Medical system based on thermal optical system and neural network

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ABSTRACT

Military personnel in the training or operational phases always need constant medical examination, but the presence of efficient medical care is difficult to implement in real-time for such cases. A wireless system for thermal tracking of soldiers was proposed, as well as tracking their vital signs in real time. Thermal cameras are used with an optical system designed to increase the accuracy of the thermal images captured as the change in the electrocardiogram, heart rate, and temperature measurements are measured using a specially designed circuit. The results from both the thermal system and the biometric system are combined and sent to a computer for analysis using a model prepared with neural network technology. The proposed system was tested, and a database was created for 127 males and 110 females during training and rest times. The neural network model achieved a response time of 85 seconds until the release of the final analysis, and the accuracy of the proposed tracking system is 96%. The main contribution of this paper is the design of an integrated portable system for rapid, in-field, real-time military medical diagnostics.

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1. INTRODUCTION

Day after day, the importance of the technology of transmitting information and data wirelessly appears, and its importance increases when it is employed to transmit medical data to soldiers and individuals in the training or operations ground where doctors and paramedics cannot be present regularly. Most of these researches begin with studying the electrocardiogram (ECG), heart, or brain. The electromyogram (EMG) is studied using self-adhesive electrodes on the area from which the signal is to be read. This is done through an electronic circuit that filters the received signal from the muscle. These circuits were used to classify human finger movement using a surface electromyography (sEMG) or MyoWave sensor. Numerous data of finger movements and hand gestures were recorded and used to form a prototype for machine learning [1]–[4]. In 2019, researchers focused on increasing the accuracy of the signals received from the EMG sensors. Where several adaptive filters were used to remove noise, taking into account the surrounding environmental changes. This development was also tested to ensure its validity, and the researchers confirmed that the proposed development reduces the noise sufficiently on the EMG signal [5]. At the beginning of 2020, the main direction of the researchers was to create a simple and inexpensive circuit to receive EMG signals. Most of the circuits designed this year have adopted a series of filters that work to reduce interference to the received signals. Several developments have also been made to test these circuits in real time. The design was based on an ARM Cortex-A53 processor. These developments proved efficient as they reduced the actual implementation time of receiving electrical signals, but this came at the expense of reducing the EMG features. The development did not stop there as using data acquisition (DAQ) and microcontroller; the sEMG system was built in 2021. The proposed system consists of 12 channels to treat shoulder signals. A prototype was added using machine learning techniques to identify the different patterns of shoulder movement. This experiment demonstrated a new approach to studying multichannel shoulder sEMG signals in real time [6]–[9].

Khushaba and Nazarpour [10] used dry electrodes to process the EMG signal in real-time using an adaptive filter to reduce noise. They analyze the received signals and sort them into time and frequency domains. The methodology proposed by the researchers proved that it reduces the noise sufficiently. Bai *et al.* [11] designed a circuit to collect the ECG signal with the addition of a circuit to remove noise. The results showed that the proposed design is suitable for mobile ECG devices due to the high accuracy of its results. Pham-Nguyen *et al.* [12] proposed a mobile wireless system to receive the EMG signal. The proposed system was tested on receiving calf and biceps signals. The researchers emphasized the proposed system gave high accuracy and that the system is light in weight and small in size. Nardo *et al.* [13] used continuous frequency domain waveform (CWT) analysis to detect muscle activity. As a practical application of the integration between engineering and medical information, the researchers directed to study the understanding of the relationship between falsehood and the disturbance of cardiac signals. An ECG was used to understand this relationship. Tests were conducted on several students while playing to assess the different cases of truth and deception. The studies then developed to suggest a methodology for detecting lies by detecting the change in the blink of an eye [13]–[16].

