Human body fever monitoring system based on Raspberry Pi and Thermal sensor

Project Final Report

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ABSTRACT

This project report presents a Raspberry Pi-based fever detection system which employs a dual-motor face tracking mechanism, along with an RGB camera with deep sensing for face detection, and a thermal camera for human body temperature measurement. The system aims to solve fever screening issues raised during COVID-19 pandemic. The paper discusses existing technical challenges in current products and compares them to commercial offerings that often suffer from high costs, power consumption, and limited mobility. The proposed solution follows the IoT standard to overcome these shortcomings and provide an efficient, portable, and cost-effective fever detection system with excellent performance and user convenience. The report outlines the design details in software and hardware, and our comprehensive evaluation of the system, highlighting its successful implementation as an innovative IoT product.

1 Introduction

Public health has been a global concern with the increased amount of population movement internationally. Severe infectious diseases, usually coming with febrile symptoms, pose significant challenges to public health, which often leads to widespread outbreaks if not detected and controlled in the early stage before spreading out, and will finally cause a worldwide disaster. In the past few years, the world has witnessed the devastating impact from COVID-19, emphasizing the growing demand for an advanced, reliable, and efficient fever detection system.

1.1 Scopes

The project aims to present a complete system which can capture the temperature of pedestrians by using a thermal camera and an RGB camera. In the system, the RGB camera will be used to implement face detection and face tracking, while the thermal camera should deliver the body temperature measured from the faces detected by the RGB camera. Once a person with fever is detected, the system will make an alarm and meanwhile send a notification to authorized personnel to report the possibly infected individual. The system in our design will be adapted to work under multivarious environments where public health is required to be monitored such as hospitals, schools, airports, and many other public gathering places. With a tunable threshold on temperature to trigger alarms, the scope of the system's application is extendable to broader situations even if one day COVID-19 pandemic no longer being a threat to public health.

1.2 Background

In terms of technology, thermal imaging cameras are nothing novel these years. Earlier in 2021, a group led by Gupta et al. (2021). has already started to use thermal cameras for employee attendance with supported fever monitoring functions. The camera provides fast and safe screening to employees to ensure the safety in their working spaces.

In terms of commercial, non-contacting fever detection systems play an important role in control of infectious diseases, due to the high infecting speed of the diseases. They ensure a safer and more efficient screening process, minimizing the risk of disease spreading among individuals, and also improve the efficiency of detections in public spaces with large numbers of people.

Many companies have already introduced these types of devices in response to the pandemic. DALI company introduced visual based temperature detector like TE-W400, TE-W300 etc. (Dali Body Temperature Screening Co. (2023)). They have a relatively acceptable accuracy ($\leq$0.6°C), though, the weight is a bit heavy to hold in hand($\leq$0.98kg), since it requires a manipulator to hold in hand for use. Also, in real pandemic or clinical control environments, such a way of manipulation still leaves risks among medical workers and patients. Additionally, it has a short 4-hour lithium battery longevity which requires a break to recharge every now and then. Other companies like Guideir, also introduced a series of similar products: IR236, QT-series, etc.(Guideir Sensmart Tech Co. (2023)). All of these products use vision based fever monitoring systems and make alarms when fever is detected. The differences are, TE-W300 can be in hold in hand with 500g, but it needs a 3-our recharge after every 4 hours of continues usage. IR236 supports high resolution and high accuracy($\leq$0.3°C) but with a very poor mobility ($\leq$45kg). Besides, most of them are all price highly, like over 10 thousands of dollars. Plus, they all require human manipulation to control the camera's direction and manually focus on faces to capture body temperature.

2 The proposed approach

2.1 Execution

The whole project development process includes the conceptual design, software algorithm implementation, hardware assembling and setups, system integration, system test with data collection, and system evaluations.

The development of our fever detection system follows the plan in early proposal in most of the parts, except several improved parts including 2 more powerful servos and 1 more dual-color LED screen to visualize system feature setups, which are already mentioned in our progressive report.

Beyond that, we have also made some extra achievements which furtherly improve our system performance but are not included in our initial proposal. Our final product has a 3d printed shell as the stand base to hold our motor and battery system to stabilize our cameras. We have also chosen a proper power bank to drive our raspberry pi system. Now the whole system is completely lightweight and portable anywhere.

2.2 Hardware

Our hardware design is shown in Figure 1 and Figure 2.

