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Thermal Screening Solution Using Infrared Thermography and Closed-Circuit Television

Katrina Angela Butihen
College of Engineering
National University
Manila City, Philippines
butihenks@students.national-u.edu.ph

David Gabrielle Feliciano
College of Engineering
National University
Manila City, Philippines
felicianodv@students.national-u.edu.ph

Rojem Pilapil
College of Engineering
National University
Manila City, Philippines
pilapilrd@students.national-u.edu.ph

Raymond Joseph Meimban
College of Engineering
National University
Manila City, Philippines
rrmeimban@national-u.edu.ph

Anthony Joseph Aguillos
College of Engineering
National University
Manila City, Philippines
aguilosaa@students.national-u.edu.ph

Joe Warren Labio
College of Engineering
National University
Manila City, Philippines
labiojq@students.national-u.edu.ph

***Abstract*— Closed-circuit television camera (CCTV) and thermal imaging devices are used to detect febrile individuals entering establishments for Coronavirus 2019 (COVID-19) containment. Real-time tracking in post-COVID is manually checked by security personnel, which has risks of less efficiency due to human errors, as advance thermal cameras are unaffordable for some business owners. The main goal is converting an installed CCTV interfaced with infrared sensor to develop an economical thermal screening system with acoustic alarm. In this project, the colored and heatmap images transmitted from the thermal camera were processed through OpenCV. A calibration method was also performed to validate the temperature reading from the thermal camera. The project comes with graphical user interface (GUI) connected into a database, which visually tracks individuals exhibits elevated body temperature. The performance of the system shows above 95% accuracy upon conducting an inexpensive calibration check. The significance of this project is highlighting the effective mitigation of virus spread which offers safe and contactless analysis of potential individuals showing early symptoms of COVID-19. Additional features can be added for future work such as facemask detector, multiple thermal camera setup, and Login Options making the device and application exclusively for business owners.**

***Keywords*— CCTV, Thermal Camera, Infrared Thermography, OpenCV, COVID-19**

I. INTRODUCTION

CCTV are mainly used for monitoring, security, and surveillance, and play a big role in this time of the pandemic. Many countries formulate strategies to fight against the spread of COVID-19 putting the spotlight on on-camera monitoring and temperature detecting devices with the goal of reviving the economy from the prolonged community quarantine. Because viruses can spread through direct, indirect, and close contact with infected people, governments and businesses have instituted manual screening via customer data gathering and body temperature evaluation before accessing private or public facilities [1].

The demand for human thermal detectors rises as part of safety precautions and early detection of common symptoms associated with the disease to break the chain of the infection. These devices deployed in establishment entry points determine if an individual has a fever. However, most temperature assessment devices require close proximity between the user and the person subject for temperature checking. Hence, thermal imaging systems got the attention of businesses as it is more advanced and promise contactless human thermal measurement tool but are considered a costly investment by some establishment owners.

Nowadays, there are extensive technology of thermal security cameras for COVID-19 symptom screening. However, the devices available in the market are highly priced, and some related projects used an inexpensive thermal sensor which does not meet the minimum standards for deployment. With so many existing systems, the researchers will develop another thermal screening solution with the use of already installed CCTV and thermal infrared imaging sensors. This project used a Raspberry Pi 4 microcontroller to process the heatmap images from the thermal camera. It also involves the use of router that acts as a gateway of all data transmitted between the hardware. Hypertext Transfer Protocol (HTTP) plays an important role which primarily the command language to process all the data needed to display on the GUI.

The project aims to innovate an already existing CCTV system of an establishment to convert it to a temperature

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measurement system by simply attaching a low-cost device. Specifically, the project interfaces CCTV and Raspberry Pi 4 (RPI4) with an embedded forward-looking infrared (FLIR) module via a router for image gathering and temperature measurements, develops a python-based Graphical User Interface (GUI) for true color image collection and heat map analysis with human temperature statistics for timely monitoring, and validates the CCTV thermal output with 95% accuracy using inexpensive calibration check.

