DEVELOPMENT OF AN INTELLIGENT VITAL SIGN MONITORING ROBOT SYSTEM

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ABSTRACT

We want to solve the problem that the elderly or heart patients will not miss the golden time for rescue in case of sudden death or emergency event at home. Therefore, this work proposes an intelligent vital sign monitoring robot system. Considering data protection and privacy issues, the heart rate of the elderly or heart patient can be measured and monitored through the millimetre wave radar on an autonomous mobile robot (AMR). Additionally, by object detection technology, the infrared thermal imager is integrated to detect the temperature of a person's head. The measured head temperature, thermal image and heart rate data can be uploaded to cloud database with blockchain technology to prevent data tampering. We develop an interrupt method for multi-target navigation of AMR to interrupt the patrol when a custom trigger situation happened and to run the interrupt process for vital signs measurement. While the interrupt process is completed, the robot will patrol again. When the system detects an abnormal situation, family members or caregivers can be notified through IFTTT service and Line notification messages. The system can help us to monitor the situations of elderly and provide response in time when a sudden emergency event or health crisis happened.

KEYWORDS

Remote vital sign monitoring, millimeter wave radar, non-contact vital sign monitoring, IoT, YOLOv7, Robot Operating System, Autonomous Mobile Robot, thermal imager, Firebase

1. INTRODUCTION

With the impact of the aging population, Taiwan would become a super-aged society by 2025 [1] as shown in Figure 1. The number of elderly people living alone is also rising rapidly in many countries [2][3]. Many elderly people living alone are afraid of that no one can help them in time when a sudden emergency event happens. According to the statistics of the Ministry of Health and Welfare of Taiwan for 2021, heart disease is the second leading cause of death after cancer [4][5]. Since health crisis of heart is always rapid and urgent, it could be hours before anyone discovers that something has happened. If there is no definitive care applied to the elderly patient living alone within the golden hour of resuscitation, the patient may die and the families may experience regrets about this. Thus, we all need to have a basic knowledge about the health of our bodies and minds and take the proper precautions. Therefore, "checking vital signs regularly and reporting abnormal conditions in real time" has become one of the indispensable conditions for taking care of the elderly living alone.

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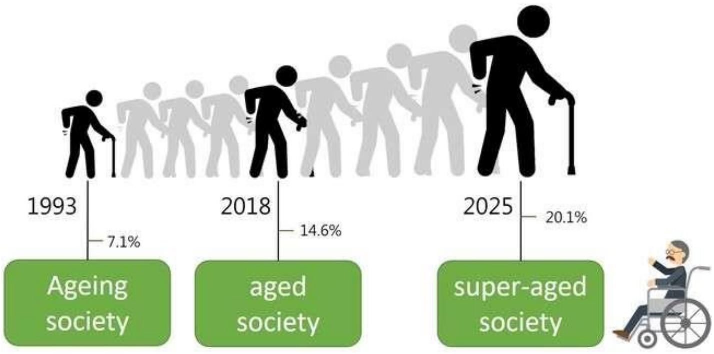


Figure 1. Taiwan's elderly people population trends

In addition, with the global spread of the COVID-19 pandemic, many people have not been able to access care for conditions such as high blood pressure, that could raise the risk of a future heart attack or stroke [6]. Therefore, vital sign monitoring systems are becoming increasing in demand for biomedical applications. The traditionally vital sign monitoring methods such as blood pressure, temperature, pulse rate and respiratory rate, etc. are contact-based vital signs sensing which may cause a lot of discomfort physically and increase the risk of infection, thus contactless vital sign monitoring is a hot issue for many researchers in recent years [7]-[15]. On the other hand, embedded signal processing and remote detection of the vital signs with millimetre wave (mmWave) radars are the most prospective technologies because the sensors do not need a physical contact to the monitored body. An mmWave radar basically measures the range, Doppler velocity, and angle of arrival of objects in front of it. MmWave radars are commonly used in many application scenarios nowadays, including remote sensing of biosignals such as respiratory rate and heart rate. In recent years, advances in semiconductor technology have made cost-effective sensor solutions more feasible. Frequency-modulated continuous-wave (FMCW) mmWave radars based on complementary metal-oxide semiconductor (CMOS) integrate all the analog and radio-frequency (RF) functionality into a single chip with a compact form factor for the sensor [16]. Such a highly integrated device enables the mmWave radar systems to be cost-effective and miniaturized.

Recently, human vital sign detectors were integrated with robots [17][18]. The obtained results highlight the benefits of fusing vital sign sensing devices and robotic entities in a wide range of healthcare applications. Therefore, we hope to solve the problem of not missing the best opportunity for golden rescue when an elderly person or a patient with heart disease is at home when there is a "sudden death" or an emergency situation. In view of this, we designed a care robot that uses mmWave modules to measure and monitor heart rate, and infrared thermography to combine with cloud database for image recognition to detect body temperature, and regularly upload the measured temperature and heart rate data to build a complete database of vital signs. When the robot detects the accident situation, it can notify the family or rescue unit in time to avoid more regrets.

Nowadays, autonomous mobile robot (AMR) with navigation system is used in various works [19][20]. Robot Operating System (ROS) provides useful packages for AMR, such as mapping, localization and navigation package, also provides useful tools for robot development [21]. The proposed robot is built on the ROS system and uses Simultaneous localization and mapping (SLAM) technology in ROS to scan the surroundings and construct a map to ensure that it can capture all areas of the space, allowing the robot to do multi-target navigation. In addition, the infrared thermal camera and mmWave module are integrated on the robot. When the robot detects the human body with the infrared thermal camera, it will interrupt the navigation to measure the body temperature and it can send an alarm message to the user's communication software such as Line Notify when the measured temperature is abnormal. The IR infrared photos will be taken at the same time and the vital signs will be uploaded to cloud-service Firebase for storage. After face detection and body temperature measurement, the robot will use an mmWave radar module for heart rate detection and will send alarms and messages when the heart rate value is abnormal. The data such as body temperature and heart rate are combined with the hash value of blockchain and uploaded to the cloud-Firebase, which can prevent important data from being tampered or used in crimes. The AI model we built is trained to classify the stability of heartbeat and the system can send alarms and messages if the last few heart rate data uploaded are unstable. If a person feels unwell when the robot is on patrol, the robot can be called through the sound source identification system to help measure body temperature and heart rate and other physiological signs, and then send messages to family members to avoid regrettable occurrences.

The system architecture of the proposed work is shown in Figure 2. Using the array microphone set on top of the robot can get the angle of the calling source based on the direction of arrival (DOA) estimation. The system can also obtain the infrared image through the thermal camera for face detection and body temperature measurement. Next, the heart rate of human can be measured with a mmWave radar when the person is static. In addition, the proposed robot uses the ROS mobile platform for multi-targeted cruise to make home security without dead ends. In terms of data processing, when AI detects abnormal values or heart rate data in the cloud database irregular changes, in addition to using IFTTT service to publish abnormal information through Line notify. Morover, all data is also stored through the cloud-Firebase cloud database and combined with blockchain technology to prevent data tampering to achieve data protection purposes.

