of 21.66 indicates a significant difference between the original and reconstructed signals. This suggests that the compression method used may not be suitable for ECG signals in terms of preserving signal fidelity and accuracy. It is recommended to explore alternative approaches that prioritize signal fidelity to ensure the effectiveness of ECG signal analysis and interpretation.

III.6 Performance improvement:

To address the challenges related to data transmission and program execution, we have identified two areas of concern. Firstly, the serial communication between Matlab and Arduino introduces delays in data transmission, and the Arduino itself requires time to execute program instructions. Secondly, the solar panel used is slow-speed photodetectors.

To overcome these limitations and enhance the overall performance and transmission capabilities of the system, we propose the following solutions. Firstly, we can optimize the data transmission speed by utilizing high-speed photodetectors with fast light sensitivity. This will ensure a more efficient and rapid transfer of data.

Additionally, we can explore alternative microcontroller options that offer improved processing capabilities. By employing such microcontrollers, we can simultaneously handle multiple channels, thereby enhancing the system's capacity for multi-channel VLC communication.

By addressing these issues and implementing the suggested improvements, we anticipate a significant boost in the system's performance and data transmission efficiency.

III.8 conclusion

The implementation of Visible Light Communication (VLC) in the medical field addresses the limitations of Wi-Fi in terms of electromagnetic interference and data security. By utilizing VLC, real-time and secure data exchange between medical devices and other devices can be achieved. The system implementation involved using Arduino UNO as the microcontroller, LED modules for transmission, and solar panel for reception. The evaluation of system performance included analyzing data rate variations, text transmission, and signal transmission at different distances, calculating the Signal-to-Noise Ratio (SNR), and assessing the impact of obstacles on signal transmission. Additionally, the application of DCT compression to ECG signals was explored, although further improvements are needed to preserve signal fidelity. Future enhancements can focus on using high-speed photodetectors and alternative microcontrollers to improve system performance and data transmission efficiency. Overall, VLC implementation in the medical field shows promise for secure and efficient wireless data transmission in healthcare monitoring systems.

Conclusion and perspectives

In the recent years, hospitals use different wireless communications networks and devices to monitor patient condition in real time to deliver higher-quality care. Whereas, many electronic medical monitoring devices are themselves extremely sensitive to electromagnetic interference cause by radio frequency (RF)-based wireless networks.

It is well shown in the literature that the visible light communication (VLC) is an emergent alternative to RF-based medical devices especially for elimination of Radio frequency interferences including lower cost and better communication between equipment, clinical staff and patients, and monitoring stations; greater security of light signals compared with RF signals; and complete safety during extended exposure to patients.

However, the challenge with using VLC for health care information is the line of sight between transmitter and receiver.

In this project, we have designed and implemented a simple VLC health care information system working in simplex mode based on a simple material available in our faculty of sciences and Technology, Abdelhamid Ibn Badis, University Algeria. Unfortunately, we have faced different challenges related to:

- Limitation of Data transfer Memory (buffer)
- Important delay in the photodetector to detect the bit '1' and bit '0'

Even if we have susscefly send the medical information as messages and the ECG signal as a function of data on real time and with a low BER, the system need to be improved to faster data transfer and use the advantages of optical communication.

As perspectives, we propose to :

1. Use more efficient microcontrollers with large Data transfer memory and faster processing time such as DSPPIC, DSP, FPGA,…
2. Search for photodetectors that work with faster detection time as well as
3. Design a bidirectional VLC system
4. Implementation of this system in the Algerian hospital

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