II. Review of Related Literature

The first coronavirus happened in the Wuhan city province of China which the beginning of the outbreak of COVID-19 December 2019. Thus, World Health Organization (WHO) announced in January 2020 that the rapid increase of cases outside China characterize and declared this outbreak as a pandemic [3].

Reported symptoms include fever, cough, fatigue, pneumonia, headache, diarrhea, hemoptysis, and dyspnea. Preventive measures such as masks, hand hygiene practices, avoidance of public contact, case detection, contact tracing, body temperature evaluation, and quarantines have been discussed as ways to reduce transmission [4].

Thermal imaging system are the latest technology being deployed to detect early symptom of coronavirus such as fever. These devices can be easily installed anywhere in a room or establishment and allow people to measure their temperature without being physically close to the device or security personnel [5]. This have been very beneficial from the preceding epidemic or pandemic outbreaks that hits humanity from the last decades such as “avian influenza, swine influenza, Middle East respiratory syndrome coronavirus, Ebola, and now, the present, Coronavirus-19 [6].

In this project, IP (Internet Protocol) camera will be coupled, instead of purchasing new camera for contact tracing, with FLIR module for face detection and temperature scanning, respectively. The already installed IP CCTV allows an extensible design for real-time data processing.

III. Design Methodology

The system architecture of thermal camera system is consisting of Network CCTV, FLIR Module, Router, and laptop. The algorithm of software used in this system are Digital Thermal Image Processing, video stream and thermal image data transfer over internet protocol, and real time video streaming and bounding box image capturing for GUI display as shown in the Fig 1.

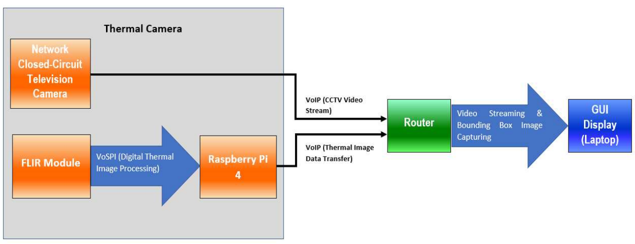

Figure 1. System Architecture and algorithm of Thermal Camera System

The CCTV cameras capture visible light and produce an RGB video that has color information, and it cannot see thermal energy. On the other hand, thermal imaging cameras are not really cameras, but an array of infrared sensors that produce heat map images that are dark when cold and white/iron palette when hot [7].

The Network CCTV and FLIR module allow the transfer of data video over Video Over Internet Protocols. Connecting Network CCTV and FLIR via ethernet cable connected directly to the router where the computer or laptop is also connected. These three devices are connected to one common network, which is the Local Area Network. The RJ-45 ethernet cable connection is preferred and recommended to minimize packet loss in the internet connection.

The standard communication protocol to transfer verifiable videos from the FLIR module to Raspberry Pi 4 is the SPI interface which shown on Fig. 1. Illustrated at Fig. 2, the module's breakout board pins will be attached to RPi GPIO pins via Serial Peripheral Interface (SPI) channels [8]. The RPi uses Raspbian Operating System where the FLIR module will configure and calibrated using Python programming language that uses the Open CV library for image processing. All processed images and data are fed directly to the computer or laptop for RGB Image and Heat Map analysis with human temperature statistics.

A. Schematic Diagram

The connection of microcontroller and thermal camera sensor is shown in the Fig. 2.

