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Development of Mobile and Real-Time Vital Signs Monitoring System with Camera Integration

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Abstract:
Pre-hospital and emergency department staff play important roles to treat patients where these two departments are correlated to each other. However, there are few misalignments between them such as dissimilar training and clinical abilities, language barriers, and high-risk clinical environments which are characterized by noise, interruption, and time restriction. The objective of this study was to develop an Internet of Things (IoT) based health monitoring system with real-time camera inside an ambulance. With this system, the emergency department can monitor the current patient's condition in an ambulance while measuring data when paramedics are having difficulties. In conducting the study, the IoT health monitoring system was developed by using ESP32 as the main microprocessor. Few sensors were used including DS18B20, MAX30102, and ESP32-CAM. In addition, the Blynk application was used as the IoT and connected through Wi-Fi, provided by the ESP32. Five respondents were assigned for the data measurement of vital signs specifically heart rate, body temperature, and SpO_2 using both standard and proposed monitoring system to calculate average and percentage error. From the results, the percentage error for heart rate was recorded as 21.56 ± 8.40%, body temperature was measured as 3.14 ± 3.41%, and SpO_2 was recorded as 2.13 ± 0.87%. Moreover, during the device construction, the camera functional was delayed for approximately 5 second. In conclusion, integrating real-time video with vital sign data in IoT-based health monitoring systems provides a comprehensive view of a patient's condition, enabling proactive treatment adjustments and better outcomes.

Keywords: Mobile; Vital signs; IoT; Monitoring system; Camera integration

1. INTRODUCTION

In this modern era, technology nowadays keeps improving day by day to enhance society's daily life. Thanks to Internet of Things (IoT) where it acts as catalyst and is widely used in many applications that are important in proficient field. IoT in medical healthcare can be referred to as interconnection between medical devices and sensors to transmit real-time patient's data to the system to be analysed, diagnosis, make decision and further treatment. In medical healthcare applications, wearable or embedded sensors are usually used to measure and collect physiological parameters from patient's body such as body temperature, heart rate, partial oxygen concentration (SpO_2), electrocardiograph (ECG), and electroencephalograph (EEG) (1).

Patient monitors are the most common medical devices that can be found in hospitals and ambulances for monitoring patients vital signs. However, monitoring patient conditions alone is not enough especially for those patients that directly come from an accident scene. Usually, before the arrival of patient to the emergency department in the hospital, paramedics inside ambulance will carry out a crucial part in facilitating quick prehospital evaluation, triage, and access to emergency treatment (2). The time used for transferring patients from accident scenes to hospital must be used by providing health monitoring systems equipped with camera equipped to ensure the patient gets treatment as smoothly as it can. The usage of camera and distance monitoring can be used by healthcare workers to monitor real-time scenes at the hospital.

Paramedics play a crucial role in monitoring patient health due to unpredictable conditions (3). Accurate data during handover to the emergency department is essential for timely treatment and preventing delays. Misinformation can lead to poor prognosis (4). The busy emergency department can also increase workload, making it a stressful environment for staff. Moreover, the lack of transition information from paramedic to emergency department also caused by variations in common language between field and hospital benefactor, lack of liability and limited time of transition to occur (5). This problem will make the treatment process for the patient become time-consuming. To overcome this problem, an interaction and information transition between paramedic and emergency department needs to be clear.

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This study focuses on developing IoT-based health monitoring systems with camera equipped and testing the accuracy of parameters taken from monitoring system with existing monitoring medical devices. The scope of this study is to develop an IoT-based monitoring system with a camera equipped that has the potential to revolutionize patient monitoring during ambulance transport. The purpose of this system is to promote early monitoring of injuries or diseases to healthcare workers at the hospital. The decision-making of treatment for patients can be done early before the arrival of patient to the emergency department. This monitoring system can save more time and transform medical services for the better. The development of monitoring systems used ESP32 as main processor in this system. The input for this system was camera and sensor, meanwhile, Blynk software was used as output to this system to show real-time monitoring scene and patient's physiology parameters. However, there are limitations when conducting this study. The sensor used in this study was MAX3012 and DS18B20 which only detect vital signs for heart rate, SpO_2 and body temperature. Others vital signs such as blood pressure, breathing rate and ECG are not included in this study.