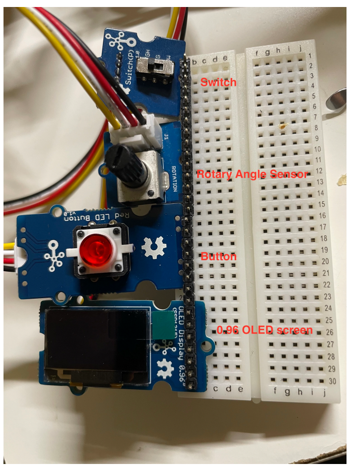

Figure 1: control board

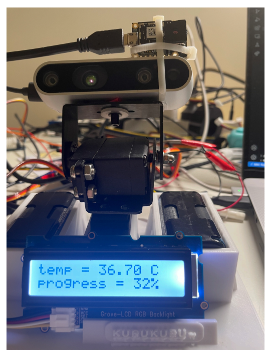

Figure 2: Screen on Two-axis Gimbal

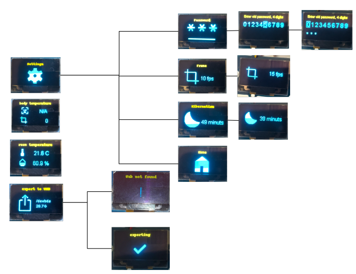

Figure 3: User storyboard

Figure 1 shows our control board, from top to bottom, are Switch, Button, Rotary Angle Sensor and 0.96 inch OLED Display. The switch controls the whole fever detection system, while Button, Rotary Angle Sensor and 0.96-inch OLED Display are used to change system settings and view the system operation status. Rotary Angle Sensor and 0.96 inch OLED Display are used to change the system settings and view the system running status. We designed a simple UI with multiple pages and multiple menus; users can switch the pages and menus through the Button and Rotary Angle Sensor and view the current page and menu through the 0.96-inch OLED Display to view the current page and menu status, specifically, our user storyboard as shown in Figure 3.

There are four pages in the Home Menu, from top to bottom Setting, Face temperature, Room temperature and Export. Users can switch pages by rotating the Rotary Angle Sensor, Specifically:

1. Face temperature On this page, the screen has two elements: temperature and frame. As mentioned earlier, we take multiple measurements to get the median and average to ensure the accuracy of the body temperature. The frame displayed in this frame is the current number of frames obtained, and temperature is the current face temperature after calculation. This page will be updated in real-time. Users can view the current face temperature through this page.

2. Room temperature On this page, there are two elements on the screen: temperature and humidity; temperature is the current room temperature, and humidity is the current room humidity; this page will update in real time, and users can view the current room temperature and humidity through this page.

3. Export Our system will record the information of people who may have a fever and store it locally; specifically, we will record the time, face temperature, room temperature and photo of the person who may have a fever, these data can be exported through this page, by connecting the USB device to the system, and the screen will show the info of the USB device, users can export the data to the USB device by pressing the button if export successfully, the screen will show the success message, otherwise, the screen will show the error message.

4. Setting On this page, the user can swap to the setting menu by pressing the button, We will discuss the setting menu in detail in the next section.

There are four menus in the setting menu, from top to bottom, which are: Password, Frame, Hibernation, and Home, Users can switch menus by rotating the Rotary Angle Sensor and entering the current menu by pressing the Button. Specifically:

1. Password On this page, the user can set the password of the system, there is a digit keyboard on the top of top of the screen. Users can use a rotary angle sensor to select the number and press the button to confirm, The password is a 4-digit number, and the default password is 0000. User need to enter the old password two times to confirm the new password. If the two passwords are the same, the screen will show the success message; otherwise, the screen will show the error message.

   Password is used to cancel the alarm. If the system detects a person with a fever, the system will alarm and not stop until the user enters the correct password.

2. Frame On this page, the user can set the number of frames to be used to calculate the face temperature, the default value is 5, and the user can change the value

between 1 and 100 by rotating the Rotary Angle Sensor, The screen will show the current value, users can press the button to confirm the value.

3. Hibernation On this page, the user can set the hibernation time of the system, the default value is 5 minutes, and the user can change the value between 1 and 60 by rotating the Rotary Angle Sensor, and the screen will show the current value, users can press the button to confirm the value. Hibernation is one of the features of our system. When the system is in hibernation, the system will not take any measurements, and the screen will be turned off, which can save a lot of power. The system will automatically wake up when the movement sensor detects the movement.
4. Home On this page, the user can return to the home menu by pressing the button.