1. *Connection between Pure thermal 2 breakout board and FLIR lepton 3.5.*
   The thermal sensor (FLIR Lepton 3.5) is mounted into our smart I/O board which is Purethermal-2 breakout board.
2. *Connection between PureThermal-2 Breakout Board to Raspberry Pi 4*
   The Raspberry Pi4 is connected to a Purethermal-2 Breakout board thru a Micro Type-B USB port. Raspberry Pi4 is powered by USB-C Power 5V/3A. Pin 33 (GPIO13) is connected in the contact of the Tack switch and the other contact is connected in Pin 34 (GND). This serves as the Power switch of the Raspberry Pi4. For the LED indicator, we connect a 1k ohm resistor and negative of LED in Pin 39 (GND) and the positive of it in Pin 40 (GPIO21).

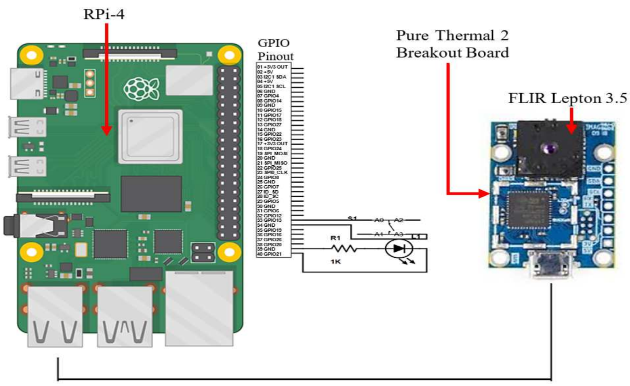

Fig. 2. Connection of Raspberry Pi 4 and FLIR module via SPI interface

B. Software Algorithm

The program structure for FLIR data transfer, collection, and synchronization is designed using Python 3 modules, and Hypertext Preprocessor (PHP) framework for web data storage. The software development modules applied to thermal imaging hardware are OpenCV, NumPy, and web development (storage) uses MySQL database through web encoding for data management of IR output image data. While on IP stream does not involve any image processing but still uses a computer vision module for extracting captured video. Lastly, the GUI is developed using Tkinter, a Python UI builder.

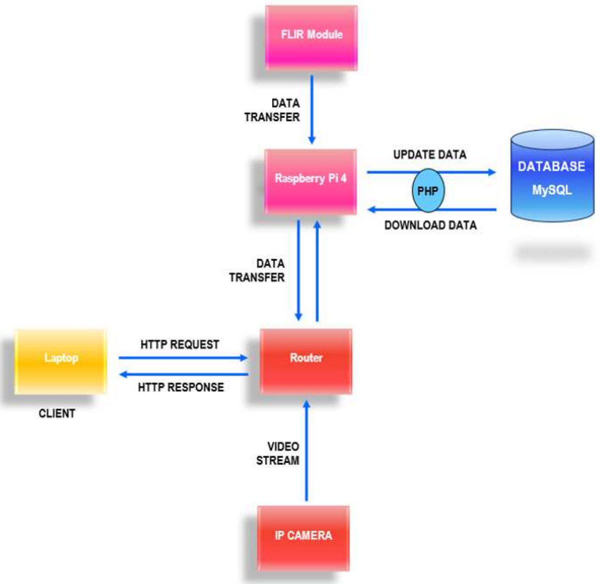

Fig. 3 Overall Software Algorithm of Thermal Camera System

To be able to access video stream and thermal data images, a command language is integrated into the Python request library which is HTTP. In this case, HTTP request and response are defined as the public function of updating and downloading data from the remote server programmed in the RPi 4 using python language, which is illustrated on Fig. 3.

Step-by-step procedure on the HTTP request and response:

1. The end-user (client) sends an HTTP request through the python scripts.
2. The python program connects to database and request data. For IP camera, the python program only requests to access real-time video streaming.
3. The data retrieved and sent information through router.
4. The client received a response containing thermal data values.

1. Digital Thermal Image Processing

The FLIR Module will be connected to the RPi 4 over the SPI interface to transfer thermal image frames. These image frames are the heat signatures of human body temperature shown on Fig. 1. The data transfer is initiated and processed by RPi for compiling pixel values extracted from FLIR thermal images which follow Video Over SPI (VoSPI) protocol, an image acquiring protocol managing the collection of frames [9]. The transferred data is synchronized for about 9 frames per second (FPS) in the form of 19, 200-pixel output values per frame as shown on Fig. 4 [10].