The study aims to develop IoT-based monitoring systems with cameras to detect early diseases or injuries of patients before their arrival in emergency departments. Traditional methods often lack real-time data, hindering professional healthcare workers' ability to detect signs of injury or illness. The proposed system will enable continuous collection and transmission of real-time video and sensor data, providing visual cues for treatment. This will enable faster, more effective interventions, improving patient outcomes and reducing the burden on healthcare workers.

2. METHODOLOGY

2.1 Top Level Architecture and Components

Figure 1 shows that in this top-level architecture, the ESP32 serves as the central processing unit, efficiently managing input, processing data, and driving outputs. The system takes advantage of three primary input sources: ESP32 CAM to provide real time monitoring camera, MAX30102 an oximeter sensor which detects heart rate and oxygen saturated level, and DS18B20 to detect body temperature. The ESP32-CAM input provides real time monitoring camera, allowing the monitor from application Blynk. The MAX30102 sensor detects a person heart rate and oxygen saturation level, ensuring a person's condition stable. DS18B20 is a body temperature sensor allowing to detect a person's current body temperature.

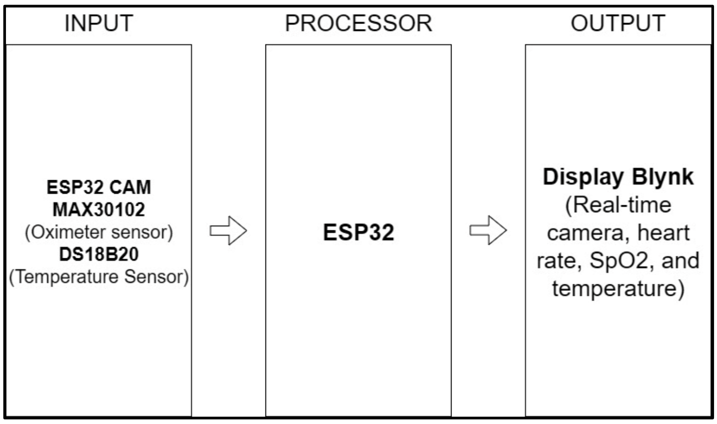

Figure 1. Top-level architecture of IoT monitoring system.

There are several important electric components needed for constructing the proposed monitoring system. The ESP32 is a series of low-cost, low-power microcontrollers equipped with dual-mode Bluetooth and integrated Wi-Fi. It is an inexpensive, very flexible microcontroller that may be used for a wide range of tasks, including embedded systems, robotics, home automation, wireless communication, and IoT devices. The MAX30102 sensor is a versatile tool used to detect both blood oxygen levels and heart rate. Additionally, the sensor can also determine heart rate by analyzing the time series response of the radiation. This dual functionality allows for simultaneous monitoring of vital signs, providing valuable insights into a person's overall health and well-being.

The DS18B20 is a 1-Wire temperature sensor designed by Dallas Semiconductor. This device is notable for its ability to communicate with a microcontroller using only one digital pin which is DQ, making it a convenient option for many applications. The ESP32-CAM is a versatile device that combines a built-in camera with Wi-Fi capabilities. However, its design comes with some limitations. One of the notable constraints is the limited number of I/O pins available.

2.2 Software Development

The first step before software development was to be to test the functionality of the sensors and camera by using specific code for sensors. This code needs to download and install the required libraries within the Arduino IDE. The libraries used was Dallas Temperature library for body temperature and SparkFun library for both heart rate and SpO_2. The code can be accessed by navigating to Arduino IDE > File > Example > Dallas Temperature > Simple. The code will automatically appear at code tab. Then, the code will be uploaded into the ESP32. The simple circuit between DS18B20 sensor and ESP32 are constructed to see whether the sensor was able to detect input which is body temperature and show the output at serial monitor. This process was repeated for another sensor.

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After the sensor functionality was verified, a Blynk template was created from the dashboard. Sensor data was inserted using the edit button, and each sensor was assigned a specific virtual pin on the dashboard. The body temperature, heart rate, SpO_2 sensor, and camera sensor were assigned to pins V0, V3, V4, and V1, respectively, to exchange data between hardware and Blynk via the Blynk server.