2.2.1 Two-axis Gimbal

Figure 2 shows our two-axis gimbal, which controls the camera to rotate horizontally and vertically. Which provides x-axis and y-axis rotation. The x-axis rotation range is 0°-180°, and the y-axis rotation range is 50°-120°Two servo motors control the two-axis gimbal, and the PWM signal controls the servo motor. Each servo motor requires a 6V power supply, Raspberry Pi can only provide 5V power, so we use the 2*4*AA battery box as an external power supply to provide power to the servo motor.

There is another screen on the front of the 2-axis gimbal, as shown in Figure 2, which displays the calculated face temperature and the progress of this detection. The screen will be turned off when the system is in hibernation.

2.3 Software

2.3.1 Face tracking

In Face tracking, we need to calculate the rotation angles of the servo motor in the x and y axes. We use Mediapipe to obtain the face and get the centre of the face. Given $frame_w$ and $frame_h$ as the size of the frame, and $face_x$ and $face_y$ as the coordinates of the centre of the face, by using these values in the following formula, we can calculate the rotation angles (θ_x, θ_y) of the servo motor:

$$\begin{aligned}\theta_x &= \arctan(\frac{face_x - \frac{frame_w}{2}}{frame_w}) \\ \theta_y &= \arctan(\frac{face_y - \frac{frame_h}{2}}{frame_h})\end{aligned} \tag{1}$$

The calculation for θ_x and θ_y is almost same. They are both calculated by using the arctan function. The numerator, $(face_x - \frac{frame_w}{2})$, gives the horizontal distance between the centre of the face and the centre of the frame. By dividing this distance by $frame_w$ and using arctan function to convert this value to an angle, which will be a positive or negative value, the final rotation angle of the servo.

2.3.2 Temperature vs Distance

After completing the alignment of the thermal image with the depth image and the RGB image, we are already in a position to acquire the appropriate data based on the face tracking. That means firstly 468 landmark points from faces are obtained based on facial recognition. Based on these locations, we can get the corresponding values in the thermal data.

We first collected the five highest temperatures from all the face coordinates and calculated their average values as the final output of the face temperature results.

However, we found in our experiments that the temperature of the face decreases as the distance increases. To solve this problem, we designed a data collection experiment.

Firstly, the average of the five highest temperatures among all the facial coordinates was calculated first as well.

Then based on the coordinates of the five highest temperatures above, a facial depth average was similarly obtained in the depth data.

Algorithm 1: Outliers Filtering Algorithm

Input: Temperature data, Distance data

Output: Filtered temperature data, Filtered distance data

Function `OutliersFilter(`*temperatures, distances*`)`**:**

$z_{\text{temperatures}} = \left| \frac{\text{temperatures} - \text{mean(temperatures)}}{\text{std(temperatures)}} \right|$

$z_{\text{distances}} = \left| \frac{\text{distances} - \text{mean(distances)}}{\text{std(distances)}} \right|$

threshold = 2

Filtered temperature data =

$\{\text{temp}_i \mid \text{for } i,\ z_{\text{temperatures}}[i] < \text{threshold and } z_{\text{distances}}[i] < \text{threshold}\}$

Filtered distance data =

$\{\text{dist}_i \mid \text{for } i,\ z_{\text{temperatures}}[i] < \text{threshold and } z_{\text{distances}}[i] < \text{threshold}\}$

return *Filtered temperature data, Filtered distance data*;

We had a group member as the subject of the experiment and asked him to first fixate at a distance of 10cm from the camera. Then the data collection will start, and the subject will gradually move away from the camera at a rate of 5cm per second until the face tracking loses its target.

At the end of the experiment, we got a scatter plot of distance and temperature (Fig. 4).

It can be seen from the graph that the temperature is indeed inversely proportional to the distance. But the relationship doesn't seem to be purely linear.

In order to see the relationship more clearly, we first calculate their z-scores and then filter out the points with z-scores greater than the threshold, i.e., remove the outliers by setting a threshold value of 2. Based on the algorithm 1, we can see how outlier filtering is done. The results plot are presented in Fig. 5.