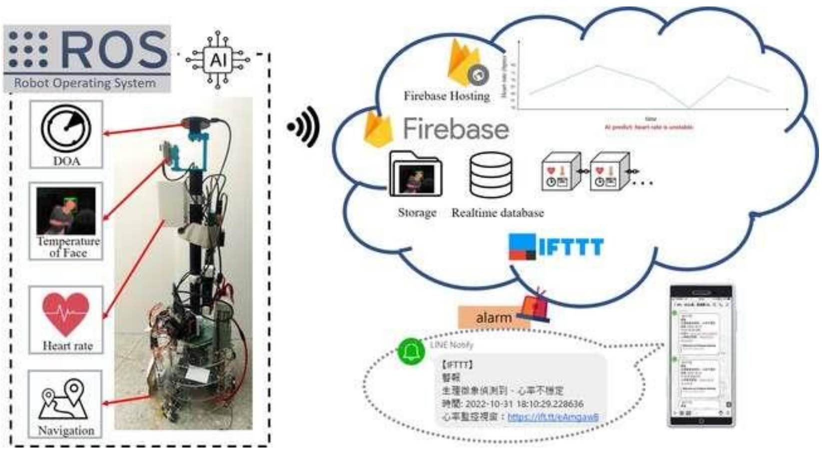


Figure 2. The system architecture

Our contributions in this work are summarized as follows:

1) Application of blockchain to store data

In the blockchain, each block includes a “hash” of the current block and a “previous hash” from the previous block. After the data is stored, other nodes will use “Hash” and “Previous Hash” to verify if the data in the database has been changed. If the data has been changed, it will be detected by the verification program and the modification will be considered invalid. Therefore, this technique can be used to prevent the tampering of important pathological data and to prevent the use of measurement data for criminal purposes. In addition, by uploading the measurement results to a cloud database for storage, we can not only build a complete database of physiological data, but also avoid forgetting to record the measurement values. Hence, it allows family members working or someone living with you to see the changes of data anytime that can achieve a preventive effect and improve the convenience of data access.

2) Contactless physiological measurements

We use an infrared thermal camera and an mmWave radar to measure human body temperature and heart rate. Since most of the measurement devices on the market use contact measurement, it is very inconvenient or uncomfortable to operate when you are alone. Moreover, the elderly often forgot to take regular measurements or are not very willing to do so, thus, when the data is abnormal, it can't be discovered immediately. Therefore, using our robot to take contactless measurements, patients or the elderly can significantly reduce the discomfort of being monitored and avoid the problem of forgetting to take measurements, which can lead to regrettable events.

3) Real-time notification of data abnormalities

When a sudden death or emergency situation occurs, it can tell your family members about the data abnormalities when the heart rate which stored in the cloud database irregular changes occur or measurements data abnormal, so that your family members can have more opportunities to grasp the golden rescue time to request medical assistance or deal with it in person at home to avoid regrettable events.

4) Sound source identification and multi-target navigation

By obtaining the direction of the sound source in the environment through the array microphone, the direction of the demander can be known through the DOA and it can hear person calling for help and find out the direction of the sound source. If the data is abnormal, an exception notification will be sent. In usual times, the robot can also be called to assist in physiological measurements and use the data as a daily physiological indicator, helping users to record and measure physiological data more easily. The frontier-based exploration algorithm is used to allow the robot building a map of the user's home [22][23]. Furthermore, the robot can use multi-target navigation with interrupt handling to monitor the elder's vital signs to avoid missing the golden hour for accidents at home. By integrated vital sign sensors with AMR to carry out navigation and monitoring, the users don't need to set up many sensors in multiple areas for monitor elderly.

The proposed robot system has eight features as shown in Figure 3:

1) Robotic search through sound source identification: When the user needs assistance, the user can call help to seek assistance.

2) AI thermal camera detects people's faces: Using self-trained face detection model by YOLOv7 neural network [24] for infrared thermal camera.

3) Automatic temperature detection: The body temperature is measured by an infrared thermal camera with a non-contact method when the human face is detected.

4) Automatic contactless measurement of human heart rate: Through the mmWave radar module, the heart rate and respiratory rate are measured in a non-contact method.

5) Multi-target navigation with interrupt handling: The proposed robot can perform multi-target navigation with interrupt handling to monitor the elder's vital signs to avoid missing the golden hour for rescue in case of sudden death or emergency event at home

6) Blockchain non-tampering technology: This technique can be used to prevent the tampering of the vital sign data and to prevent the use of data for criminal purposes.

7) Cloud storage with AI detection: The thermal image with face detection, body temperature and heart rate of a person are uploaded at the same time to the cloud for storage. In addition, we use an artificial neural networks (ANN) model to inference for the detection of abnormal vital signs.

8) Notification of abnormalities: By using the push notification method, families or emergency units can be notified of emergencies for elderly people in real time.

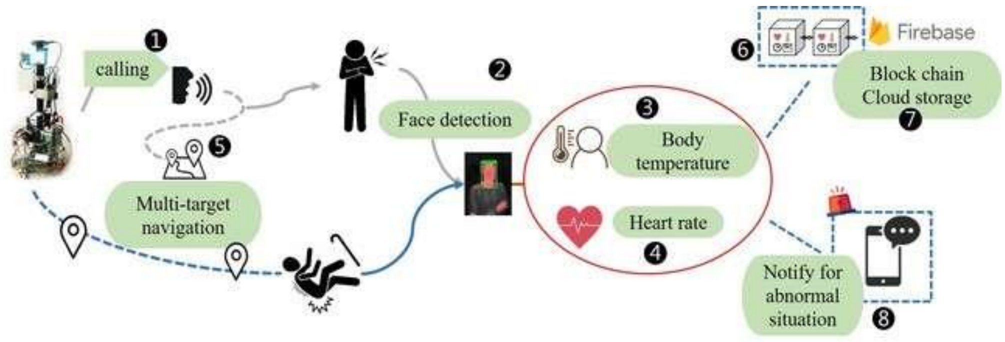


Figure 3. The features of the proposed robot system

The structure of this paper is as follows: the second part introduce system development tools and techniques; In Section III, the experimental results and discuss are presented. Finally, we make a conclude.

2. SYSTEM DEVELOPMENT TOOLS AND TECHNIQUES

The system includes robotic system and the cloud service. The robotic system includes a Neuron Omni Bot [25], Jetson Nano, Respeaker mic array v2.0 array microphone, mmWave radar (BM201-VSD), Thermal Camera, Jetson Xavier. The robotic system environment includes ROS, Ubuntu 18.04, Python3.7. The cloud services we used are firebase, IFTTT and Line as shown in Figure 4. The AI frameworks we used are Yolov7 and Tensorflow. We will introduce these techniques in detail below.

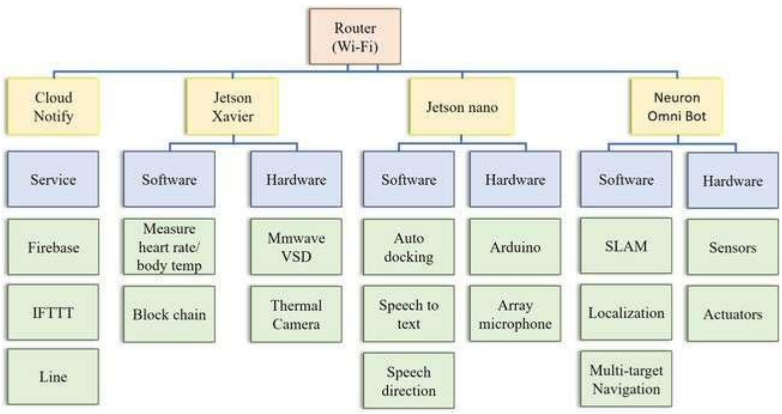


Figure 4. The system block diagram

2.1. **Robotic Operating System (ROS)**

ROS is an open source operating system for robots and supports several modern high-level programming languages [26][27]. This proposed robot is developed based on the ROS environment and uses the ROS topic method to transfer information between nodes to support the needs of multi-hardware module integration development as shown in Figure 5. The “Topic1” and “Topic2”, etc. in Figure 5 are the different topics in the ROS. Communication on topics happens by publishing and subscribing ROS messages with specific topic between nodes [28].