In 2018, the development of devices and applications for analyzing the electrical signals of the brain, nerves, and heart to detect lies became the focus of many researchers. Scientists have developed many methods and methodologies using machine learning technology to classify heartbeats and analyze electroencephalogram (EEG) signals taken from the human brain to detect lies. A test was conducted on a group of 10 people, and the extracted readings were analyzed. However, scientific research has not stopped developing, as some have used the MUSE sensor to receive EEG signals. The results are analyzed to discover deception and lies. Recent research has achieved higher accuracy than its counterpart [17]–[20]. Numerous scientists have used neural network technology and deep learning to create models that analyze vital signs and parameters to discover truth and lies. These templates can assist law enforcement officials with questioning, as well as help recruiters for companies. These models relied heavily on the automatic identification of the truth from the electrical signals of the heart and cerebral cortex. There are also some special techniques that are used with machine learning models to measure heart rate and respiratory signals [21]–[23].

Despite the efforts made by researchers to measure important vital parameters and apply them in daily civilian life, they did not address their military uses. The researchers also did not address the improvement of thermal imaging performance by using any of the secondary or auxiliary systems. Therefore, in this paper, an integrated portable system for measuring vital parameters is presented in addition to a thermal tracking system used for military diagnostic purposes in military training yards and fields. The proposed system is designed in a unique way to be compatible with military uniforms, as it is installed in a certain way inside military uniforms to measure vital parameters and send them to the computer wirelessly. At the same time, thermal imaging of individuals is done through the thermal camera and the built-in optical system, and the measurements are stored on the computer. The measurements are collected and analyzed through a model designed using neural networks to extract the final decision on the extent of the soldier’s efficiency for training or conducting the field mission.

2. RESEARCH SIGNIFICANCE

The main contribution of this paper is the design of an integrated portable system for rapid, in-field, real-time military medical diagnostics. The system is designed to be installed inside the soldiers' military uniforms so that it sends measurements in real time without affecting the soldiers' performance in training. The range and quality of thermal images have been improved, which increases the distance of thermal image capture. The designed neural network model gives a decision on the validity of the soldier to participate in the operations according to the measurements that take place in a time not exceeding 85 seconds.

3. METHOD

In this section, the work method is presented, which is divided into the: i) EMG circuit design, ii) the most important specifications of the thermal imaging camera, and iii) optical system design to improve image quality. Figure 1 shows the functional outline of the proposed work methodology. It is noted from. Figure 1 that the circuit for measuring the electromyogram and heart rate depends on a microcontroller to receive the data and send it wirelessly to the computer. At the same time, images are captured with a thermal imaging camera supported by a unique optical system, and the images are sent to the computer.