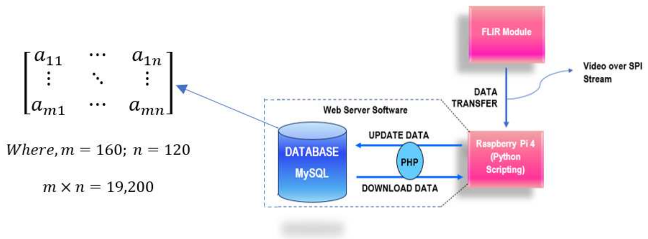

Fig. 4. Thermal data output from database, 19200-pixel data

The FLIR output data was considered as dynamic data in the form of a 160x120 matrix that needed to be updated periodically to synchronized image frames while streaming on Graphical User Interface (GUI) without any data lagging. RPi processed and received using program modules provided by the manufacturer's software development kit (SDK), all the data from FLIR that changing over time as new image data becomes available, specifically, 9 times per second.

The received thermal data is undergone reshaping into 1 long row matrix before encoding to the database and updating the information on every image frame received by the RPi. This ensures that the data is formatted into a serial format that can be transmitted over HTTP.

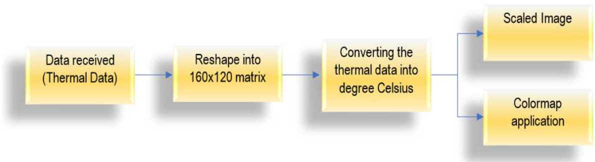

Fig. 5. Thermal data numerical scaling and colormap application

In the Fig. 5, the received data is given out 1x19,200 matrix serial data. When the software receives this, the serial data reshape it back to the original 160x120 resolutions of the thermal image then converts it to degrees Celsius as shown on the formula below (2).

FLIR module is a 160x120 infrared camera system that provides a total of 19, 200-pixel arrays in one image frame. Each pixel has a pixel output value representing scene temperature values in Kelvin multiplied by a scale factor to include decimal values. A 100% resolution is equivalent to a scale factor of 0.01 per pixel and a 0% resolution is 0.1. By default, the resolution of the FLIR camera at ON-power state is always at 100% resolution without any calibration needed, and 0% resolution when OFF-power state as shown on the Table 1 [10].

TABLE I. Thermal Camera Sensor Pixel Output Resolution

Pixel Resolution	Scale Factor
0% (OFF-power state)	$0.1\ or\ \left(\frac{1}{10}\right)$
100% (ON-power state)	$0.01\ or\ \left(\frac{1}{100}\right)$

For instance, if a single pixel with 100% resolution holding an output value of 30875 indicates that the pixel measuring a 35.6 °C or 308.75 Kelvins. The detailed formula to get Kelvin temperature is shown below (1), where Scale Factor is always equal to 0.01 [10].

$$\boldsymbol{T_{Kelvin}(K) = [Pixel\ Output\ Value * Sacale\ Factor]} \quad (1)$$

The formula for converting to Celsius is shown below (2),

$$\boldsymbol{T_{Celsius}}(°\mathrm{C}) = \boldsymbol{T_{Kelvin} - 273.15K} \quad (2)$$

As shown on Fig. 5, converted thermal data undergone image scaling which is used to mathematically associate the pixel temperature values to the colormap. The thermal image is a single channel and has no color information. To make the image visually useful to identify between cold and hot regions, `COLORMAP_HOT` is applied that is built-in with OpenCV. As shown in Fig. 6, the colormap has a normalized value of 0 and 1 which is equivalent to 0–255-pixel value when the image has no color information [11].