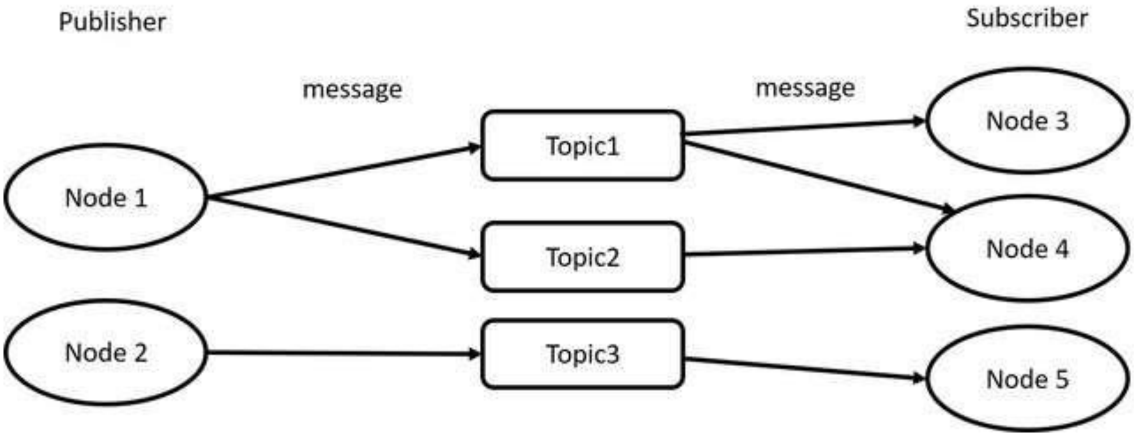
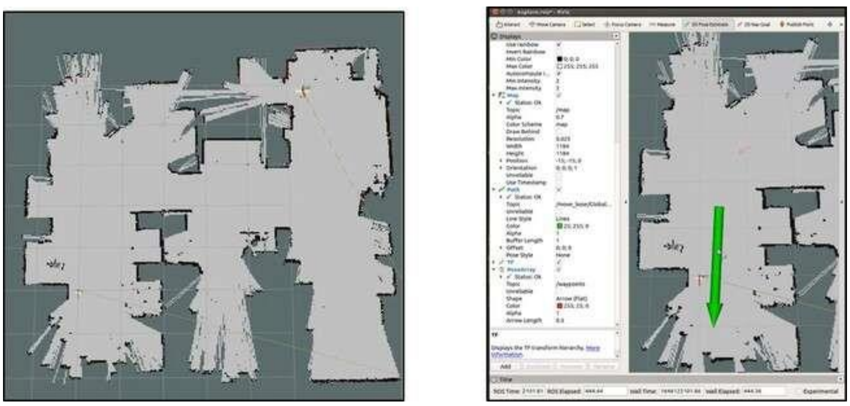


Figure 5. The topics and nodes in ROS

2.2. **Navigation**

In the ROS robot operating system, we use SLAM (Simultaneous Localization and Mapping) technology to construct a map of the environment as shown in Figure 6(a). The move_base ROS Node is a major component of the navigation stack [29]. For single-point navigation, through the combined development of the follow_waypoint package [30], single-point navigation can be transformed into multi-point navigation. The “follow_waypoints” node can listen for waypoints given as poses. When the node is instructed, the goals will be published to “move_base” node one by one by. We can use the 2D Pose Estimate in the Rviz tool to build a new autonomous obstacle avoidance and self-defined multi-target navigation function in a closed environment as shown in Figure 6(b).



(a) (b)

Figure 6. (a) A map of the environment. (b) The 2D Pose Estimate in the Rviz tool.

2.3. **Distress Voice Detection**

Through "Google's Speech to Text API" function, the system can convert the speech into text and the system will send warning notifications when the text contains distress-related phrases. Speech Recognition is a python library for performing speech recognition, with support for several engines and APIs, online and offline. Here we choose Google Cloud Speech API to recognize input speech and convert it to text [31]. PyAudio is required in order to use microphone input. Figure 7 is the process of converting speech to text with Speech Recognition. When person is calling for help, the exception notification will be sent to Line notify to inform his/her family.

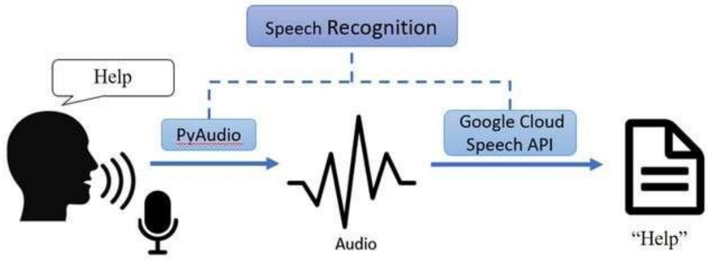


Figure 7. Process of converting speech to text with Speech Recognition

2.4. **Sound Source Identification**

A microphone array has multiple microphones that work together to record sound. Microphone arrays of various geometrical forms have been used for sound source localization and identification [32]. In this research, the Respeaker mic array v2.0 developed by Seeed is used. It has a shape of circular with four digital MEMs microphones located at 90 degrees to each other. This array microphone device is capable of detecting sound from a maximum distance of 5 meters. The ReSpeaker supports USB Audio Class 1.0 (UAC 1.0) that allows connecting to a host for data exchange and estimate DOA. All major operating systems, including Windows, macOS and Linux, are compatible with UAC 1.0 and can run voice algorithms on these systems. In this work, the DOA data during the period of some voice are stored in an array. When the sound signal is detected for more than 2 seconds, the elements of the array are sorted in descending order of occurrence using the sorting algorithm. Then, the recorded DOA data in the array are processed with statistics. We calculate the mean of the selected DOA data within 2 standard deviation. In this method, the interference from the noise sound can be reduced. This resultant DOA data means that the system recognizes sound coming from. The resultant angle value is then published to the robot base control node with ROS topic for rotation as shown in Figure 8. The "/respeaker_node" is the node for evaluating sound direction. According to the resultant DOA data, the robot can rotate to face the sound source, thus, the face detection can be performed by infrared thermal camera. If a person feels sick when the robot is on patrol, the robot can be called through the sound source identification function to face the person who is calling for body temperature and heart rate measurements.