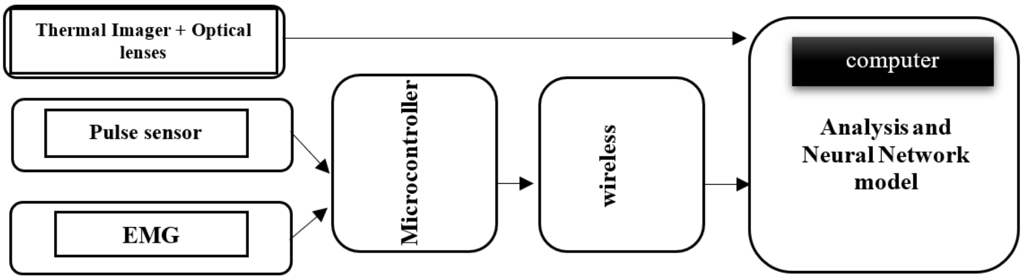


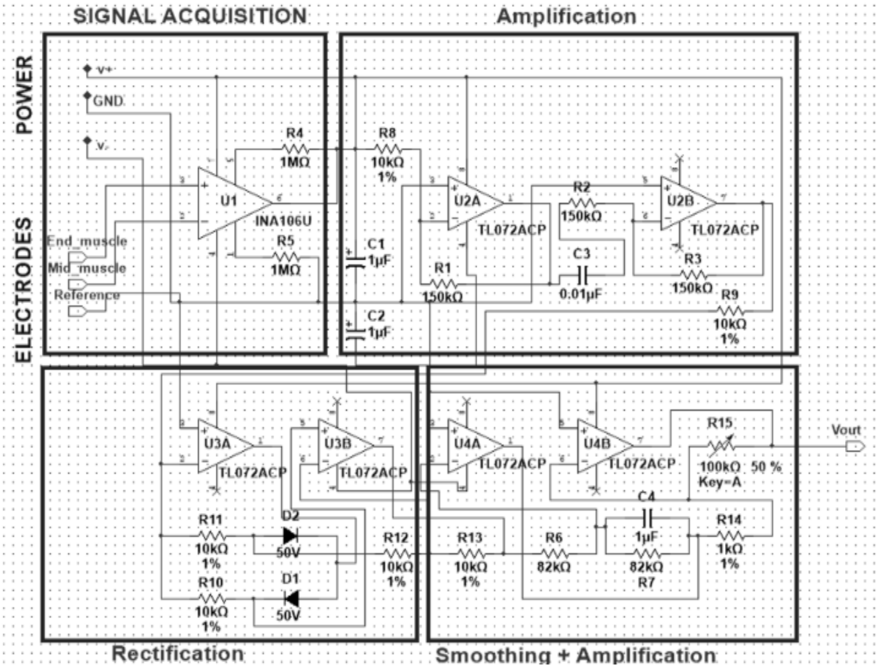
Figure 1. Block diagram of proposed system

MATLAB is used to analyze the captured thermal images and analyze the electromyographic signal, as well as other vital data. Python is used to design a program using neural network technology to help decide whether soldiers are fit for missions or medical care. The outputs expected to be obtained from the supervised machine learning model is the initial diagnosis of the presence of any defect in the vital readings of individuals, as well as the follow-up of the development of the vital readings during training and the immediate reporting of any defect. The model is supervised during training until we reach the highest possible diagnostic accuracy during actual work in the field. EMG is measured to diagnose neurological disorders; however, it can be used with other systems, as in this research. Existing EMG systems are too expensive and out of reach. Figure 2(a) shows the proposed design of the EMG circuit. Figure 2(a) shows the division of the circuit into four sections (signal acquisition, amplification, rectification, and smoothing/amplification), respectively. We will start with the signal acquisition stage, where the INA106 IC is used as a difference amplifier. The amplifier works to measure and amplify small voltage differences between the measurement terminals. This amplifier is connected with two 1 MΩ resistors to ensure the optimum voltage delivery (to make the measurements more accurate). The amplifier output is connected to the amplification stage, which is the second stage. At this stage, the signals are taken and amplified on two chains. The inverting amplifier is connected to amplify and reflect the signal using the TL072 chip and two resistors of 150 and 10 kΩ, respectively. These two resistors are used to adjust the gain of the amplifier. To reduce noise and also to compensate for the error in the direct current (DC) in the signal, a capacitor is added. The second amplifier works as a high-pass filter that cancels out the low-frequency noise on the signal. This is done by connecting two 150 kΩ resistors in addition to a 0.01 uF capacitor. The third stage (rectification) is the signal correction stage.

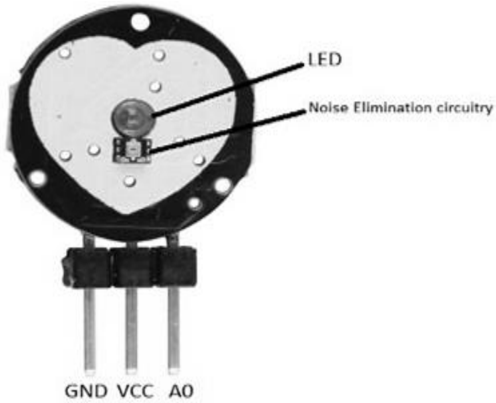
In this phase, the negative parts of the received signal are taken and converted into positive ones. As a result, the received signal becomes all positive. In addition, a low-pass filter is used to prepare the signal for transmission to the microcontroller. All of this is done using (five 10 kΩ resistors, two 1N4148 diodes, and another TL072). The final signal is sent from the third stage to the fourth stage (smoothing/amplification). This stage consists of a low pass filter to filter the received signal and send it to the microcontroller. To design this stage, another TL072 chip, two 82 kΩ resistors, a 100 kΩ trimmer, and a 1 uF capacitor is used. Then the signal measurement electrodes are connected, one to the GND pin, the other to pin 2 of the INA106 IC chip, and the third pin to pin 3 of the same chip. A small protection circuit is designed using two 1 uF capacitors. To connect the signal to the microcontroller, pin 1 of the fourth chip TL072 is connected to the A1 input of the microcontroller (ATmega328P). At the same time, the pulse sensor is used to measure the change in heart rate, as shown in Figure 2(b). This sensor measures the change in the volume of blood vessels coming from the heart with a finger. The measurement is done by placing the index finger on the light-emitting diode (LED) in the middle of the sensor, and then the sensor measures the change in light as a result of the expansion in the capillary vessels of the finger. The sensor output is analog, so it is connected to pin A2 in the microcontroller.