The data type declaration is crucial for accurate processing and storage of sensor data. In this project, heart rate and SpO_2 were declared as double, body temperature as an integer, and the camera as a string. Floating-point numbers (floats or doubles) require more data to send over a network than integers. For IoT apps like Blynk, where data is frequently transmitted over limited network, this is especially crucial. Faster transmission, lower power usage for battery-operated devices, and less network congestion are all results of smaller packet sizes. The minimum and maximum ranges for these data were set to zero and 150 respectively. Sensor data was also specified in appropriate units, such as °C and %. However, the heart rate in Blynk does not have a specific unit, like beats per minute (bpm). After completing the template, Blynk will display an Auth Token, which is the primary identification of each device in the Blynk Cloud.To connect data and virtual pins, the template from the dashboard must be selected in the app's menu. The interface is divided into two sections: the lower section features three-gauge widgets for monitoring patient vital signs, and the upper section features a video streaming widget for live streaming of patient conditions, enabling healthcare professionals to collect data before emergency department arrival. After configuration apps and dashboards were completed. The following step was to construct the whole code for the system as Supplementary Data.

2.3 Hardware Development

The next step was hardware development, which is an important factor in creating a great device. It involves designing whether in circuit or device case to make up in as one product. This process is also important to ensure that the device is well arranged and protects the internal component and sensor from being damaged by the environment since it is a sensitive part. Without it, the data collected may be inaccurate.

The circuit was constructed by using a website called Circuit.io. This online website provides a range of microprocessor selection including ESP32, which has more advantages than Thinker CAD. Thinker CAD in contrast offer limited selection and focused on the Arduino platform. Figure 2(a) shows the circuit configuration for the proposed study while Figure 2(b) shows the completed install circuit for the proposed project. The circuit shows the connection between MAX30102, DS18B20 and ESP32 with resistor of 4.7kΩ. ESP32-Cam is installed with its base to provide a convenient way to connect the camera, but the coding is still involved with Auth Token to ensure the connection camera with the Blynk apps.'

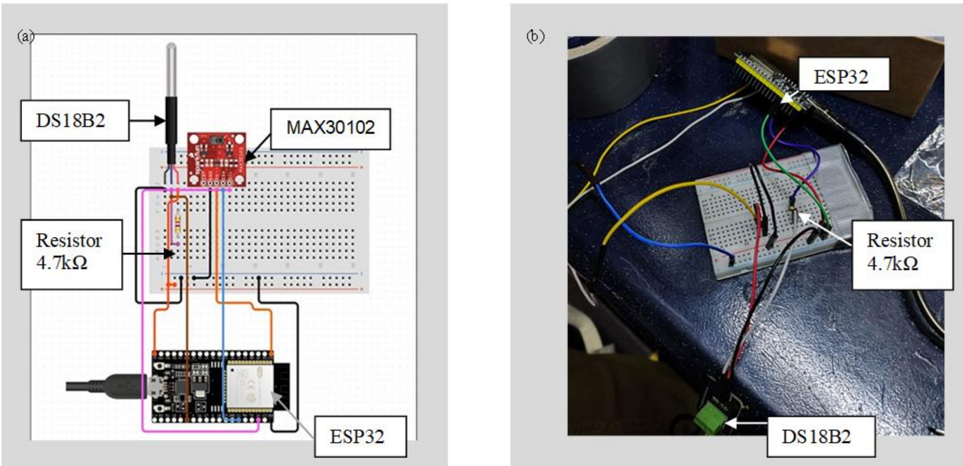

Figure 2. (a) Circuit configuration and (b) complete installation.

2.4 Data Collection and Validation

The data collection process involved measuring the vital signs of five fourth-year students from the Department of Biomedical Engineering, Faculty of Electrical Engineering, UTM. The vital signs of the candidate were measured using both standard monitoring systems and proposed project monitoring systems. The standard monitoring device was the Apnea Monitor from Nihon Kohden BSM-3763. The data was collected in a clinical lab at room temperature at 18°C.The data was recorded using Google Form and then formatted in Excel for better organization and calculation. After taking all vital signs, the data was tabulated in a table.