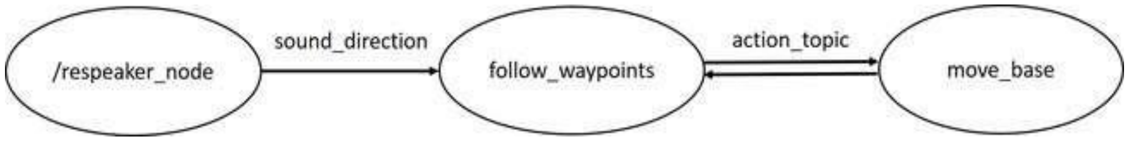


Figure 8. The sound direction can be published with ROS topic for rotation

2.5. **Heartrate Measurement**

2.5.1. **MmWave radars**

MmWave radars transmit electromagnetic wave signals with a wavelength in the millimeter range. The mmWave FMCW radars transmit a frequency-modulated signal continuously by a transmit antenna (TX ant.) [33]. The modulated signals hit objects in their path then reflect. A radar system can determine the range, velocity and angle of the objects by capturing the reflected signal with the receive antenna (RX ant.). An FMCW radar system transmits a chirp signal with frequency as a linear function of time. A chirp of the FMCW is a sinusoidal waveform with start frequency (f_c), bandwidth (B) and chirp duration (T_c) characteristics. The transmitted radio frequency signal varies between f_c and the $f_c + B$ with a chirp period T_c. The frequency slope S is the rate of change of frequency. FMCW transmitted chirp signals which increases in the frequency periodically. The instantaneous frequency f can be expressed as (1):

$$f(t) = f_c + S(t - t_0) \tag{1}$$

where $S = B/T_c$ is the frequency slope and f_c is the starting frequency at time point $t = t_0$. During a chirp period, the frequency increases linearly from fc to $f_c + B$, with a slope of S [34].

While a chirp is reflected off an object, an echo signal will be captured by the RX antenna. The received signal is a replica of the time delay from the transmitted chirp. Suppose the radar detects only a single object, d is the distance to the detected object from a radar, and τ denotes the round-trip time between the radar and the object. Then the round-trip time τ can be mathematically derived as (2):

$$\tau = 2d/c \tag{2}$$

where c is the speed of light. When the RX chirp and TX chirp overlap, a frequency mixer combines the received signal with the transmitted signal to produce two signals with sum frequency and difference frequency. Then, the mixer signal is forwarded to the low-pass filter to generates difference frequency between the receive and transmit signals. Low-pass filter will remove the high-frequency signal. The TX-signal and RX-signal are reflected from an object with round-trip time τ. Through the design of radar, an intermediate frequency (IF) signal with a new frequency f is formed by a "mixer" combining the RX and TX signals. IF signal is only valid in the time interval when the RX chirp and the TX chirp overlap, the frequency versus time of the IF signal is a straight line. The round-trip time τ is typically a small fraction of the duration of the transmitted signal T_c. The beat signal spectrum is a ‘sin(x)/x’ or ‘sinc’ function which center beat frequency is f_b, and spectral width is $1/(T_c - \tau)$, equal to the reciprocal of the period in which the received and transmitted signals overlap in time. For $\tau \ll T_c$, the target spectral width is approximately $1/T_c$. Thus, the non-overlapping segment of the TX chirp is usually negligible. A Fourier transform converts a time domain signal into a frequency domain, so a single tone in the time domain produces a single tone in the frequency domain. In the case of quasi-stationary or a simple stationary scene, a signal object in front of the radar produces an IF signal with a constant beat frequency f_b derived as (3):

$$f_b = S \cdot \tau = S \cdot 2d/c \tag{3}$$

where S is frequency slope and any object movement is negligible. Hence, by measuring the beat signal spectrum, the target range d can be calculated by (4)

$$d = 0.5 \cdot c \cdot f_b / S \tag{4}$$

Thus, in FMCW radar, range is proportional to beat frequency. By measuring the spectrum of the beat signal, the target range d can be obtained.
The IF signal can be expressed as

$$x_{IF}(t) = Ae^{j(2\pi f_b t + \emptyset_0)} \tag{5}$$

Where A represents the amplitude, f_b is called the beat frequency, and $\emptyset_0 = 4\pi d f_c / c$ is the initial phase of the IF signal. The difference between the initial phases of the RX chirp and TX chirp is the initial phase of the signal at the mixer output. The IF signal is digitized at the Analog-to-Digital Converter (ADC) to obtain the data samples. Consider an IF signal that is sampled N times by an ADC converter resulting a discrete-time signal sequence $x(n)$, periodic sampling of the analog signal $x_{IF}(t)$ will produce such sequence with the numeric value of nth number in the sequence.

$$x(n) = x_{IF}(nT) \qquad 0 \leq n \leq N \tag{6}$$

where n is an integer and T is the sampling period.

By performing discrete Fourier transform (DFT) operation on x(n), the kth DFT output can be expressed as (7):

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{kn} \qquad 0 \leq k \leq (N-1) \tag{7}$$

where N is the number of samples to be transformed, n is the sample index of the time domain signal, k is the frequency index of the frequency domain signal which refers to frequency step values, and $W_N^{kn} = e^{-j2\pi kn/N}$. The actual algorithm to processing the IF signal is fast Fourier transform (FFT). The processing operation resolves objects in range referred as the "range-FFT".

2.5.2. **Heart Rate and Respiration Rate Measurements**

The signal phase of the range-FFT can be extracted to estimate the object displacement, in our case the subject's chest [15]. The resulting phase $\Delta\phi$ can be derived as (8):

$$\Delta\phi = 4\pi\Delta d/\lambda \tag{8}$$

λ represents Radar wavelength and Δd represents the displacement.

The chest displacement is filtered with a bandpass filter to separate displacements due to breathing and heart-beating as shown in Figure 9. To extract the heart rate, FFT is applied to the filtered signal. Thus, the mmWave radar can used to measure heart rate and respiration rate in real time, and the system can determine whether the body is moving through "SumEnergyHeartWfm" [35] to decide whether to use the data or not. The data will be stored and processed to estimate the heart rate while the person is static.

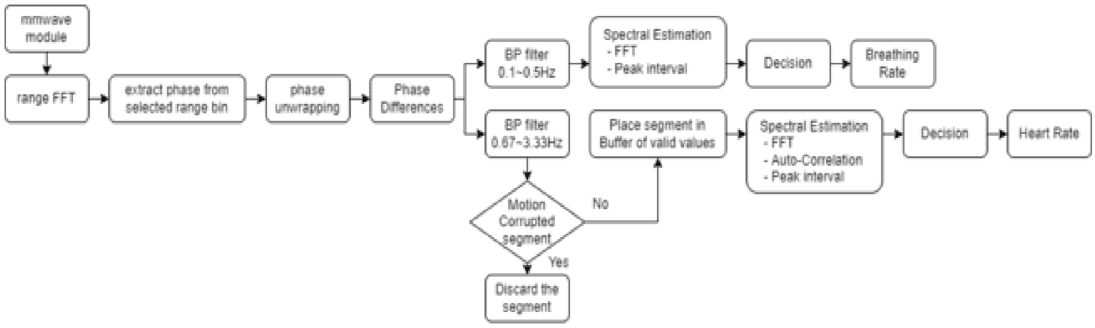
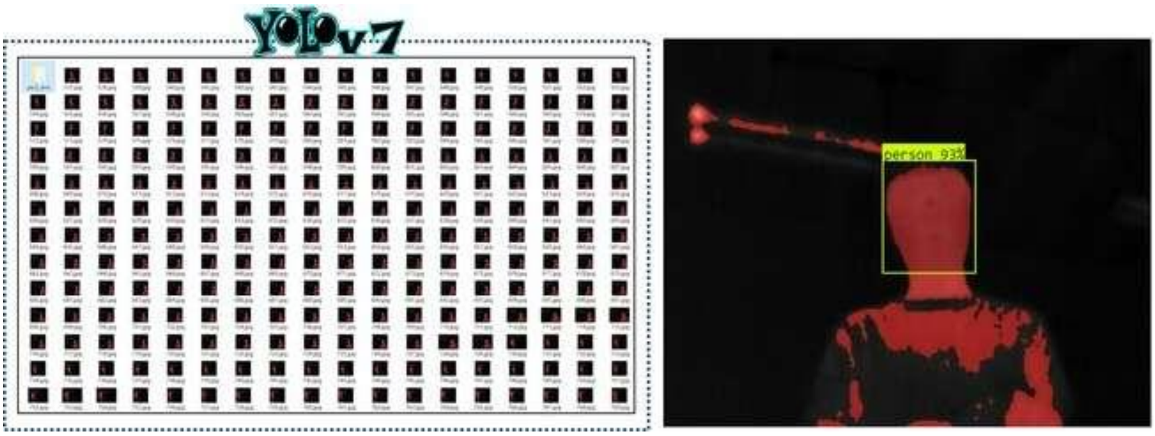


