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Employing light fidelity technology in health monitoring system

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ABSTRACT

Light fidelity (Li-Fi) is an emerging technology that has been in transferring data packets in internet of things (IoT) applications. During the COVID-19 pandemic, healthcare institutes try to manage the rapid increase of patients' numbers. The healthcare team may not have the ability to monitor patients' stats around the clock with the conventional techniques. In this paper, a healthcare monitoring framework to exchange health data between biosensors and terminals employing Li-Fi technology is proposed. It exploits Li-Fi to transmit data towards a terminal then to a cloud platform. It is intended for use in highly dense healthcare institutes where the number of patients is high. Exploiting Li-Fi to establish connection to cut high cost of other transmission technologies including wireless fidelity (Wi-Fi) and provides less complexity and shorter latency. We evaluate the framework in a real-life environment using biosensors and Li-Fi communication model (for network infrastructure), these two components are connected to a computing terminal to help health staff monitor patients. The computing terminal is connected to a cloud platform to provide remote monitoring and computing resilience. The framework shows superior performance in real-world scenarios compared to Wi-Fi. A comprehensive analysis has been conducted to show the differences between Li-Fi and Wi-Fi.

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1. INTRODUCTION

As number of connected devices growing rapidly, an emerging network infrastructure is proposed namely internet of things (IoT) for the sake of exchanging data between sensors and system via Internet. Employing IoT in healthcare bring a huge attention recently. Wireless sensing technology is widely established in healthcare institutes. Patients need to be monitoring more frequently especially those suffer specific health problems. Healthcare pioneers have envisioned a connected or smart hospital in which all medical devices are connected wirelessly and provide accurate and timely data [1]. Wireless local area networks (LANs) such as wireless fidelity (Wi-Fi), which provide safe and secure wireless communication, are limited in surgery environments because of possible electromagnetic interference (EMI). This means that the deployment of an optical wireless communication technology (Li-Fi) utilizing light is an option to consider in the hospital environment. Li-Fi in healthcare has been explored in a variety of recent research studies, where patient monitoring can be performed very efficiently. The Wi-Fi monitoring technique is slower and offers less bandwidth than Li-Fi. Due to the fact that Wi-Fi uses radio frequency waves, there is a high possibility that these waves could harm human body [2]. To overcome this problem, this paper proposing a framework that employing Li-Fi technology in healthcare field, the proposed framework is based on transmitting information through optical wireless medium. Sensors including heartbeat and temperature are exploited in the proposed system and their collected bio-information is transmitted via Li-Fi.

During the COVID-19 pandemic, most of healthcare institutes around the world exceeds its capacity, with such high number of patients, healthcare team could not properly monitor patients' wellbeing around the clock. Biosensor monitoring system play a vital role to provide imminent health problems to enables a quick intervention to help patients. Body worn sensors can provide real-time health condition information to a server that analyses received information and alert healthcare team in case of a patient requires an immediate attention. Despite wearing personal protective equipment during the COVID-19 pandemic to mitigate the risk of infection, still many of healthcare workers get infected. According to [3], every 100 healthcare worker that got infected died, with such high rate of infection and mortality, this brings the need for a new technology to monitor patients remotely to limit the risk of infection. Remote health monitor system requires to provide bioinformation wirelessly to a nearby terminal to be analysed. Healthcare systems need to meet some criteria such as low data loss rate, cost effective, portable, and easy to install and maintain. Many researches have been carried out to embrace IoT in healthcare industry as in [4]–[6], most of these studies employ Wi-Fi and Bluetooth to exchange data between sensors and terminal, such technologies could have limitations including network congestion as sensors environment could be dense in healthcare institutes and may not handle and manage such massive number of connected devices results in loss in valuable data. In this paper we propose a healthcare monitoring framework to exchange health data between bio-sensors and terminal and cloud platform by employing Li-Fi technology. The proposed framework helps healthcare staff to monitor patients' state lying in intensive care unit (ICU) by observing their bio-information in real-time maner. The framework has the following objectives; firstly, to provide clinical support for making healthcare systems more efficient and affordable, secondly, to collect accurate patient data and provide online access to necessary information, finally, to help staff providing fast assessment and treatment.

