Contactless Body Temperature Monitoring of In-Patient Department (IPD) Using 2.4 GHz Microwave Frequency via the Internet of Things (IoT) Network

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Abstract

Since the COVID-19 situation keeps going on started from 2019. Many solutions are to against the spreading of coronavirus disease. The nurses have died, and other medical workers are in critical condition from operating in the hospital. It is a deadly virus that kills many humans; Thailand's solutions have urged the public to be confident about the Government's handling of the 2019-novel Coronavirus. At the same time, everyone has to embrace the new normal lifestyle and social distancing while patiently waiting for scientists and doctors to discover vaccines and treatments to defeat COVID-19. This work proposes an innovation of wireless body temperature that instead of the used manual by medical workers in the hospital of "the contactless body temperature monitoring (CBTM) of the in-patient department (IPD)." The proposed CBTM implementation applied artificial intelligence and Internet of Things (IoT) technologies. The specified infrared body temperature on the MLX90614 DCI used for the medical field was selected to embed the IoT-CBTM for IPD using the IoT platform. The MLX90614 is an accurate sensor that matches to use for medical promotion. The detected information data from IPD will be sent to the host computer and stored in the cloud internet service at a microwave band frequency of 2.5/5.0 GHz. This paper presents the accuracy test of the IoT-CBTM prototype calibrated with the manual body temperature verifying device under Thai Industrial Institute to close with the accuracy standard requirement. The experiments were repeated many times until raise up over 70% to get more reliability accuracy. The findings indicated that the proposed prototype achieved a reliability calibration of 74.7%. The actual use of IoT-CBTM is convenient to the nurse, doctor, and medical workers to collect body temperature data into the host computer, and they can monitor this information at all times in the working room, which is far away from the COVID-19 patients. Therefore, this novel innovation was achieved because it took to try out at a local health-promoting hospital in Songkhla Province, Thailand, which the IoT-CBTM system was satisfied by the medical staff because it can save their time, and genuinely reaching the new norm on medical distancing real-time monitoring.

Keywords COVID-19 · CBTM · IPD · TISI · COVID-19

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1 Introduction

The insidious pandemic of the new coronavirus disease (COVID-19) has profoundly disrupted the world, leaving people in distress and claiming hundreds of thousands of lives. The authors agreed that the convergence of AI and IoT could redefine industries, businesses, economies, and medical functions. The digital world is becoming more complex annually. Scientists and researchers have come up with innovations in the field of technology. A significant breakthrough in digital technology is Artificial Intelligence (AI), which AI is a keyword that defines various concepts in information technology and AI-based solution, such as computing, software creation, and data transmissions [1]. Therefore, IoT devices, also known as smart objects, are becoming more innovative and more efficient. These intelligent objects have already been pervasive in our daily lives, such as smart TVs, speakers, and intelligent locks. Furthermore, these smart objects are expected to revolutionize soon many application domains, such as healthcare, energy conservation, and transportation [2].

AI-enabled devices are more intelligent and capable of doing a specific task, saving a lot of resources and time. IoT, mobile, and network applications provide a paramount way out due to less cost and adaptable features [3]. The critical functionality of IoT is to provide links to accessible resources with reliability, effectiveness, and intelligent device. The IoT brings smartness, typically self-possessed of sensors with smooth functionalities, a remote server, and the network.

Wireless communications are significantly crucial for their versatility, mobility, and favorable prices. Wireless fidelity (WiFi) is essential, and the utilization of WiFi has been growing to complement traditional wired networks. WiFi has been playing an increasingly important role in the context of networked and virtual organizations and enterprise information systems. Both ad hoc and infrastructure modes have been used in WiFi. In his case, an access point (AP), permits communications of WiFi electronic devices with a wired based local area network (LAN). Though a router. Thus, a wireless local area network (WLAN) arises based on AP, which has reached the personal office level. Point-to-point and point-to-multipoint setups are used both indoors and outdoors, with specific directional and omnidirectional antennas. WiFi uses microwaves in the 2.4 GHz and 5 GHz frequency bands and IEEE802.11a, 802.11b, 802.11 g, and 802.11n standards [4, 5]. All of these information related into the proposed novel innovation of contactless body temperature monitoring of IPD Using 2.4 GHz Microwave Frequency via the IoT Network. More details will be presented according to the following Sections.