Figure 9. The process flow for heart rate and respiration rate measurements

2.6. **Face Detection & Body Temperature Measurement**

As a single-stage detector, YOLOv7 has the advantages of high accuracy and speed. In this study, we try applying YOLOv7 to perform face detection. The infrared thermal imaging camera is used to obtain the face dataset and tag the sample. The YOLOv7 neural network is trained to detect and locate the face as shown in Figure 10, and we also can measure the temperature in the resultant ROI range. We built it into a ROS package for face detection and body temperature measurement.



(a) (b)

Figure 10. The system architecture (a) the training data set, (b) the validation result

2.7. **Blockchain**

In the block chain, the “previous hash” of the current block equals the “hash” from the previous block. When calculating the hash of the current block, all the data will be added to the previous hash to generate a new hash value as shown in Figure 11. Therefore, when the data of any block in the block chain is tampered with, it will be discovered by validation program when the previous hash of the next block is not equal to the hash from the previous block during the validation process. Thus, it will be considered as an invalid modification. The hash value between blocks is inseparable from the uploaded data. Therefore, this technique can be used to prevent the tampering of the vital sign data and to prevent the use of data for criminal purposes.

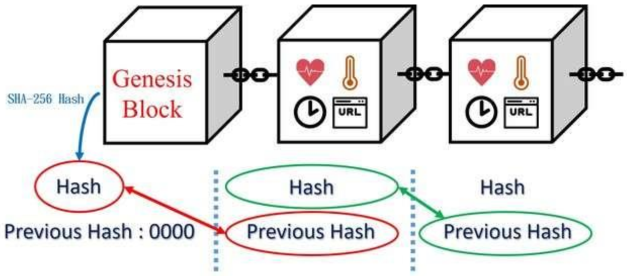


Figure 11. The concept of blockchain

2.8. Cloud Storage

We use Firebase Storage and Firebase Realtime Database services to implement IoT service. As the "/mix_node" node in ROS system can subscribe topics to get and process the body temperature data (from "/Thermal camera" node) and heart rate data (from "/mmwave" node). The resultant thermal images of human face detection are stored in Firebase Storage and named with the timestamp when uploaded. There is a Uniform Resource Locator (URL) for each stored image in Firebase Storage. In real-time database, we process the data with blockchain technology by combining heart rate, body temperature, time stamp, thermal image URL, the hash value of the previous block data and index to calculate the hash value for the next block, and then upload all the data to the cloud space of database to generate the next block when the person is not moving as shown in Figure 12. While the vital sign is abnormal, the notification will be sent to Line notify through IFTTT service.

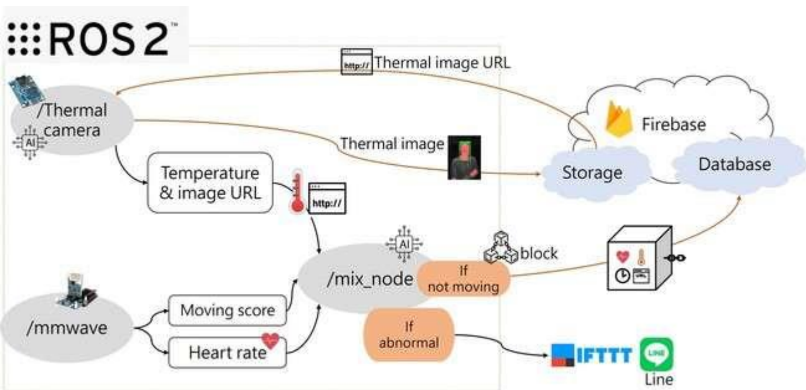
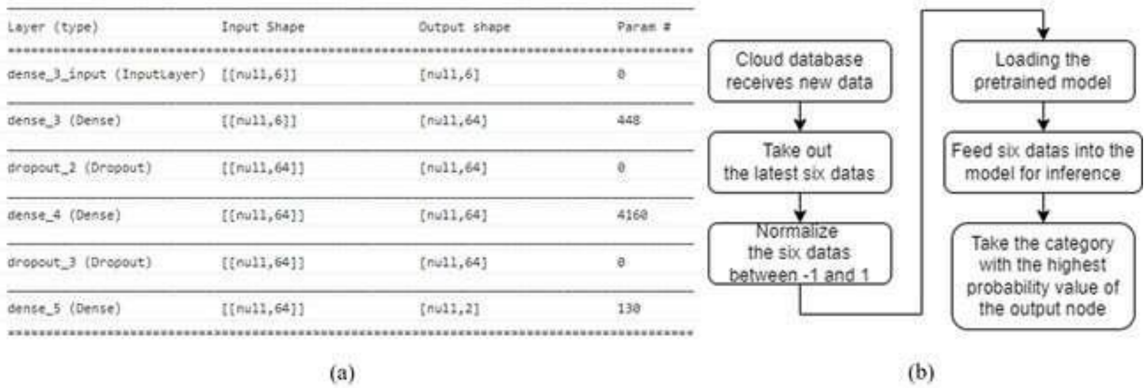


Figure 12. The data process flow for the cloud storage

2.9. Detection with AI Model and Alert Notification

We use the latest 6 heart rate data in the cloud database and pre-trained AI network models for heart rate stable status classification as shown in Figure 13 (a). There are 6 input nodes and 2 output nodes for this AI model. The notifications can be sent while heart rate irregularity is predicted by AI model. As TensorFlow.js [36] is the implementation of the popular ML framework of Google in Javascript. We built the AI model with Keras framework, and trained the AI model on Google Colab. Then we converted the trained model to tensowerflow.js and stored the model file on cloud by firebase hosting service. We conducted an AI model for heart rate stable status detection on Firebase Hosting and build a heart rate curve website to show the results of AI inference in the browser. The process flow of AI inference is as shown in Figure 13 (b). We also use the Webhooks and Line services in IFTTT, trigger services by sending web request commands and publish messages through Line Notify. In this system, the abnormal measurement value will be used as a trigger service item and an alert notification will be sent to the user's cell phone through Line Notify to prevent unfortunate events from happening.