The rest of the paper is organized as follows. Section 2 presents background and related work. System architecture of proposed health monitoring is explained in section 3. Section 4 describes configuration of the evaluating scenarion. The result and disscution of the propsed framework is illustrated in section 5. Section 6 concludes the paper.

2. LITERATURE REVIEW

The light fidelity (Li-Fi) technology is a new solution for high-speed data networks that was developed by a German physicist Harold Haas. In a Li-Fi network, data can be transmitted by means of the illumination of an LED bulb, thereby gaining the name visible light communications (VLC). During the era of Internet, communication becomes quick, secure and reliable through wired and wireless networks. Wireless networks have become more relevant in general domestic applications as well as health care applications. In hospitals, wireless networks are preferred because cables that are running across the body of a patient can cause contamination. Due to the increasing dependence on wireless internet, Wi-Fi technology is being strained, creating a massive demand for radio spectrum and bandwidth [7]. To reduce this strain on Wi-Fi, a high-speed wireless technology known as Li-Fi has been developed which finds applications almost everywhere, even in VANETs applications [8].

Mishra *et al*. [9] proposed a method to monitor electrocardiogram (ECG) via collecting data using sensor and transmitting them employing IEEE 802.11 wireless local area network (WLAN) Wi-Fi technology to an interface in a Raspberry Pi, the received data is published to cloud, then collected data visualized using a graphical user interface (GUI) at remote healthcare centre. Patil and Bhole in [10] presented a system model that charting the collected ECG data from patient using Raspberry Pi and AD8232 ECG module to detect heart problems. Yadav and Patil presented a simple acquisition system that employs ECG sensor connected to ADC and Raspberry Pi to visualise gathered data on screen [11]. Bansal and Gandhi [12] designed an ECG system consisting of three broad aspects including: a) data acquisition, to collect ECG data; b) data transmission, allowing to transmitting ECG data to doctor or family members via IoT based development board and one of communications technologies such as Wi-Fi, Zigbee, WLAN, and 3G, 4G, 5G, or Bluetooth; and c) cloud infrastructure to store patients' medical data to be analysed. Gaigawali and Chaskar [13] designed an ECG cloud-based monitoring and fibrillation detection system. The system is consisting of three parts, includes ECG acquisition sensor, cloud platform where collected data is stored and analyzed, and the last part is ECG mobile application. Berl *et al.* [14] used the Raspberry Pi to monitor a person's body temperature and pulse rate. The paper is concerned with the integration of wireless health sensor networks and cloud computing. Cloud computing had performed to store data by amazon web service through the Amazon EC2 cloud service [15]. Nitin *et al.* showed a study about using ATMEGA 32 to monitor patient pulse rate, blood pressure, and temperature. An RS232 interface and a GSM module are used for serial communication with external peripherals, which includes continuously sending the specified parameters to the doctor [16]. The work of

Vikas Vippalapalli was aimed at developing a smarter health system. Based on the findings, healthcare can be provided no matter where people reside across the globe. Temperature, pulse rate, and blood pressure are obtained, processed with Arduino, and visualized with LabVIEW [17]. Wang Ping describes a novel patient monitoring and tracking system that uses temperature, ECG, accelerometer, and web portal technology to review the status of patients remotely. In order to transfer information, a ZigBee transceiver is used to provide a short range of communication [18].

3. METHODS

Global health has become one of humanity's greatest challenges. Patients' health need to be monitored remotely in hospitals to avoid delay in services providing and reduce staff members (physicians and practitioners) [19]. The use of information technology (IT) and its growth applications has enabled life to become easier for all. The proposed system uses Raspberry Pi 4 microcontroller and sensors including ECG, heartbeat, and temperature to monitor patients status. These sensors collect data from patient as analog signal. Then these analog signals are transformed into digital type and stored in Raspberry Pi mini computer which is ARM based architecture. Then the collected data is transmitted through visable light from the sender side (sender gateway) using Li-Fi lamp. The receiving gateway on the receiveing side receives the transmitted data via photo detector (receiving gateway). In the ICU, the receiver unit containing universal asynchronous receiver-transmitter (UART) transceiver (universal asynchronous receiver transmitter) which is connected to the terminal, the receiving healthcare data is visualised every time interval. Additionaly, the healthcare data is uploaded to a cloud platform to be accessed and visualised remotely. The proposed model enables healthcare staff to monitor patients' status 24x7 and the related health information is updated effortlessly.