A thermal camera is a camera that takes pictures using infrared (IR) radiation, unlike regular cameras that use visible light. The most important advantage of thermal cameras is that they are sensitive to wavelengths from 1 micrometer to 14 micrometers. Figure 2(c) shows the thermal camera used in the proposed system. Figure 2(c) illustrates the MD16U human body temperature measurement thermal imaging. Table 1 provides some specifications for thermal imager as shown on the official website. As it appears from the table, The temperature range is 30 °C to 40 °C with an accuracy rate of ±0.3 °C. The distance that thermal imager measures the temperature is greater than 0.5 m, as shown in Table 1. This represented a major challenge in this work. Therefore, it was necessary to design an optical subsystem to operate in the near and mid-infrared wavelengths.

The range of the thermal imager camera when capturing thermal images is not more than half a meter, and this greatly affects some of the wavelengths around which this work revolves. It was, therefore, necessary to design and implement an optical system that would increase the range to five meters. The proposed optical system shown in Figure 3 has a resolution of five megapixels.



(a)



(b) (c)

Figure 2. The main parts of the system: (a) circuit schematic of EMG, (b) the pulse sensor and (c) thermal imager

Table 1. The specification of thermal imager

Specification	Description
Pixel pitch	17 um
Frame rate	≤12 Hz (image and temp output at the same time）
Image calibration	Single point, two-point, dynamic dead point correction, automatic gain, and false color.
Temperature range	30～40℃
Temperature accuracy	Inbuilt black body, ±0.3 °C (ambient temperature 20~30 °C)/±0.5 °C (ambient temperature 10~40 °C)
Temperature data output	120×322（Image and temperature stitching up and down）

Figure 3 shows a 2D diagram of the optical subsystem. The optical system consists of an array of lenses that collect incident light. The front lens of this system is made of SK2 and has a radius of 118.9 mm and a thickness of 10.44 mm. The rear lens has a diameter of 100.961 mm. The two surfaces of the lens are spherical and convex, but their radii have different curves. The use of an aspherical lens reduces monochromatic aberration. Also, the use of a group of lenses, as is done in the proposed design, can help in moving parallel rays. The two mileage angles on the center lens are taken into account as the sk16 has a thickness of 6.34 mm, a front radius of 52.3 mm, and a rear radius of 32,651 mm. This lens reduces astigmatism, coma, and spherical aberration. As for the last lens, it is manufactured from SK16 and is 111.76 mm thick, with a front radius of 48.4 mm and a rear radius of 33.956 mm. That last lens is the one that faces the charge-coupled device (CCD), so it is a convex coiled lens that solves the problems of image and field curvature. The design and manufacture are based on the theories of optical systems and image aberration as in reference [24], [25]. Optical materials for lenses and anti-reflective coatings are selected for lighter weight and reduced light absorption and reflection. Table 2 shows the most important fabrication characteristics of the three lenses used in the proposed optical system.

Figure 4 shows a seidel diagram of the lens array using Win Lens and Zemax software and gives information for the best results for the deviation values for the proposed optical system. Detailed values for each type of optical aberration are shown in Figure 4, where the red color expresses spherical expressions. While green indicates coma and violet indicates astigmatism. Field curvature, lateral color, axial color, and distortion aberrations are distinguished by blue, light green, dark green, and light blue, respectively. As shown in (1) and (2) are used to obtain the Seidel aberration function [25].