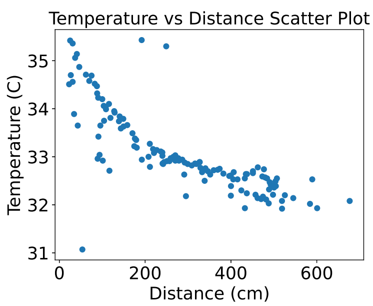

Figure 4: Temperature vs Distance Scatter Plot.

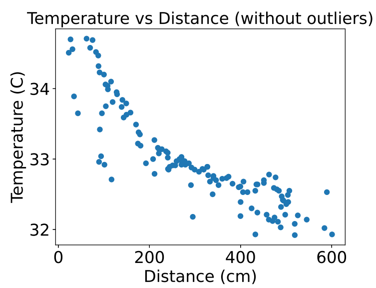

Figure 5: Temperature vs Distance Scatter Plot (without outliers).

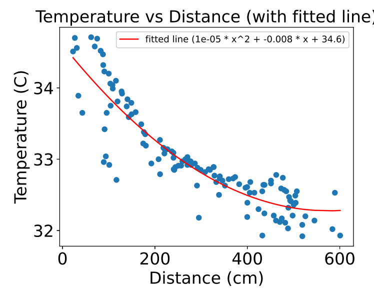

Figure 6: Temperature vs Distance Scatter Plot (with fitted line).

We calculate the standardized temperature on top of the data in Fig. 5. Standardized temperature means that the measured temperature values are corrected for the distance factor to get a more accurate temperature value.

First we fitted a quadratic polynomial fit line using the 'np.polyfit' function to model the relationship between distance and temperature (Fig. 6).

The 'np.poly1d' function was then used to convert the fitted coefficients into a callable function, 'fit_fn' , which calculates a predicted temperature value based on distance.

Given that the body temperature of our experimental subject at the time was 37 degrees Celsius. Therefore, the formula is as follows:

$$\begin{aligned} \mathrm{T}_{\text{fitted}} &= \text{fit\_fn}(\text{distance}) \\ \mathrm{T}_{\text{corrected}} &= (37 - \mathrm{T}_{\text{fitted}}) + \mathrm{T}_{\text{raw}} \end{aligned} \tag{2}$$

With this formula we get a more accurate value of body temperature that takes into account the influence of the distance factor on the measurement results.

3 Evaluation

First, we fixed the camera to test the temperatures read from different distances in a single frame. From the following graph (Figure 7), it can be observed that there is a significant fluctuation and error in the temperatures obtained at different distances. Therefore, our program is set to continuously read multiple frames of temperature to remove outliers, and the camera is moved to prevent erroneous distance and temperature estimations caused by the face being in different corners of the camera's view.

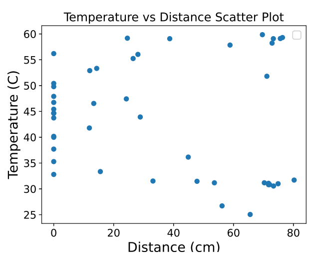

Figure 7: Figure-Outlier

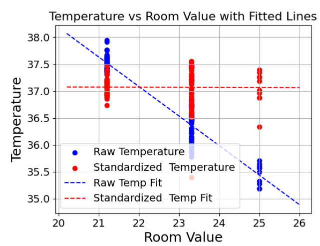

Figure 8: Figure-Room-Temperature

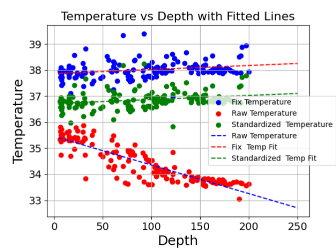

Figure 9: Figure-FINAL

To obtain more accurate values, we conducted numerous experiments to correct temperature biases. We primarily used an infrared thermometer temperature gun and the indoor temperature and humidity sensor from the project.

In the initial phase of the project, we had corresponding data to adjust the temperature. At this time, the temperature of the camera would change significantly based on distance. As the distance gradually increases, the measured temperature tends to approach room temperature (decreasing relative to body temperature). After preliminarily adjusting the temperature formula based on distance, we discovered that ambient room temperature also affects the results of temperature measurement. The higher the room temperature, the higher the measured body temperature.

Our planned adjustment aims to minimize the effects of both these variables. That is, when keeping other variables constant, only by changing either the room temperature or the distance the measured temperature would remain consistent and not vary with the changes.