Layer (type)	Input Shape	Output shape	Param #
dense_3_input (InputLayer)	[[null,6]]	[null,6]	0
dense_3 (Dense)	[[null,6]]	[null,64]	448
dropout_2 (Dropout)	[[null,64]]	[null,64]	0
dense_4 (Dense)	[[null,64]]	[null,64]	4160
dropout_3 (Dropout)	[[null,64]]	[null,64]	0
dense_5 (Dense)	[[null,64]]	[null,2]	130

Figure 13. (a) The AI model for heart rate stable status detection. (b) The process flow of AI inference.

2.10. Multi-Target Navigation with Interrupt Handling

The navigation function can be modified to an MCU-like interrupt function for event occurrence, which can interrupt the patrol when a custom trigger occurs and execute the interruption process and return to the patrol target before the interruption after the interruption process is completed as shown in Algorithm 1. By editing the programs in “/follow_waypoint” node and using the “wait_for_message” function of ROS, it can continue to wait for the message of the trigger point during the patrol process. If it enters the interrupt program, the patrol will be stopped. After the interrupt program flow is completed, the robot can patrol again. There are two interruption processes designed for the work. One is interrupt through sound source identification, so that the patrol can be interrupted and the robot can be controlled to rotate to face the person who is calling. The other is face detection through the infrared thermal imager. When the robot is patrolling and finding human face through thermal camera, an interrupt will be triggered to stop the robot patrolling and start measuring vital signs.

Algorithm 1. The proposed interrupt method for multi-target navigation.

```
while(1):
  try:
    angle = waiting for specific topic message with limited timeout
    if (current angle == angle)
      raise ValueError
    if (current angle != angle)
      cancel the current goal on navigation
      waiting for specific topic for interrupt handler completed with timeout=None
      send the current goal for navigation
      current angle = angle
      continue
  except rospy.ROSException as e:
      pass
  except ValueError:
      pass
  result = get the status for goal
  if (result ==SUCCEEDED)
      break
```

3. EXPERIMENT RESULTS

In this paper, we add the vital sign monitoring functionality to a commercially available Neuron Omni Bot robot. We use an NVIDIA Xavier NX to connect an FMCW–MIMO radar sensor operating in the 60 GHz RF band (Batman BM201-VSD mmWave EVM Kit) [37], the IWR6843 sensor from Texas Instruments, and the Thermal Camera FLIR Lepton 3.5 with 160x120 resolution to detect the heart rate of people and temperature running, respectively, by running algorithms on an NVIDIA Xavier NX Developer Kit. We also add hearing capability to the robot. We use a Respeaker mic array v2.0 with a NVIDIA Jetson Nano Developer Kit. The implemented robot is as shown in Figure 15. The corresponding function for each hardware is shown on Table 1.

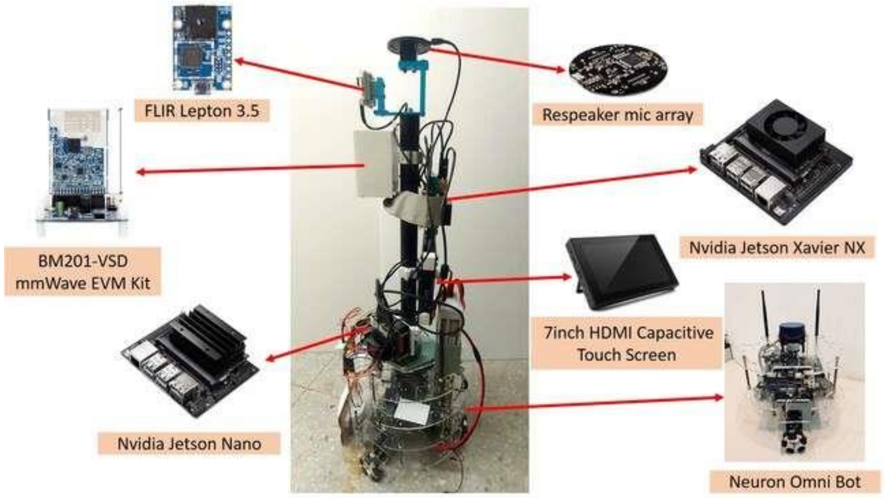


Figure 15. The proposed ROS-based intelligent vital sign monitoring robot

Table 1. The corresponding function for each hardware.

Function	Hardware		
Database Blockchain System Real-time notification of abnormalities	NVIDIA Jetson Xavier NX		
Face Detection & Body Temperature Measurement	NVIDIA Jetson Xavier NX	IR Camera	
Heart rate measurement	NVIDIA Jetson Xavier NX	mmWave radar (BM201-VSD)	
Sound Source Identification	Neuron mini Bot	NVIDIA Jetson Nano	Respeaker mic array v2.0
Navigation	Neuron mini Bot		

3.1. Experiment Results of Sound Source Identification

In this research, the Respeaker mic array v2.0 developed by Seeed is used. The DOA data for each chunk during the period of some voice are stored in an array. When the sound signal is detected for more than 2 seconds, the elements of the array are sorted in descending order of occurrence by using the sorting algorithm. Then, the stored DOA data in the array are processed with statistics method. The process flow for sound source identification is shown in Figure 15. The experiment results of sound source identification are shown in Figure 16. The accuracy after applying the processing algorithm is above 62% for sound source identification.

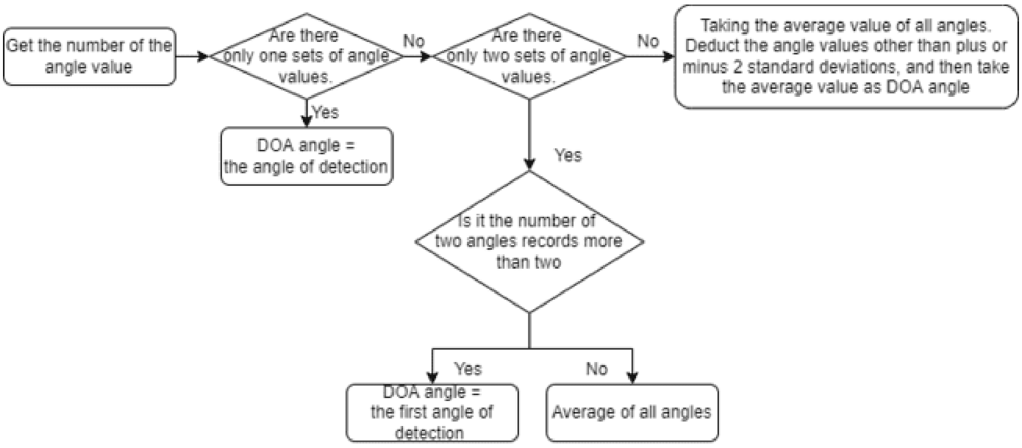


Figure 15. The process flow for sound source identification

Figure 16. The experiment results of sound source identification

3.2. Experiment Results of Face Detection and Body Temperature Measurement

The YOLOv7 neural network is trained to detect the face. By using augmentation methods on roboflow website, the dataset was constructed with about 1600 images. For training purposed, the dataset was divided into train dataset and test dataset. The portion of train dataset is 92% from datasets, 6% for validation dataset and 2% for test dataset as shown in Figure 17. Figure 18 shows the results of loss and precision. The precision for person is 0.994. Figure 18 shows the results of face detection and temperature measurement in a region of interest (ROI) range. The temperature shown in Figure 19 is 31.76 degrees Celsius.