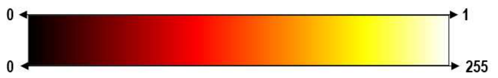

Fig. 6. Open-CV Hot Colormap

To relate the pixel temperature value into the chosen colormap, the proponents set the minimum and maximum temperature which is equivalent to 0-255 as illustrated on Fig. 7, and the formula for image scaling is shown below (3),

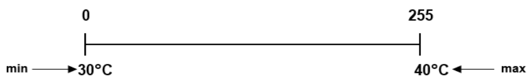

Fig. 7. Scaling the maximum and minimum temperature of thermal camera system

$$\boldsymbol{Scaled\ Image} = \frac{\boldsymbol{Pixel\ temperature\ value - T_{min}}}{\boldsymbol{T_{max} - T_{min}}} \times \mathbf{255} \quad (3)$$

2. IP Camera Real Time Streaming Protocol

The IP camera used for prototyping supports RTSP streaming protocol and ONVIF. RTSP protocol is used to establish and control the real-time video streaming on the thermal camera software without any modification done on the RGB video stream [12]. Through OpenCV, the software only opens the IP camera video stream for video capturing. The software was programmed to send RTSP to describe requests for real-time stream and return a video stream. The video stream is not recorded by the software and establishes an extract-then-display operation to maintain the flexibility of the GUI and computer performance.

3. Data Management

Due to the compliance constraints, the data collection is strictly breakdown into two processes. First, data log in text form which is collected per day and only included information of the date, time, temperature readings, and category, only exceeded threshold have an indication. Second, the image of the person is only placed inside the data log if the individual registers a temperature above 37.5 degrees Celsius (°C). The latter is designed for the operator can continue to run the software for temperature screening, not to populate the laptop or computer's memory storage, and most importantly, for privacy purposes.

IV. Photos of Prototype

The Fig. 8 below is the main hardware of the project which are the FLIR Lepton 3.5, and the RPi 4 which is the brain of the system that already programmed to process thermal data. A LED light is built-in RPi that acts as an easy visual confirmation that the thermal camera is operational, and tack switches are used to shut down the RPi and stop processing thermal images.

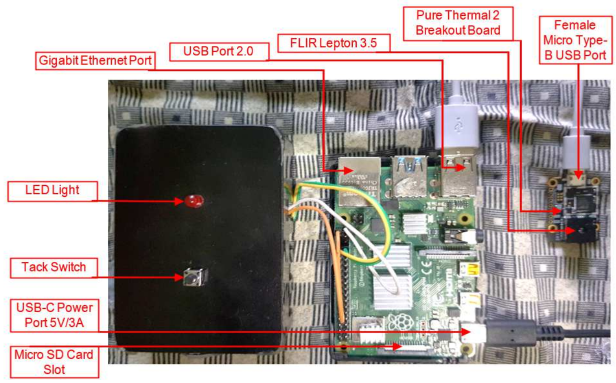

Fig. 8. Main Hardware of the Project

Fig. 9 shows whole CCTV thermal camera system. The two main hardware are connected to the router through an ethernet cable (RJ-45), and the thermal module is connected to the microcontroller using a type-B USB cord. In the project implementation, the thermal camera is attached to the top of the IP Camera with a tripod platform designed by the proponents that is shown on Fig. 10, as the final design of prototype.