3.1. System architecture

The proposed system consists of two main parts, hardware and software components. Hardware component contain the main hardware parts (devices) of the system. While the software component contains the main Python scripts to run the system. Figure 1 demonstrates the block diagram of the proposed system architecture.

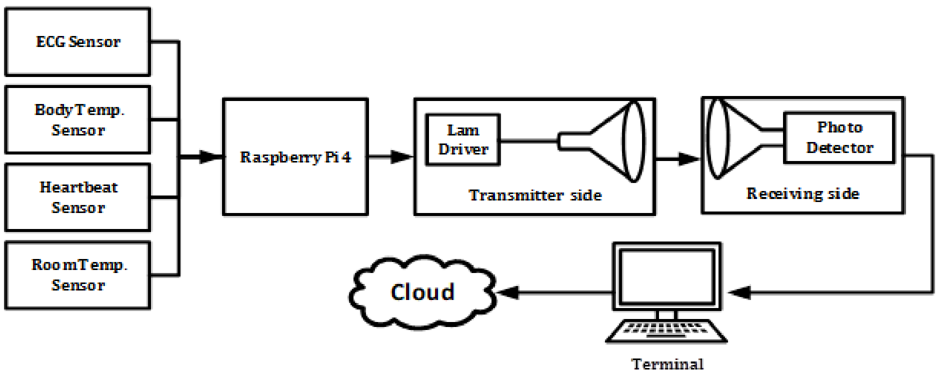

Figure 1. The proposed system architecture

3.2. Hardware component

A proposed health monitoring system comprises sensors and additional peripherals for efficient operation. A variety of sensors were used, including the heartbeat sensor, body temperature sensor, temperature humidity sensor module (DHT 11), and ECG sensor. While the peripherals included Raspberry Pi 4, sensors cable, analog to digital converter (ADC 3008), and Li-Fi equipment such as Li-Fi transmitter module, Li-Fi receiver module, Li-Fi LED, and USB to serial interface.

3.2.1. Raspberry Pi 4

Raspberry Pi 4 model B as in Figure 2, has released on 2019 and it is considered the latest addition to the Raspberry Pi brand in the computer category. It has a significantly faster processor, better multi-media performance, and has the ability to communicate with various types of devices. It's features can be listed as follows: high performance quad-core 64-bit processor, a pair of micro-HDMI ports support two displays with resolutions up to 4K, hardware video decoding up to 4Kp60, 8 GB RAM, Wireless networking with dual-band

2.4/5.0 GHz, Bluetooth 5.0, gigabit ethernet, USB 3.0, and PoE features. As compared to the Raspberry Pi 4 model B+ of the previous generation, these improvements can be noted [20].

3.2.2. Heartbeat sensor (A0318)

The heart rate sensor as shown in Figure 3 uses a photodiode (light detecting resistor) to detect finger pulses and an infrared LED to give the heart rate as beats per minute (BPM). Phot plethysmography (PPG) is the method used in heartbeat sensor. Blood volume changes in the vascular system of any organ in the body will result in changes in low light intensity in that region. Thus, as light is captured by blood, the pulses of a heartbeat are proportional to the signal pulse, so the blood volume flow rate can be calculated from the heart's pulse rate. As a result of this timing, monitoring the pulse rate becomes more important [21].

Figure 2. Raspberry Pi 4

Figure 3. Heart pulse sensor [21]

3.2.3. Analog to digital converter (MCP 3008)

The MCP3008 is a 16 bit eight-channel analogue-to-digital converter (ADC). It is inexpensive, easy to install, and requires no additional components. It is operates via the SPI bus protocol, which is supported by the Pi's GPIO header [10]. Figure 4 shows the MCP3008.

3.2.4. ECG sensor (AD8232)

AD8232 ECG sensor as illustrated in Figure 5 measures the electrical activity of the heart in a cost-effective manner. To obtain a clean signal from the heart's ECG signals, an amp is used to filter out the noise. AD 8232 is designed to extracts and amplifies isolated signals in noisy backgrounds, mainly originating from the muscle's activity and the motion artifacts generated by a patient's body [22].