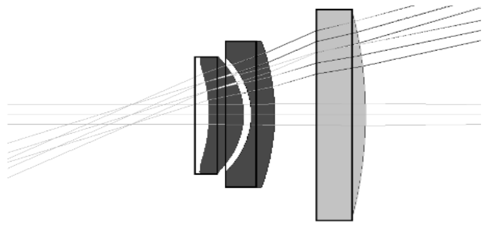


Figure 3. Design of optical system

Table 2. Technical speciation design of an optical subsystem

Lens Number	Effective Focal Length	Numerical Aperture	Lens Material	Clear Aperture (f)
1	8.0 mm	0.547	S-LAH64	7.71 mm
2	10.0 mm	0.545	S-LAH64	9.88 mm
3	12.0 mm	0.546	S-LAH64	13.50 mm

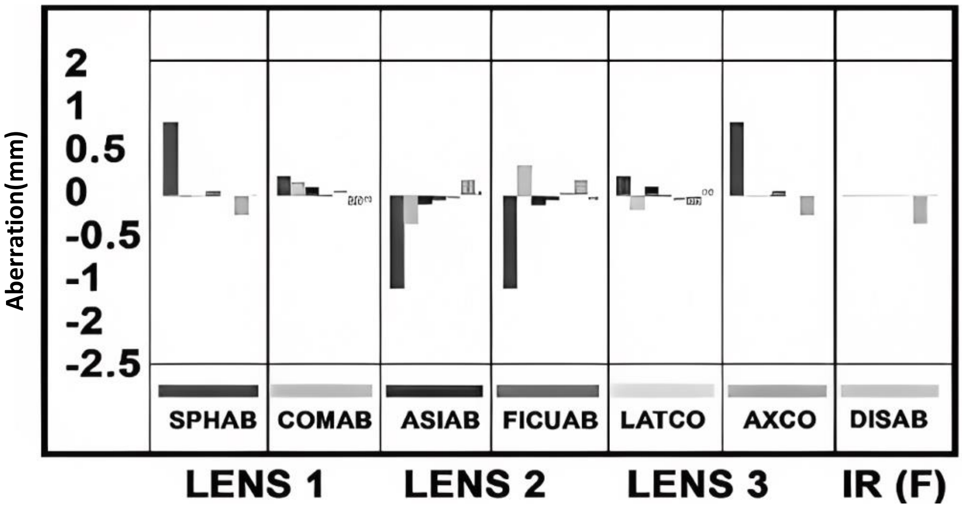
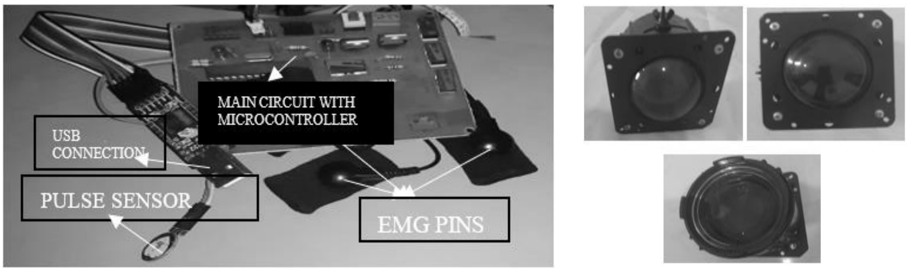