1.1 Motivation

The novel innovation using AI and IoT technologies can provide substantial value across the entire life sciences value chain, from research and development digitalization to enhancing the patient experience. This remote technology based on IoT platform is especially true in Coronavirus-19 disease, directly impacting public health measures on service medical in social sectors. The novel contactless body temperature monitoring of the in-patient department (IPD) uses the medical promotion internet. IoT has started to find broader applications in the field of medical material management visualization [6]. The proposed IoT-CBTM used for the in-patient department assists in avoiding public health problems by aiding in medical treatment. The device can automatically track the body

temperature of IPD using a wireless infrared sensor that embedded an IoT-Microcontroller module with AI-based software components that are part of an IoT-CBTM. This solution increases medical treatment quality while the seriously COVID-19 disease situation regarding the ward's routine activities measures the vital signs, such as heart rate, blood pressure, and body temperature. Based on these data, the medical officer can remotely observe the patient's monitoring process. This paper focuses on a remote body temperature monitoring system, which proposes to keep up with emergencies during COVID time. The proposed item works on microwave frequency which is a form of electromagnetic radiation, and it operates frequencies ranging from 300 to 300 GHz [7].

In this paper, the infrared thermometer sensor is adopted to measure body temperature on the forehead. Measuring a person's temperature can be done in several ways, and in this work, the infrared thermometer sensor MLX90614 DCI infrared sensor was adopted to measure a person's surface temperature with non-contact on the forehead. Long-distance measurement of a person's body temperature may be used to reduce cross-contamination risk and minimize the risk of spreading Coronavirus disease. While typically -70°C to 380°C , but in consideration of body temperature period is about 37.0°C , which is the average temperature, some studies have shown that normal temperature can be within a wide range, from 36.1 to 37.2°C . Therefore, this proposed prototype proposes understanding the benefits, limitations, and proper use of these contactless body temperatures. The improper use of them may lead to inaccurate temperature measurements. Thus, the accuracy issue was solved to get more reliability of the prototype according to the discussion section. This paper has organized as the following sections: Related works are mentioned the literature reviews of current and previous areas; following with the proposed IoT-Body temperature monitoring, which is consisted of (1) Proposed framework of body temperature monitoring of IPD (2) Embedded medical body temperature sensor-IoT controller (3) Proposed AI-Based programming design. The following Section presents the experimental results and discussions. Lastly are the conclusions.

2 Related Works

The application of remote health monitoring is still new in Thailand and many other countries [8]. Some papers researched health monitoring; Sumit et al. [9] innovated wearable sensors for remote health monitoring. They have researched the remote health monitoring systems on physiological parameters and activity monitoring systems.

Moreover, Tamilselvi et al. [10] have studied the IoT-based health monitoring system. Their proposed system was specially designed for actual-time monitoring of the health parameters of the coma sufferers. The technologies used in this system were GSM and IoT to recognize the patient's condition. The parameters studied were temperature, heart-beat, eye blink, and peripheral capillary oxygen saturation (SPOS). Those parameters were detected using sensors for fetching the patient's body temperature, coronary heart rate, eye movement, and oxygen saturation percentage.

Similarly, Saowakhon et al. [11] also studied the development of IoT heartbeat and body temperature monitoring systems for community health volunteers. The device uses Arduino that connects to the heartbeat and temperature sensors with the data connection to the ThingSpeak IoT platform in real-time through an internet network.

Many works were researched the health parameters of a patient using remote monitoring. Similarly, Goncalo and Rui have studied a non-contact infrared temperature acquisition

system based on the internet of things for laboratory activities monitoring. The temperature monitoring inside the building was the proposition that needs to solve the problem. The iRT non-contact temperature sensor was used for a data acquisition system based on IoT, which was designed to be a cost-effective solution. Their work was similar to the proposed contactless body temperature monitoring of IPD via an IoT network because the iRT non-contact infrared was used.

According to the related works studied, authors would like to discuss their advantages and disadvantages in more detail according to Table 1 below.