Figure 4. MCP 3008 [10]

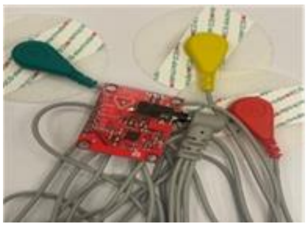

Figure 5. ECG sensor [22]

3.2.5. Temperature sensor

DHT11 is a low-cost digital humidity and temperature sensor as shown in Figure 6. The sensor measures the humidity in the air by using a capacitive sensor and a thermistor, and creates a digital signal on the data pin. The method is simple to use, but data needs to be captured at the right time [23].

3.2.6. Li-Fi transmitter module (Tx)

This side of the board will transmit the data since it's connected to LED arrays that are used to send the data. Once data is transmitted, it will be received by the receiving side (Rx). The Figure 7 presents the Li-Fi Tx module [24].

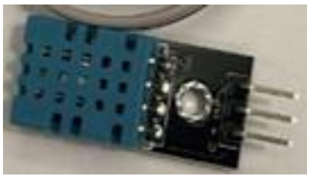

Figure 6. DHT11 sensor [23]

Figure 7. Li-Fi Tx [24]

3.2.7. Li-Fi receiver module (Rx)

On the receiver side, the data is received using the led panel. A serial UART can be connected to the PC in order to display the LEDs on the hyper terminal. Figure 8 illustrates the Li-Fi Rx module [24].

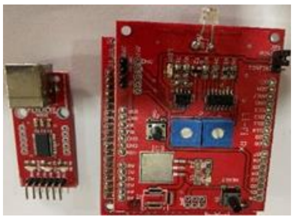

Figure 8. Li-Fi Rx [24]

3.2.8. Li-Fi LED

Light-emitting diodes (LEDs) are semiconductor devices that emit light when they are fed with an electric current. A semiconductor material produces light when electrons and holes (the particles carrying the current) combine together. However, most three LEDs produce a monochromatic light occupying one wavelength, not explicitly bright. Light is emitted from solid semiconductors, such as LEDs, which are considered solid-state devices. The term solid-state lighting distinguishes organic LEDs. There are plenty of lighting technologies that utilize heated filaments (such as incandescent and tungsten halogen lamps) or discharge gases (such as fluorescent lamps). In the past, LEDs produced only red light, but new LEDs can also produce red, green, and blue (RGB) light. In recent years, LED technology has been improving so that they can produce white light too [25].

3.3. Software component

Raspberry Pi 4 runs Linux-based Raspbian operating system. To collect and transforms health care information, a Python script is excuted on the Raspberry Pi, Python v.3 is employed. Unlike many other languages, Python can easily be interpreted and support many network configurations.

4. MODELING THE EXPERIMENT SCENARIO

In order to evaluate the proposed framework, we implemented a platform that contains two main components, the first component as mentioned in section 3.2 is the hardware component that includes biomedical sensors and microcontroller (Raspberry Pi 4) alongside Li-Fi and Wi-Fi kit. The other component, is the software component which includes Python scripts to perform as a health monitor application that reads biomedical information to be analysed and make it available on the cloud (beebotte platform).

The experimients is implemented based on client-server model which is divided into two sides including transmitter and receiving side. The transmitter side is responsible for collecting healthcare information (heart rate, body temperature, and ECG) alongside room temperature, then the collected information is sended to the microcontroller to be transmitted to Li-Fi led or Wi-Fi router. The receiving side receives the transmitted data and visualise it on the terminal and upload it to the Beebotte cloud platform in real-time maner. With Li-Fi, the data transmision is carried out through visible light to the receiver side (main health server), while with Wi-Fi, data tramsission is done via Wi-Fi transmitting technology.

The transmitter side implementation as illustrated in Figure 9 contains biosensors to read bio-information and send it to MCP chip to be digitilised (for ECG sensor only), the Raspbary Pi 4 acts as edge computing node that excutes a Python script that initilise connection with Li-Fi led and receives collected bio information then transform it in light form, then performs the sending process via transmitter gateway (lam driver, sheild, and Li-Fi LED).