Figure 17. The data set on the roboflow website

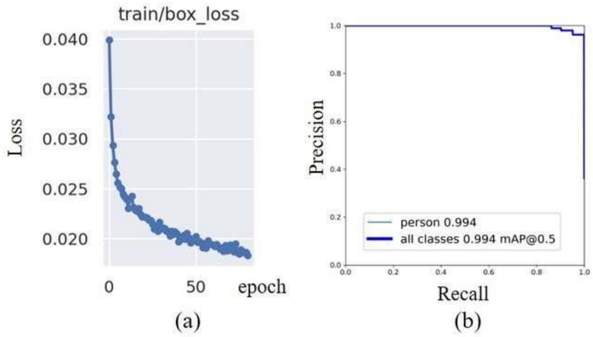


Figure 18. The results of loss and precision (a) loss versus epoch, (b) precision versus recall

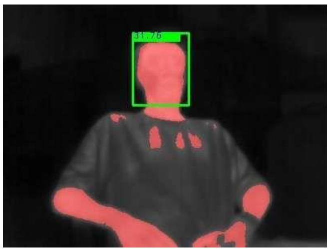


Figure 19. The results of face detection and temperature measurement in the ROI range

3.3. **Experiment Results of Heart rate measurement**

The mmWave radar can measure heart rate and respiration rate in real time. Through "SumEnergyHeartWfm" value, we can judge the body moving or not to decide whether to store the data or not. The data will be processed and estimated for the heart rate while the person is static. Figure 20 shows the heart rate measurement results with a person moving and static. Figure 21 shows the abnormal situation that the measured heart rate is too low.

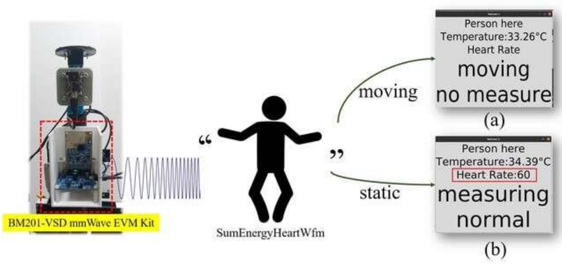


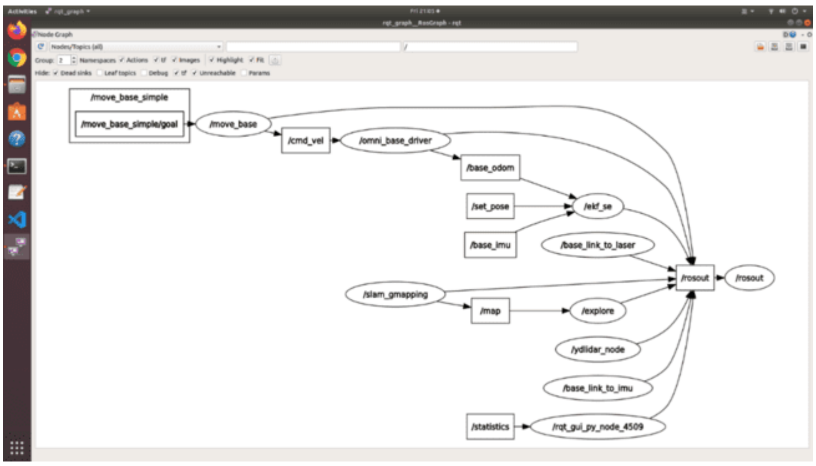
Figure 20. The results of the heart rate measurement (a) a person is moving; (b) a person is static

(a) (b) (c)

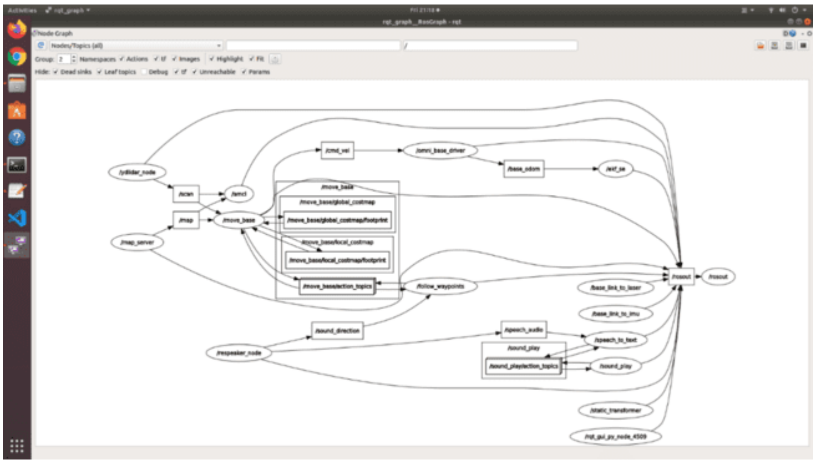
Figure 21. The abnormal situation: (a) a person is in front of the proposed robot; (b) the detected thermal image and temperature; (c) the alarm occurred owing to the measured heart rate is too low

3.4. **Experiment Results of Navigation**

In the ROS robot operating system, we use SLAM (Simultaneous Localization and Mapping) technology to construct a map of the environment, and then use the ROS navigation and custom package to build a new autonomous obstacle avoidance and self-defined multi-target navigation function in a closed environment This proposed robot is developed based on the ROS environment, and it uses the ROS topics method to communicate between nodes to support the needs of multi-hardware module integration development. Figure 22 (a) shows the ROS nodes for robot SLAM. In rqt_graph, you can see the "/explore" node as a checkpoint node, which can be used to automatically create a map, and receive sensor data through "/ydlidar_node", "/ekf_se" and other nodes, and use the "/move_base" node to transmit the message with "/cmd_vel" topic to control the robot to realize the map construction by automatic exploration. Figure 22 (a) shows he ROS nodes for multi-target navigation. You can see that follow_waypoints nodes are used as checkpoint nodes, which can be used to wait for the messages with "/sound_direction" topic to trigger interruptions and publish new target points to "/move_base" node. After patrolling to one of its endpoints, it will publish the next target point to navigate the robot to the new target to realize multi-target navigation and patrol.