3.1 Quality of Analysis

We have the following formula to adjust the temperature.

```
fitted_temperature = 3.6e-05 * distance**2 + -0.0178 * distance + 33.65
stand_temp = (37 - fitted_temperature) + temperature
k = 0.563 if Rtemp < 22 else -0.5
final_temp = stand_temp + (k * (Rtemp - 22))
```

The following graph (Figure 8) shows tests conducted at the same distance under three different temperatures. It can be observed that at a constant distance, as the room temperature changes, the temperature we adjusted based on the formula decreases with the indoor temperature. Theoretically, we want to achieve a result where room temperature does not affect our measurement data.

Now, the declining line we currently see is not what we want. Therefore, we added a value K and made adjustments. The graph mentioned above shows the results when K is set to -0.5 for temperatures greater than 22 °C and set to 0.563 for temperatures less than 22 °C.

The change in the value of K is due to the linear regression adjustments we made earlier based on distance. Hence, a trend shift occurs at 22 °C. As can be seen from the graph, with the now adjusted data, room temperature does not affect our temperature measurements; it remains a smooth, consistent line.

3.2 Discussions of results

The following graph (Figure 9) visually demonstrates the accuracy of the linear regression equation we adopted. We have three variables in this equation. The first variable is room temperature, which we've already adjusted based on the K value as mentioned above. The second variable is distance, which has the most significant impact; as the distance gradually increases, the measured temperature also gradually decreases (relative to the human body, it essentially approaches the ambient room temperature). The final variable is the body temperature we aim to measure.

This graph shows the temperature variation trend observed when changing the distance while keeping the room temperature constant.

The red color represents the original data points we tested, and the connected line is depicted by a blue dashed line. It can be seen that as the depth increases, the temperature we measure gradually decreases.

The blue indicators, which emanate from post-linear regression adjustments, provide a representation of our primary alterations in correlation to distance. It is unequivocally discernible that we have transmuted the diminishing trend trajectory into a markedly consistent curve. Within such parameters, distance ceases to exert influence on thermal measurements. In instances where the ambient environment manifests elevated temperatures, the recorded corporeal temperature consistently exhibits amplified readings. The aforementioned blue indicators, in conjunction with the associated blue trajectory, encapsulate the definitive thermal readings we have ascertained. This interpretation rectifies any perturbations induced by the prevailing ambient temperatures, calibrating the entirety of the trajectory to approximate between 36 to 37 °C. This harmonizes with our established thermal benchmark of 36.8 °C, as delineated by the infrared thermometer.

It is imperative to acknowledge that the temperature gun, which employs infrared mechanisms for thermal detection, is concomitantly influenced by the prevailing ambient temperatures. In light of this, we have additionally employed a mercury thermometer to calibrate and rectify the bias in forehead temperature readings, taking into account both the ambient environment and the authentic corporeal temperature deviations.

4 Conclusion

Compared to the research by Lin et al. (2019), our infrared facial recognition temperature measurement technology offers superior continuous tracking capability, enabling accurate temperature measurements from various angles. In contrast, the method of Lin relies on low-cost LWIR cameras, which restrict its application in high-traffic and mobile scenarios.

Our device not only supports continuous power supply but also features automated rotation via servos. This automation both conserves energy and significantly reduces the need for manual operation. Simultaneously, our technology achieves three-dimensional tracking at 180 degrees in all directions, ensuring precise measurements when pedestrians are moving.

It's worth noting that most existing industrial products do not support this type of rotational detection, making it challenging to detect in front of moving pedestrians. However, our continuous tracking technology offers consistent and accurate temperature measurements in high-traffic areas, significantly reducing the risk of false alarms. As single temperature measurements may contain errors, continuous measurements can better capture face temperatures, minimizing discrepancies and outlier occurrences. This continuous tracking ensures more reliable and feasible temperature readings, preventing measurement failures due to pedestrian movement. Obtaining a reliable and steady value makes the issued alerts more reasonable, minimizing the likelihood of false alarms.

Despite current speed and frame rate limitations, hardware upgrades, like advanced servos and efficient processors, can enhance our system's tracking and measuring capabilities.

In summary, compared to the research by Lin, our approach demonstrates greater advantages in areas with high foot traffic and movement. Through our continuous tracking technology, we offer a more reliable and stable solution for real-time measurements.

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