The receiving side as shown in Figure 10, receives data in light form and then redigitilised it to be processed by the terminal. The terminal is connected to receiving gateway unit via UART adapter. A Python script is excuted to decode receiving information to be visualized and uploaded to Beebotte cloud platform in real-time maner.

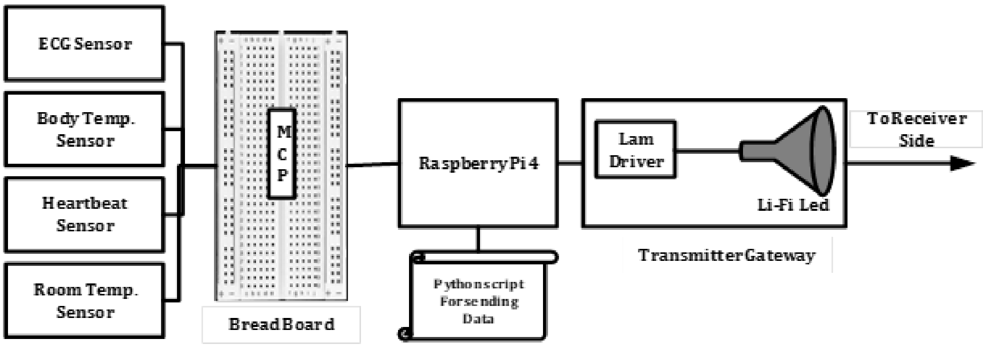

Figure 9. Transmitter side diagram

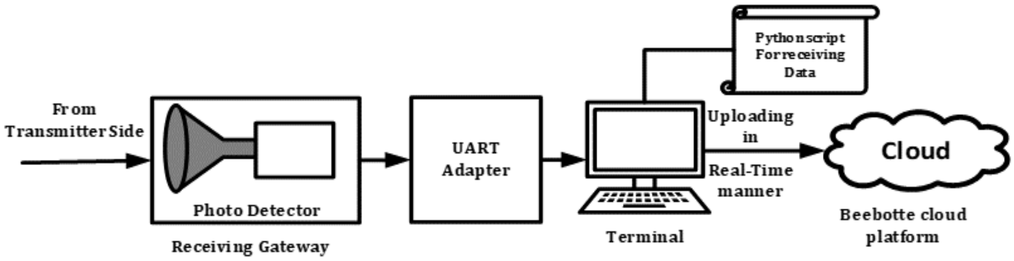

Figure 10. Receiver side diagram

5. RESULTS AND DISCUSSION

In order to evaluate the proposed system, we analysed the network performance based on two main points. Firstly, using data delivering latency from healthcare sensors to the main health server (the terminal), delivering patients status with shortest latency could have a crucial impact on workflow of healthcare system and could save lives also. Experiments were undertaken within 30 minutes of data harvesting and delivering to the terminal then to the cloud platform. We observe the network performance with the selected technologies (Wi-Fi and Li-Fi) in terms of end-to-end latency as can be illustrated in Figure 11.

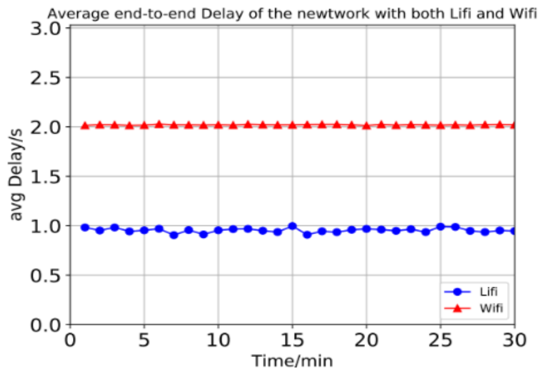

Figure 11. Average end-to-end delay for both Wi-Fi and Li-Fi

With Li-Fi technology network achieves the shortest E2E delay as it employs infrared and visible light spectrum for data communication which allows to faster data transmission and faster packets delivery process. Delivering packets with Wi-Fi technology take longer compared to Li-Fi, as Wi-Fi uses electromagnetic waves at various radio frequencies for data transmission. Despite the poor performance of Wi-Fi in terms of delay, it shows similar performance with Li-Fi in terms of network throughput, the reason behind the similarity of both technologies, they are considered reliable transmission mediums (both achieves 100% throughput). Table 1 presents a comparison of Li-Fi and Wi-Fi technologies [26].