(a)



(b)

Figure 22. The ROS nodes in the proposed system (a) for SLAM, (b) for multi-target navigation

3.5. Experiment Results of Cloud Storage

We use Firebase's Storage and real-time database to save the judged face pictures in Storage and name them with timestamps and record images and generate URLs. We combine the data with blockchain technology, using heart rate, body temperature, time , thermal image URL and index to calculate the hash value of the current block data. We use SHA256 to get the hash of each block referred as equation (1). Then, upload all the data to the cloud database. Figure 23 shows the stored data in Firebase Realtime database. You can see that the value of previoushash of index 4 block is equal to the value of hash of index3 block. Figure 24 shows the stored imaged in Firebase Storage.

$$\text{hash} = \text{SHA256}(\text{heart rate}+\text{body temperature}+\text{index}+\text{timestamp}+\text{previoushash}+\text{URL}) \qquad (1)$$

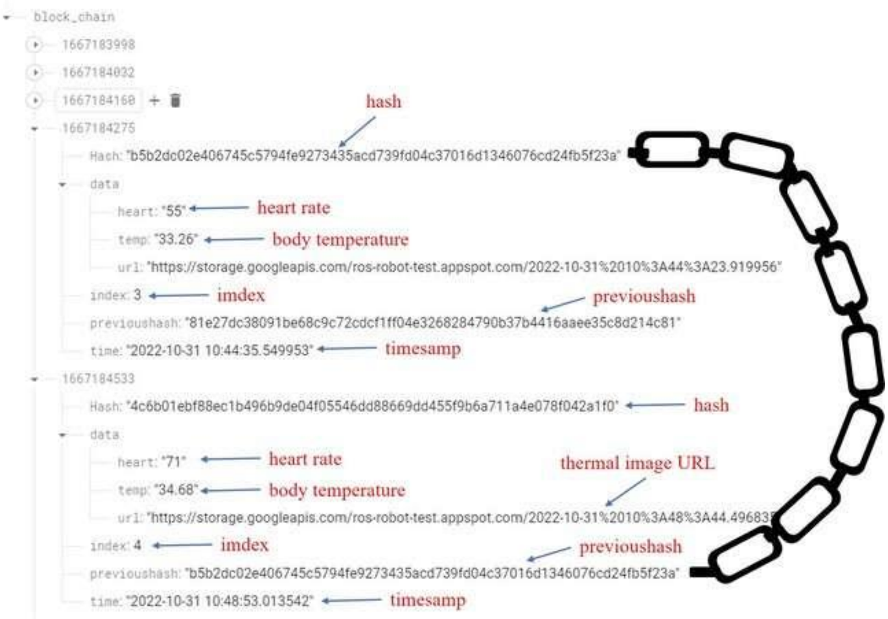


Figure 23. The recoded data in Firebase Realtime database

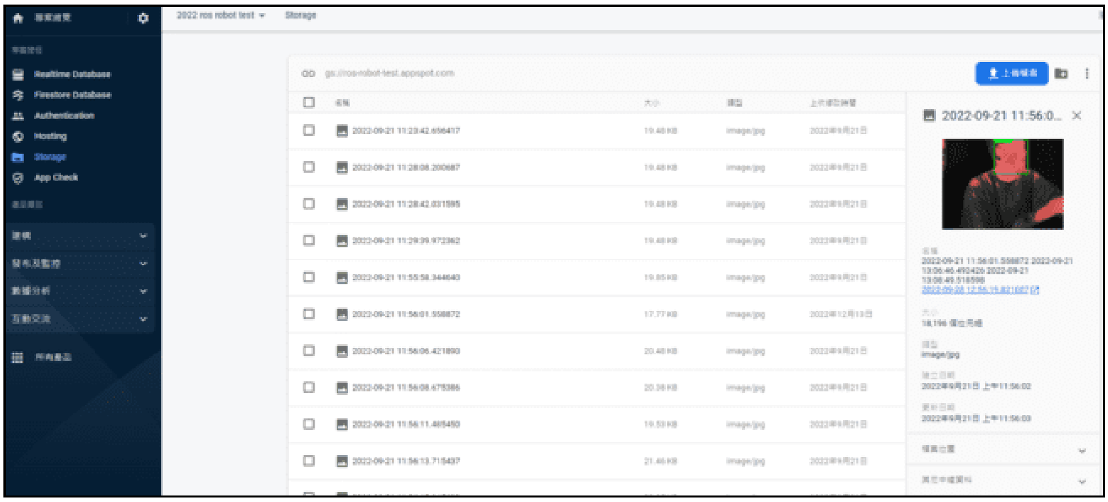


Figure 24. The recoded images in firebase storage

3.6. **Experiment Results of Detection with AI Model and Alert Notification**

In this work, when one of the data of the heart rate or body temperature is abnormal, the function of webhooks through the IFTTT service is used to send the data to the Line to inform the user's family as shown in Figure 25. After the notification, you can see all the data of a single measurement, the data of abnormal warnings, the timestamp, the thermal imager pictures stored in Firebase Storage, and the heart rate monitoring curve on Firebase Hosting to understand the abnormal data and the actual situation of the elders at home as shown in Figure 26.

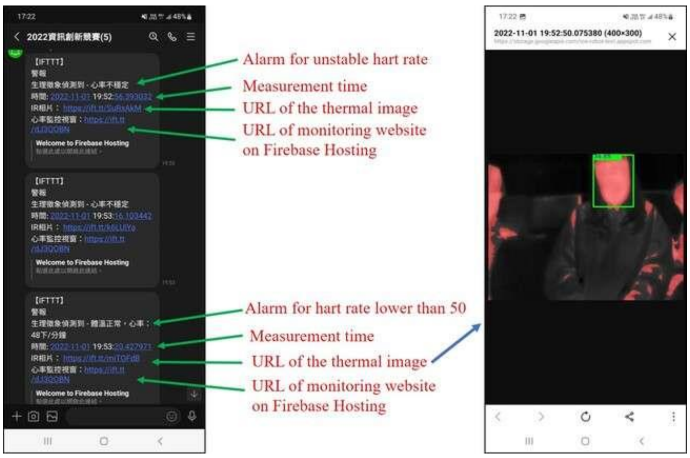
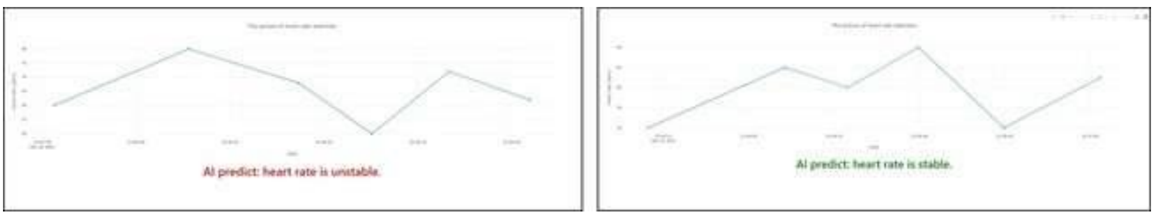


Figure 25. Results of Line notification through IFTTT



(a) (b)

Figure 26. The heart rate monitoring curve on Firebase Hosting website (a) unstable (b) stable

4. CONCLUSIONS

We hope to solve the problem of not missing the golden hour for rescue when the elderly or patients with heart disease are suffering sudden death or emergency event at home. Therefore, this study proposes an intelligent vital sign monitoring robot based on ROS. It also uses frontier-based exploration algorithm that allows the robot to explore and build a map of the user's home. We also develop multi-target patrols for home safety. An array microphone is used to hear person calling for help and the system can find out the sound direction. Then an interrupt will be triggered to stop the robot patrolling and start measuring vital signs. The heart rate is measured and monitored through the mmWave radar. Moreover, the infrared thermal imager is combined with object recognition to detect the human face and measure body temperature, and the measured body temperature and heart rate data can be uploaded to cloud database. Considering data protection and privacy issues, blockchain technology is used to establish a vital signs database. When the system detects an abnormal status, it will send a Line message notification to notify the family or the rescue unit in time. With the proposed system, it can take care for the "heart" of the elderly and home safety. The reason for not using RGB cameras but using thermal camera for face detection is that we concern the privacy. The system allows family members work with peace of mind outside and avoid "sudden death" or missing the best opportunity for golden rescue in case of abnormal situation.

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