According to the review of previous works, the prominent point of this work is that the proposed uses a non-contact infrared temperature sensor MLX90614-DCI, a specified body temperature medical sensor. The powerful infrared radiation rays can detect and cover human body temperature max to 50 cm without any contact on the human body, which matches during the epidemic COVID-19 and can respond to social distance measures. Therefore, in this Section, just enough the analysis and consider the advantages and disadvantages of the previous research work. Namely, more details in the proposed "Contactless body temperature monitoring of IPD using 2.4 GHz microwave band frequency via the IoT network" will be described in the following sections below.

3 Proposed IoT-Body Temperature Monitoring System

The contactless body temperature monitoring of IPD via the IoT network proposes to use in a hospital during the COVID-19 situation. The concept was not complicated using a non-contact infrared temperature sensor embedded with an ESP32-IoT module. The information involved is detailed in the following items.

3.1 Proposed Framework of Body Temperature Monitoring of IPD

The related studies of "Contactless body temperature monitoring of IPD via the IoT network" were reviewed. This Section presents the overall system that designed and developed an embedded system using an infrared temperature sensor that works with an IoT-WiFi controller on the NodeMCU ESP32 board. The detected data will be transferred to users via the internet network, and it will be stored on a cloud internet system. The proposed system is presented in Fig. 1 below.

The system was designed to embed the software programming according to the user's requirements. The monitoring module for IPD using IoT network uses innovative embedded medical sensor and smart monitor applied in conjunction with the IoT technology. The information can be viewed at any time, and it alerts when something goes wrong. The information data will be stored on the cloud network, which is a storage system on the internet). The highlight of this innovation is storing data in real-time, and it can be browsed through the online internet system with the notification system. Therefore, this prototype improves hospital management and patient care by reducing infection risk from working in a risky area.

3.2 Embedded Medical Body Temperature Sensor with IoT-Controller

This Section presents on IoT-Microcontroller embedded DCI90614ESP infrared. The IoT-Microcontroller adopted to use is ESP32, a single 2.4 GHz WiFi and Bluetooth combo

Table 1 Considering the pros and cons of relevant research

No	Research title	Advantage	Disadvantage	Remark
1	Wearable sensors for remote health monitoring (M. Sumit et al.)	<p>Wearable sensors are used, being progressively more comfortable and less obtrusive</p> <p>Sensors can measure several physiological parameters</p> <p>Low-power</p> <p>Compact wearables,</p> <p>Inexpensive computing</p>	<p>Transmit data through GSM network, which is low rate data transmission</p> <p>Rather high cost for service charge</p> <p>A radio transmission modem uses high power</p> <p>Users' mobility may cause frequent failed connections</p>	Discomfort of wearing the wearable sensors on the body
2	IoT-based health monitoring system (V. Tamiliselvi et al.)	<p>MAX30205 human body temperature sensor claims with offers $\pm 0.1^{\circ}\text{C}$ (MAX) accuracy for thermometer applications</p>	<p>Arduino UNO controller board is connected to the GSM module, which is entirely lacking technology</p> <p>GSM is a higher service cost compare to IoT</p> <p>Service which can connect to WiFi anywhere</p>	There is no mention of the maximum temperature measurement range
3	Development of IoT heartbeat and body temperature monitoring system for community health volunteer	<p>IoT and GSM technologies are used</p> <p>The results are compared between the commercial thermometer and proposed prototype to analyze the different results</p>	<p>There is no mention of the maximum temperature measurement range</p> <p>It is not clear about analyzed results of the comparison to the reliability of the proposed system</p> <p>IoT and GSM is the higher cost compared PWSN</p>	

Table 1 (continued)

No	Research title	Advantage	Disadvantage	Remark
4	Proposed the contactless body temperature monitoring of IPD using 2.4 GHz microwave frequency via the IoT network	<p>Accurate MLX90614-DCI medical sensor with a max long range of 50 cm</p> <p>Contactless body temperature monitoring of IPD is presented using a wireless and non-contact approach</p> <p>Microcontroller on board with WiFi module with high-speed processing</p> <p>Future work plans to plus an additional function with personnel wireless sensor network (PWSN) can work without WiFi connection in case of internet network system down</p>	<p>An option of wireless sensor network without internet network is waiting for installation</p> <p>Need real-time monitoring system with WiFi internet connection</p>

Fig. 1 Proposed IoT-CBTM system

chip [12]. It is designed to achieve the best TSMC ultra-low power consumption and RF performance with robustness, versatility, and reliability in a wide variety of applications and power scenarios. Meanwhile, the non-contact infrared body temperature for IPD above absolute zero ($-273, 15^{\circ}\text{C}=0$ Kelvin) emits electromagnetic radiation from its source, proportional to its intrinsic temperature. The medical sensor module can communicate with it through its I²C interface, high precision non-contact temperature measurements. It is also a thermal comfort sensor for the mobile air conditioning control system, which matches the healthcare section [13, 14].