For each candidate, three repeated reading for each vital sign using both the proposed monitoring system and standard monitoring system were recorded and calculated its average. Then, the average values for each candidate were then used to compute individual percentage error using Equation 1. In this equation, the "proposed reading" reflects the average vital sign value acquired from the proposed project monitoring device, whereas the "standard reading" corresponds to the measurements from the standard monitoring device.

$$Percentage\ Error, \% = \left| \frac{Proposed\ Reading - Standard\ Reading}{Standard\ Reading} \right| \times 100\% \quad (1)$$

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This method produced five error values for each parameter. Then, the mean and standard deviation were calculated using Equation 2 where x_i is each individual percentage error, $\bar{x}$ is mean of all percentage errors and n is amount of data.

$$Standard\ Deviation, \mathrm{SD} = \sqrt{\frac{\sum(x_{i-\bar{x}})^2}{n-1}} \quad (2)$$

3. RESULT AND DISCUSSION

3.1 Validation of new IoT-based Vital Signs Monitoring System

Tables 1 and 2 show the data of candidate's vital signs value by using both standard and proposed monitoring system and its average values. Meanwhile, Table 3 shows the five values of percentage error for parameter, mean values and its standard deviation. Data validation is an important phase in the data management lifecycle (6). It goes beyond merely checking for mistakes or inconsistencies; it's about establishing if the collected data is suitable for purpose and can be relied on to assist decision-making and analysis.

Table 1. Results of subjects' vital signs from standard monitoring device.

Candidate	Standard Monitoring System (BSM-3763)											
	Body Temperature, °C				SpO_2, %				Heart Rate, Bpm			
	R1	R2	R3	Average Value	R1	R2	R3	Average Value	R1	R2	R3	Average Value
1	35.00	34.00	35.00	34.67	100.00	97.00	96.00	97.67	89.00	87.00	83.00	86.33
2	32.60	32.70	33.00	32.77	97.00	97.00	97.00	97.00	81.00	85.00	84.00	83.33
3	32.20	32.50	33.00	32.57	98.00	97.00	93.00	96.00	79.00	82.00	70.00	77.00
4	29.20	29.40	30.00	29.53	97.00	97.00	97.00	97.00	77.00	90.00	85.00	84.00
5	29.50	30.00	31.00	30.17	99.00	98.00	98.00	98.00	77.0	73.00	72.00	74.00

Table 2. Results of subjects' vital signs from proposed monitoring device.

Candidate	Proposed Monitoring System											
	Body Temperature °C				SpO_2, %				Heart Rate Bpm			
	R1	R2	R3	Average Value	R1	R2	R3	Average Value	R1	R2	R3	Average Value
1	31.62	31.57	31.87	31.69	100.00	100.00	99.00	99.67	100.00	107.00	107.00	107.67
2	33.75	34.31	34.44	34.17	100.00	97.00	100.00	99.00	88.00	93.00	115.00	98.67
3	31.31	32.00	32.75	32.02	100.00	99.00	99.00	99.33	107.00	88.00	107.00	100.67
4	29.56	29.69	30.00	29.75	99.00	99.00	99.00	99.00	88.00	93.00	93.00	91.33
5	30.06	30.31	31.50	30.29	99.00	99.00	99.00	99.00	78.0	93.00	107.00	92.67

Table 3. Percentage error and standard deviation calculation.

Parameter	Percentage Error, %					Mean, %	Sum of Squared Differences	Standard Deviation, %
	1	2	3	4	5			
Body Temperature	8.60	4.27	1.69	0.75	0.40	3.14	46.40	3.41
SpO_2	2.05	2.06	3.47	2.06	1.02	2.13	3.04	0.87
Heart Rate	24.72	18.41	30.74	8.73	25.23	21.56	281.79	8.40

The results from the table can be presented in the form of mean ± SD, where the mean represents the average percentage error between the proposed and standard monitoring systems, and the standard deviation indicates the degree of variability among candidates. A lower standard deviation reflects consistent measurements, whereas a higher value indicates greater variability. From Table 4, the body temperature (3.14 ± 3.41%) and SpO_2 (2.13 ± 0.87%) errors were low, demonstrating good measurement accuracy and consistency of the proposed monitoring system. In contrast, the heart rate error (21.56 ± 8.40%) was considerably higher and exhibited greater variability.