Figure 4. Seidel diagram of the lens array

$$ƐX = S1ρ3 \sin Φ + S2Y ρ2 \sin 2Φ + PY2 ρ\sin Φ \quad (1)$$

$$Ɛy = S1ρ3 \cos Φ + S2Y ρ2 (2+\cos 2Φ) + (S3+ P) Y2 ρ\cos Φ + S5Y3 \quad (2)$$

where *ƐX* and *Ɛy* are the Seidel aberration in the x and y-axis, respectively, while S1 represents the spherical aberration and S2 is the Coma coefficient as illustrated in (1). S3 and S5 indicate astigmatism and distortion, as shown in (2). The Petzval parameter is denoted by the symbol (P). For the equations to give an accurate result, it was necessary to add the ideal height of the image plane and also the position angle of the beam, and the height of the beam shining on the lenses and symbolize them with the symbols (Y, Φ, and ρ) respectively. A model was created for the laboratory experiment before the field experiment inside the military uniforms. Figure 5(a) shows the final diagram of the electromyogram and heart rate circuit. All electronic components used are available in the local market. The optical system is implemented using three lenses after designing them on the Zemax program. A portable bag weighing no more than 500 grams is designed to carry the thermal camera and the optical system. There is also a three-legged stand for placing the camera and the optical system on it while taking measurements. The set of lenses is manufactured according to the specifications mentioned in the first section, taking into account that the length of the chassis is 20 cm, the diameter of the interface is 10 cm, and the middle diameter is 5.5 cm. The optical system is designed in such a way that the focal length of the entire system can be adjusted via a switch at the top of the system, as in Figure 5(b). The optical system is internally charged with nitrogen gas to overcome humidity and ensure lens purity inside.



(a) (b)

Figure 5. Final work; (a) printed circuit board of EMG and pulse sensor and (b) final finishing for optical system

4. RESULTS

The proposed system consists of two parts, where the part containing the measurement circuits is placed inside the military uniforms, and the other part is the thermal camera integrated with the optical system. Figure 6 shows a simplified explanation of the use of the proposed system. Thermal images are taken, and at the same time, the change in heart rate and the change in the electromyogram are recorded. The proposed optical system gives the system flexibility in analyzing the images so that the quality is higher, and it also reduces the burden on the computer in the analysis. The proposed integrated system works with two image analysis systems, the first system is the optical system, and the second system uses image analysis tools on the computer using the MATLAB program. The proposed optical system acts as an analyzer of the images captured by the thermal camera, dividing the captured images according to the red, green, blue (RGB) color scheme. This method reduces stress on computer processors and shortens the analysis period for the rest of the results. All captured thermal data and images are sent to the computer. Using MATLAB, thermal images and EMG measurements are analyzed, as shown in Figure 7. Two hundred thirty-seven (237) people were tested to verify the effectiveness of the proposed system, where the measurement was made on 127 men and 110 women.

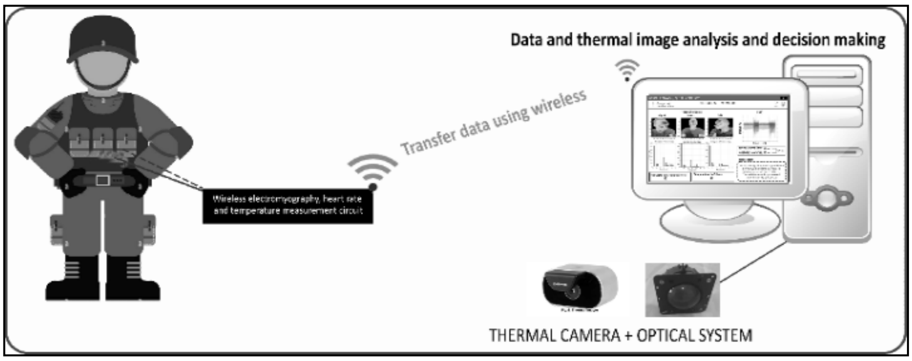
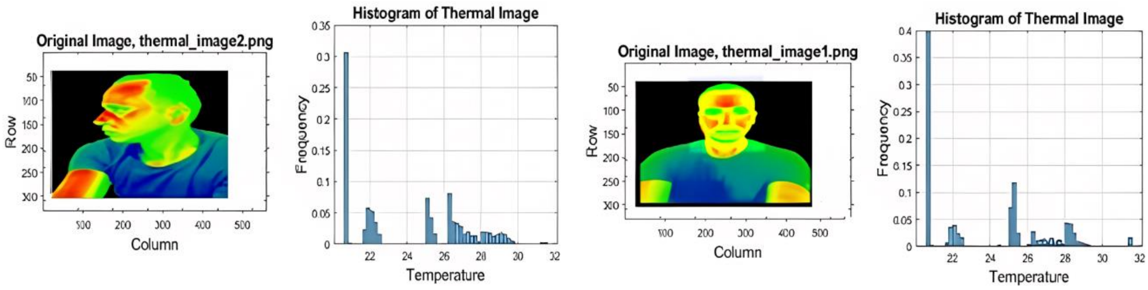