Figure 2, aside from WiFi-Controller ESP32 and the long-distance medical sensor, detects a maximum of 50 cm. An organic light-emitting diode (OLED) was adopted to create digital displays in the temperature monitoring device. Blue OLED is emitted in this type, and it generates a brighter light. Also, it is more uniform and more energy-efficient

Fig. 2 Schematic circuit of CBTM device for IPD based on individual design

than regular fluorescent lights [15], with in-built antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, and power management modules. Moreover, it added versatility in applications with minimal print circuit board requirements.

3.3 Proposed AI-Based Programming Design

This Section describes the AI-based programming design of a non-contact infrared sensor with an IoT-ESP32 controller device. The functions of this device were designed according to the user's requirements. The sequences of the prototype's working are shown in the following steps according to the flowchart in Fig. 3.

The contactless body temperature monitoring was programmed on an AI-based IoT network platform that provides the structure. This proposition and overall approach is to analyze and identify replicability of application by analyzing recurring use case patterns and reusability of different AI-based software programming components that are an essential part of an IoT [16, 17]. The prototype module was designed to specify a use for hospitalized patients who usually needed to observe their body temperature regularly. The embedded program can detect the human's body temperature according to the user's design, which is usually checked every 4–6 h, but the temperature is monitored every 1 h in the design. The detected temperature will be verified at the temperature reference of 37.5 °C. Namely, when the monitored data is lower than the reference value, it will be sent to the cloud internet for further analysis. In contrast, when the monitored

Fig. 3 Flowchart of contactless body temperature monitoring system based-IoT network

data is equal to or higher than 37.5°C , the alarm function will notify the user and the user's computer.

This function design makes it much easy for the user in a medical ward. The prototype can reduce and close contact with vulnerable patients and save time for regularly measuring temperature. The prototype also supports the patient to rest due to reducing interference from the temperature measurement every 4 h.

3.4 The IoT-CBTMs Communicate on WiFi-Mesh Network

This sub-section proposes the IoT-CBTM communication on the WiFi-mesh network, which is using wireless mesh routers. The critical piece of equipment at the center of traditional WiFi networks is to broadcast the wireless signal to which CBTM devices connect. A router seamlessly routes internet traffic between a connected modem and WiFi-enabled gadget to computers and bright devices.

Figure 4 presents the IoT-CBTM management system using mesh routers, which can help eliminate dead zones rather than broadcasting WiFi signals from a single point. The Mesh router system has multiple access points. One point links to the modem and acts as the router, while one or more other access points, often called satellites, capture the router's signal and rebroadcast it [18]. More details on experimental results are mentioned in Sect. 4.2.

Fig. 4 Concept of AI-Based IPD body temperature monitoring and the IoT application

4 Experimental Results and Discussions

This Section presents the experimental results and discussions on contactless body temperature monitoring of IPD through the IoT platform. The proposed device using a microwave frequency band of 2.4 GHz internet onboard for data transmission.

4.1 Calibration Experiment Test

Figure 4 presents the monitoring results of two infrared temperature sensors. The first device (sensor#1) is the typical body temperature under the Thai Industrial Standards Institute (TISI), compared with the proposed device (IoT-Sensor#2) is embedded infrared sensor into the microcontroller-IoT device. Both devices are tested based on the same conditions using the same Person's temperature at the nearest time at the distance of 5 cm (Fig. 5).

The results showed that both devices are the proposed embedded infrared body temperature device, which has an average value of 36.60 °C, and the standard device has an average value of 36.72 °C, which are different from the value of the temperature 0.33.