3.2 Proposed of New IoT-based Vital Sign Monitoring System

In this part, it shows the final product of the proposed monitoring device. Figure 3 shows the final product of the proposed monitoring device with a case to protect the microprocessor and others important component. The device is also attached with a power supply compartment to place the power bank. This is to ensure the tidiness of the device. While Figure 4 shows the Blynk interface with functional gauge widget and video streaming.

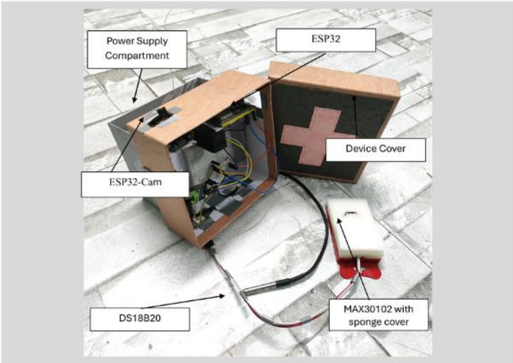

Figure 3. Final product of proposed monitoring system.

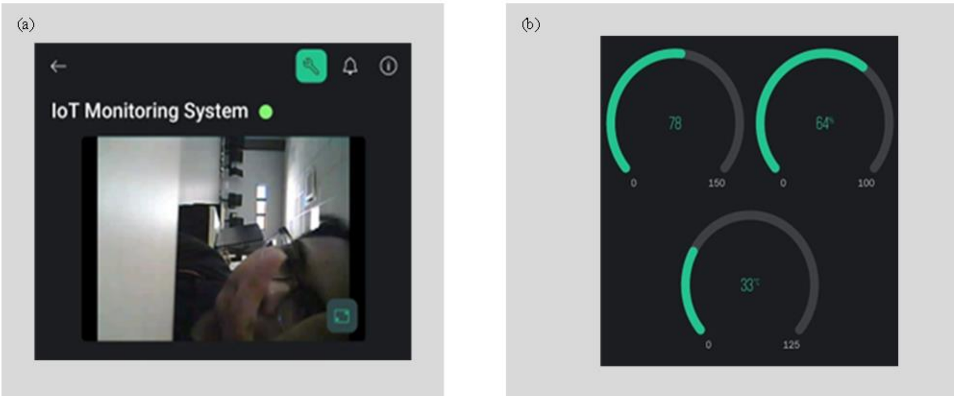

Figure 4. Working Blynk app interface.

This part will discuss the outcome from the result after conducting data collection, calculation and testing the final form device. From the result the highest error was heart rate with 21.56 ± 8.40%. This might be due to environmental factors as the photodiode from the MAX30102 detects surrounding infrared making the reading significant difference (7). For both body temperature value on standard and proposed device, it is showing lower value than normal human temperature which is 37 °C. The changes in body temperature happen due to room temperature (8). This data collection was conducted in a clinical lab with room temperature around 18°C. As for the camera, it has slight delays of around 5 seconds, which might be due to internet connection or compatibility of sensor and device.

4. CONCLUSION

In conclusion, the objective of the study was achieved, and it is preferable in constructing IoT-based health monitoring system with real-time integration camera. The integration of real-time video feed, in addition to the collecting of vital sign data, allows for a more comprehensive awareness of the patient's condition, allowing for proactive alterations to treatment plans and the prevention of negative consequences. The problem may come from the individual itself, thus having more monitoring and data taken from others may help to get better results. For the limitations and future works recommendations, it suggests that the proposed device has more vital sign to detect from the patient such as blood pressure, ECG and breathing rate. By expanding the variety of physiological parameter that may be constantly recorded would provide healthcare personnel with a more comprehensive dataset to assess the patient's overall status and make more educated judgements during the critical prehospital period. Moreover, an additional feature for two-way voice communication might have a big impact for future works. This bidirectional interchange of information can permit a smoother transfer of patient history, present status, and any pertinent observations made during transit, hence increasing the continuity of care and the capacity to give targeted treatments upon the patient's arrival.

AUTHORSHIP CONTRIBUTION STATEMENT

Muhammad Ikmal Danish: methodology, experimental work, formal analysis, investigation, conceptualization, writing – original draft; Mohd Riduan Mohamad: supervision, methodology, resources, writing – review & editing, validation, funding.

DATA AVAILABILITY

Data supporting this study's are available upon reasonable request.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

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