Figure 6. Scheme of the methodology

The first part of the system is installed inside the military uniform, where it sends the heart rate and EMG signal wirelessly to the computer. The second part of the system, which is the optical system and the thermal camera, is also installed at a distance of 5 to 10 meters to receive thermal images of the soldiers being tested. To confirm the accuracy of the work of the thermal camera system and the optical system designed, a detailed test was conducted on many soldiers. An analysis of three different cases of three soldiers photographed by a thermal camera supported by the proposed optical system is presented. The first case, as in Figure 7(a), shows the results of image analysis using the MATLAB program to obtain an accurate graphical relationship between the color temperature wavelength (frequency) and temperature in degrees Celsius. The histogram curve shows the relationship between the change in temperature and frequency as it gives clear values of temperature rise in red, and a corresponding rise appears on the histogram curve. Figure 7(b) also shows the change in temperature on the graph curve of the second-state thermal camera. The histogram curve shows that there is a significant change in frequency with increasing temperature. The proposed neural network model relies on data to train, learn and improve accuracy over time. However, the learning algorithms of this model have been tuned for accuracy to adapt to changing inputs. When using neural network technology, keep in mind that tasks in image recognition and analysis can take minutes versus hours when compared to manual recognition by human experts. The proposed model allows us to classify and aggregate data at high speed. Thermal images and EMG measurements are used as inputs to train the model. When the model is used for decision-making in real-time, the model compares the new inputs with the inputs stored during training, and the decision is extracted with the highest possible accuracy. In general, when working on a neural network problem, it is not possible to know the best algorithm for the previously posed problem. The solution was to try a bunch of algorithms and see what worked best. A set of powerful algorithms that give the highest accuracy and give the best performance have been tried and studied. Five algorithms are used to build the proposed model to compare the best among them to aid diagnosis and prediction, as shown in Table 3. The five algorithms used are (naive bayes (NB), k-nearest neighbors (KNN), support vector machine (SVM), random forest (RF), and simple logistic regression (SL)). Table 3 shows the accuracy and effectiveness of each of the five algorithms. Python language was used to create the proposed neural network model. The model compares and analyzes the inputs with the pre-training results to derive the final decision.



(a) (b)

Figure 7. System results (a) case one and (b) case two

Table 3. Performance of five algorithms

Criterion	NB	SVM	RF	SL	KNN
Accuracy	90.40%	98.56%	95.98%	95.65	87.39
Sensitivity	89.40	98.50	96.80	96.10	87.40
F-score	88.40	98.72	96.70	96.00	86.90

5. CONCLUSION

To sum up, an integrated portable medical tracking system for soldiers in the training and mission fields is presented. The proposed system is divided into two main parts, where the first part is a very small system that is installed inside the military uniforms of soldiers that measures important vital parameters and sends them to the computer. On the other hand, the second part is a thermal imaging camera supported by a specially designed optical system. The proposed device achieved a measurement response time of 1.5 seconds. The soldiers' vital parameters measurement system achieved an accuracy rate of 96% compared to other measurements of ordinary devices. The system is designed expertly and is small in size so that it is easily integrated into the soldiers' uniforms. The optical system designed to be installed on the thermal camera gives an awesome possibility to increase the range of vision of the thermal camera up to 15 meters, with 100% thermal tracking accuracy. The designed neural network model gave an accuracy rate that can be reached so far in the proposed method of use of up to 96%. The method of designing the integrated system to run the automated diagnostic model on a tablet device gives the system strength and the ability to work in all different military environments. The proposed system can be used in many different applications and fields such as military fields, where this system is designed to be compatible with the helmets of pilots and marine divers to measure the vital parameters of individuals carrying out difficult tasks or arduous training. The system can also be easily modified to be used in emergency departments for doctors and nurses, especially in cases of infections that do not require contact with patients. This study and the models based on machine learning technology proposed in it can also be used to separate the different symptoms of a number of diseases. The system is designed with low cost and high accuracy.

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