Figure 6 presents the density group of both devices' measured body temperature test between the proposed wireless IoT-body temperature device and the standard device, dense at about 36.60–36.72 °C. According to the plotted results of both sensors in Fig. 6, they are compared of the proposed IoT-wireless infrared body temperature and infrared body temperature under TISI Standard. The results found that the correlations of both devices are related at 0.603**. The statistical results have shown that the two devices were related to each other positively weak correlation. In contrast, both devices' results can be summarized as work independently, but according to the different values of body temperature testing for 60 times, it is about 0.33 only. The results depend on the interference factors, such as distancing a test and other human factor stability.

Correlation coefficients are used to measure how strong a relationship between variables. There are several types of the correlation coefficient, but the most popular is Pearson's. Namely, Person's correlation is a correlation coefficient commonly used in linear regression [19, 20] (Table 2).

Fig. 5 The comparison of body temperature movement monitoring of both sensors test

Fig. 6 The density group of the measured body temperature test

Fig. 7 Testing a device's accuracy performance

Table 2 First correlation test of both devices using SPSS software

		Correlations	
		Commercial sensor	IoT_CBTM
Commercial sensor	Pearson correlation	1	.603**
	Sig. (2-tailed)		.000
	N	60	60
IoT_CBTM	Pearson correlation	.603**	1
	Sig. (2-tailed)	.000	
	N	60	60

**Correlation is significant at the level (2-tailed)

Therefore, the proposed device has verified the reliability of both devices using statistical proof. It was found that the wireless IoT-body temperature monitoring device implemented has a reliability rating of up to 74.7%. In case it needs to up the value higher, it must be calibrated for few times.

Table 3 analyzes the reliability test of the proposed IoT-wireless CBTM. Reliability theory is essentially applying probability theory to the modeling of failures and the prediction of success probability (Fig. 7).

This Section mentions some of the critical points in the reliability of the proposed device; these parameters are the reliability and validity are the two most important properties that test scores can have. Reliability tells about consistently the test scores measure body temperature. On the other hand, the validity tells whether the test scores measure the correct values for particular test use. This research’s highlight is about accuracy tests of several measuring for body’s temperature, which focus on forehead within the same conditions to achieve the calibration as close as possible.

4.2 Multi-Node Experiment Test

This sub-section presents the experimental results of the multi-node experiment test on the CBTM of IPD via the IoT network platform. The multi-node of CBTM devices related to the WiFi mesh network for communication between the CBTM devices, host server, and users. Each node serves as a hop point for other nodes in the system to assist the nodes farthest from the router to deliver a strong WiFi signal as they are talking to other nodes and not relying on one-to-one communications with the router. As a result, the wireless router can provide average solid communication with the router via a 5 GHz radio band. The data will be traveled into a mesh system with multi-node networking devices that operate 5 GHz based on IEEE801.11ac wireless technology. Samples of data collected from three IoT-CBTM device nodes are shown in Fig. 8.

The findings show the temperature measurement of body organs tested by three volunteers. It was found that the average body temperature of the first volunteer was 36.81 °C with the forehead measurement test. On the other hand, the palm was also tested using the same proposed IoT-CBTM device but saddened the temperature was stranged rise over 38.00 °C. Moreover, his armpit also was tested using a commercial digital thermometer with model macro life, and the average result came up with 36.31 °C. These are the sample results collected from the multiple IoT-CBTMs using a WiFi-mesh communication network. It proves a robust and reliable WiFi signal; moreover-the mesh routers have few other prominent benefits.

Table 3 The reliability statistics results referring the standard TISI device

Reliability statistics	
Crobach’s alpha	N of items
.747	2

Fig. 8 Data sampling from the IoT-CBTM device nodes

5 Conclusions

The proposed contactless body temperature monitoring of IPD via the IoT platform is a green technology using powerful WiFi and Bluetooth modules that target a wide variety of IoT for medical promotion applications ranging from low-power sensor networks to the most demanding tasks. The proposed device was helpful to reduce the contact, proximity

between patients and healthcare professionals. Furthermore, the information data is organized to send and record into the cloud database system, which is further easy to analyze and evaluate by a relevant expert. This proposed automatic body temperature monitoring system is a pilot project that improves and develops in various ways even more in the future.

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Declarations

Conflict of interest The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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