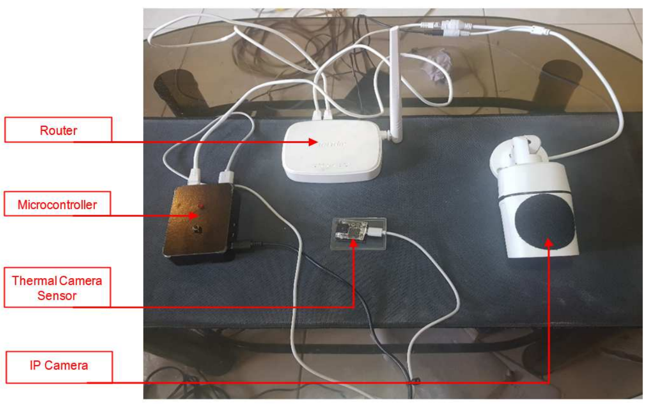

Fig. 9. CCTV Thermal Camera System

Fig. 10. Final Design of Prototype

V. Results

A. Graphical User Interface

The GUI was built according to the proponents' software designed which illustrated below on Fig. 11. The GUI consisted of 4 sections, thermal and CCTV stream, daily temperature statistics, bounding box customization, snapshots display with time information, and its corresponding individual temperature. The bounding box customization is added to the GUI for easy manipulation of the bounding box according to the operator's preference. Additional real-time monitoring innovations are visual and acoustic alarm systems to easily recognized and warned end-user as the individual has elevated temperature.

Fig. 11. Graphical User Interface

B. Thermal Output Data Validation

Accuracy is highly prioritized on the system's process. To ensure the accuracy of temperature readings after applying colormap from OpenCV, an inexpensive calibration check have been performed, although FLIR thermal camera is laboratory calibrated. This thermal output validation is a calibration check process recommended by the module's manufacturer to evaluate the margin of error. The accuracy verification carried out by making a baseline measurement which measuring target with known temperature using digital stainless-steel thermometer and comparing that known temperature by the measured temperature that came from thermal camera.

The test conducted implies that the temperature readings were able to meet the margin of error of 5% (±5℃ accuracy) after the OpenCV colormap was applied to the thermal output pixel data.

TABLE II. Thermal Output Data from Thermal Camera and Digital Thermometer

Condition	Testing	Time	Temperature on Thermal Camera (°C)	Temperature on Digital Thermometer (°C)
Hot Water	Test 1	16:11:30	38.50	37.90
	Test 2	16:35:11	36.64	36.30
	Test 3	17:01:05	35.30	35.10

At the Table 2, the known temperature against the measured temperature gives a small difference in temperature readings up from Test 1 to Test 3 and can be considered accurate in terms of numerical data obtained. The known temperature is the readings from digital thermometer, and measured temperature is from thermal camera. For the record, the minimum threshold is 33.5°C and the maximum threshold is 37.5°C.

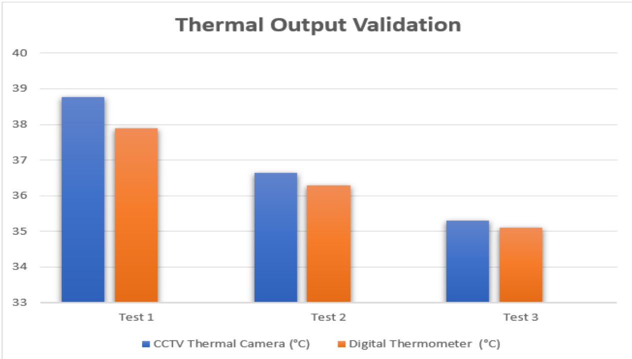

Fig. 12. Thermal Output Data Comparison

Analyzing the result by observing the column graphs as illustrated on Fig. 12, plotting the testing results in Table 2 showing that the known temperature against the measured temperature give a small difference in temperature readings up from Test 1 to Test 3 and can be considered accurate in terms of numerical data obtained.

The accuracy between the known and measured temperature were calculated by using the formula (4). Converting the accuracy result to percentage using the formula (5) giving every test conducted a relative accuracy of 97.70%, 99.06%, and 99.43% which implies that the temperature readings from the thermal camera were reliable as its error was below 3%, which very closed to the known temperature shown in Table 3.

$$\textbf{\textit{Accuracy by}}\ \mathbf{100\%} = \mathbf{1} - \frac{|\textbf{\textit{known temperature}} - \textbf{\textit{measured}}|}{\textbf{\textit{known temperature}}} \quad (4)$$

$$\textbf{\textit{Relative Accuracy}} = \textbf{\textit{Accuracy}} \times \mathbf{100\%} \quad (5)$$