Table 1. Li-Fi vs Wi-Fi technologies features [26]

Features	Light Fidelity	Wireless fidelity
Communcation standard	802.15.7	802.11b
System components	Lamp driver, LED bulb and photo detector	Routers and subscriber devices station (Desktop, Laptop, PDAs
Transmission technology	IrDA based devices	WLAN 802.11 a, b, c, g, n, ac, ad standard devices
Topology architecture	Point to point	Point to multi point
Data transmission medium	Visible light	Radio waves
Transmission frequency	10000 times of Wi-Fi	Radio spectrum range
Frequency band	100 times of Tera Hz	2.4 GHz, 4.9 GHz, and 5GHz
Data transfer speed	1-3.5 Gbps	WLAN 11 n offer 150 Mbps, WiGig/Giga, IR offers sbout l-2Gbps
Coverage area /meter	Where light is available	20-100 (WLAN 802.11 b /11g)
Interference issues	No interference issue with RF waves	Interference with neighbor AP routers
Ecological impact	Low	High
Privacy assurance	high	low
Data delivery	High rate	Low rate due to interference issues
Latency	Microseconds	Milliseconds
Cost	Less	high
Market maturity	Low	High

Table1 demonstrates the main key differences between Li-Fi and Wi-Fi technologies and shows how Li-Fi outperforms Wi-Fi in many aspects:

- Security: Wi-Fi uses radio waves that can be accessed outside walls which allows third party to intercept signal, however data transmission using light (Li-Fi) cannot be penetrated through walls which makes data transmission more secure [27].
- Data transmission mode: Wi-Fi networking technology employs radio waves to transmit data over the air to Wi-Fi enabled clients in the coverage area. Wheras, Li-Fi networking technology employs light waves that produced by solid-state lighting transmitter to transmit data in an area [26].
- Wi-Fi employs radio waves inside the electromagnetic spectrum to transmit data packets. The available radio frequencies for Wi-Fi technology is range from 3 Hz to 3,000 GHz. In comparison, Li-Fi employs visible light communication to transmit data packets. So, Li-Fi has more frequencies range available, (400,000 GHz up to 800,000 GHz), As a result, Li-Fi has more potential [28].
- Coverage range: Wi-Fi is able to connect all devices that are within a 15 to 45 meters radius to the Internet. With radio waves, able to penetrate walls to complete data transmission process. However, light waves cannot pass through dark surfaces, limiting the range of Li-Fi only to the area where light is available [29].
- Data transfer speed: wired data transmission is usually go up to 100 Mbps transfer rate, however, Wi-Fi transmission speeds are significantly slower (ranging from 1 Mbps to 50 Mbps). On the other hand, Lifi speeds are 100x faster compare to Wi-Fi technology, this is due to light travels faster than radio waves, results in, instant data transmission and highly efficient connectivity [26].

6. CONCLUSION

Through wireless communication innovation, it will able to simplify peoples' lives as well as making it safer and more secure. In the proposed framwork, IoT technology and different sensors are combined to improve the data transmission latency and security of many existing health monitoring systems. The proposed system helps to monitor patient stats especially patients sitting in ICU. In this paper we employed the technology of Li-Fi and Wi-Fi as meduims to transmit health information. We observed that with Li-Fi technology, information is being sent with shorter delay compared with Wi-Fi, besides Li-Fi can handle more sensors without affecting network performance in terms on density, additionaly, networks with Wi-Fi technology could be collapsed due to increase number of sensors per patient leding to data congestion issue. In the short term, Li-Fi technology will be able to benefit businesses in the communication sector and enable higher performance networks in many communication fields and make data easy to access instantly. Ultimately, the proposed framework provide reduction in effort and an increase in productivity. The Li-Fi technology would be safer, greener, and cleaner than conventional communications technolgy. For future works, it is possible to build alert systems based on GSM/GPRS module whenever patient sensor data approaches to abnormality. Adding more sensors to track health will make people's lives more flexible and independent. Build a cloud orchestration tool to make the proposed system runs in more automation manner.

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