TABLE III: Thermal Output Accuracy and Relative Accuracy

Condition	Testing	Accuracy	Relative Accuracy
Hot Water	Test 1	0.9770	97.70%
	Test 2	0.9906	99.06%
	Test 3	0.9943	99.43%

The Fig 13 shows difference of the target accuracy and the relative accuracy. The third objective of this project is to obtain the target accuracy of at least 95% but the results achieve percentage values higher than the target accuracy which indicated a good result for the proponents. Interpreting the pattern of the column graphs, clearly shows that the thermal camera device used on this project gives an accurate temperature reading.

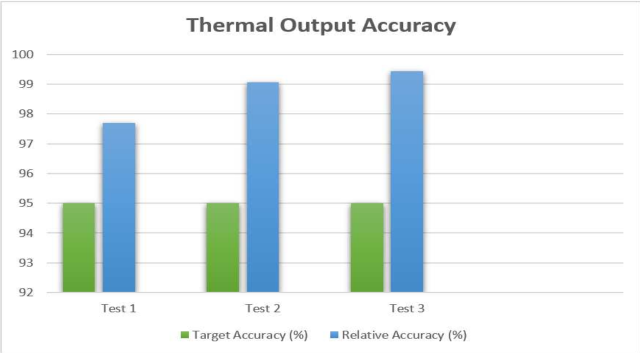

Fig. 13: Thermal Output Accuracy Comparison

VI. Discussion and Analysis

Based on the data gathered, the proponents verified the validity of the thermal data output of the IR camera after correlating it to the known temperature. Despite the factors that can affect the calibration check, such as the ambient temperature, the proponents still attained an accepted error for their device. These findings give another supporting detail regarding the reliability and accuracy of this CCTV thermal camera even though the module's specification is already factory-calibrated upon purchase.

The proponents consider the technical specifications on the selection of hardware that will meet the project concept and industry standards with the goal of minimizing the cost. Based on averaging and estimations of prices of commercially available thermal cameras and developed project design, the price comparison and other properties are illustrated on Table 4,

TABLE IV: Properties comparison of commercially available and developed thermal camera system

Properties	Commercial	Project
Alerts	Available	Available
Average Costs	\$650-\$7,500	\$339.83 (Prototype)
RGB Camera	Built-in	Integrated to installed CCTV
Thermal Camera	Not all meet FDA requirements	Meet FDA requirements
Memory storage	Depending on the manufacturer	Thermal: cloud-base Software: Laptop Storage

The recent proponents in was conducting a project testing in local health center where the project was evaluated by local nurses. The setup procedure has been shown and how the operator can monitor the thermal and true images from the laptop. The evaluators try the system and subject theirselves on temperature screening. The purpose of this project implementation is to identify is the developed system can be adopt by community.

VII. Conclusion

The researchers have developed an economical CCTV thermal system that can perform contactless body temperature of individuals by integrating an IP camera into a thermal imaging module. It lessens the risk of interacting with the person infected with the virus, as it offers an automated temperature measurement system using the developed python-based GUI that shows real-time CCTV and thermal video stream, individual body snapshots with corresponding time, and temperature, and daily temperature statics. The system successfully detected the above normal body temperature of individuals and activated visual and sound alarms. The thermal output validity was able to meet the accepted percent error of less than 5%. In addition, the temperature screening must be one-at-a-time to obtain the highest possible accuracy, and if strict compliance with the Data Privacy Act wanted to be implemented, the system must be integrated with higher-level information technology security experts. Additional features to be added for future work such as facemask detector, application menus for multiple CCTV setups, and login options for the establishment owner or employees. The most important aspect of this research is that a CCTV camera is integrated and converted into a non-contact CCTV thermal monitoring system which is preferred during this pandemic.

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