An Infant Monitor with Remote Temperature Sensor

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***Abstract*— The goal of this project was to model, design, and analyze a proof-of-concept design of a remote temperature and image monitoring system for infants. The motivation for this project was that infants are particularly susceptible to dangerous fluctuations in body temperature due to illness or environmental factors. Our proposed system will record the temperature of the infant (subject) non-invasively using an infrared temperature sensor placed within close proximity of the infant and compare it with the normal body temperature. The system will provide email alerts to the parent or caregiver upon detection of an abnormally high body temperature of the infant or low room temperature. The system will also provide camera recording for verification of the infant. This allows the system to monitor several infants at once (e.g., in a daycare setting) and also provide confirmation that the detected object is indeed a human.**

I. INTRODUCTION

Taking care of an infant is not an easy task and maintaining their wellness can be challenging while they are sleeping. Baby monitors show a great improvement in the last few years in terms of functionality and options. Despite many concerns about how secure they are, choosing the right one can be a life saver to infants. In 2016, a tragic death of one year old Sammie J. Volmert in Texas due to HVAC malfunction raised the attention to the need of infant monitors that are capable of temperature sensing [1]. Infants can experience difficulties in maintaining their body temperature; thus, they are especially vulnerable to dangerously high or low environmental temperatures resulting from factors such as excessive/inadequate bundling or climate control malfunction. Further, the onset of a fever would also result in a higher than normal body temperature.

Advancements in infrared thermal sensors have made it possible to detect body temperature from a distance (i.e., without direct contact). Studies have shown that remote temperature sensing via infrared sensors can be more precise than direct contact thermometers [2]. Heat radiated by objects can be indirectly measured in infrared light waves by using a thermopile that generates electromotive force when infrared waves containing heat energy information are focused upon it. In the ideal case, these values are directly proportional to the temperature of the object (or human), thus can be used to infer its temperature [3].

The focus of this project is to design a remote temperature system integrated as part of an infant monitoring system specifically for keeping track of infant body temperature. Using an infrared temperature sensor, it is possible to design a remote temperature monitoring system that would be integrated as part of a standard audio and/or video monitoring system already used for infants to increase the prospective level of care that can be administered remotely by the administrator (parent or caregiver). If the sensor detects an abnormal temperature level, it would alert the administrator via email. Although the specific use case of infant monitoring is mentioned throughout, we realize that this system can also be used for patient monitoring in a clinical or home setting. Also, applications like security cameras and energy management for home appliances can benefit from our system with minimum amount of modifications.

II. BACKGROUND AND RELATED WORK

A. *Body Temperature Control*

Some units that are used for stabilizing an infant's body temperature (especially newborns) have been proposed that utilize remote temperature detection by measuring the radiated heat coming from the surface of the child's body (using a strategically-placed thermistor) as the system provides heat to the child [4], [5]. This is essentially a feedback controlled, closed loop regulated system that adjusts the heat output to aid the infant in maintaining his body temperature.

B. *Wearable Temperature Sensing*

Many existing infant temperature monitoring systems are wearable direct contact thermometers that are either a standalone device featuring an adhesive strap for direct wearability (e.g., as a bracelet) [6], a device made for integrating into the infant's clothing [7], [8], or a smart sensing pacifier [9]. Because these units are directly attached to the child, there is a distinct advantage in that the child can move around and still be monitored automatically. However, there are still notable drawbacks with these systems. First, these systems are necessarily dependent on battery power which decreases convenience and reliability. Second, small devices such as this typically use low power radio communication protocols (such as Bluetooth and Zigbee) that have limited range with the receiver. The effectiveness of the unit is existent in so much as the administrator is careful to always place the receiver within the required proximity of the infant. In the case of the pacifier unit, reliability is decreased even more because the infant decides when to use it.

C. *Remote Temperature Sensing*

Remote temperature sensing via infrared sensors provide the benefits of increased reliability for the following major

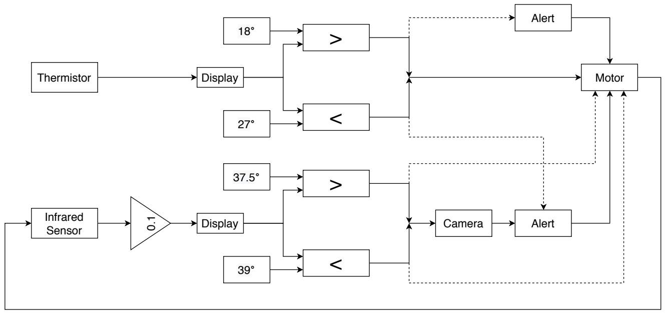

Fig. 1. Functional model of the system. The main purpose of the system is to ensure both the room temperature and the infant temperature are within safe levels.

reasons: no inherent need for batteries, a noninvasive temperature sensing method, and ability to monitor multiple children at once. Upon detecting abnormally high or low temperatures, these systems will either trigger an audible alert or send a virtual alert to a dedicated handheld device [10] or smartphone. To enhance the sensor's field of view, it is necessary to provide pan and/or tilt capabilities to the device [2]. These systems are not without some obvious disadvantages. For one, the system is constrained to a field of view that limits its effective range to that of a small room or crib. Also, as the distance between the sensor and the infant increases, the more the measured area of the sensor is likely to represent the background temperature rather than the target (i.e., infant). This could lead to false negatives and false positives in regard to detection of dangerous temperature levels. In fact, we discuss this further in our analysis of one specific infrared sensor model.

III. MODEL

The functional model of our system is shown in Figure 1. Two main metrics are monitored by the system: the room temperature and the remote temperature measured by the infrared sensor. If the room temperature is too cold, the system will trigger an alert. The infrared sensor measures the temperature of the infant and if the infant has a fever or is overheated due to excessive bundling, the system will trigger a corresponding alert. If no problems are found with the temperature readings from either the room or the infrared sensor, then the default state is that the motor is actuated to tilt the sensor back and forth to cover the desired area. This tilt is required because the sensor has only a 5.5° field of view along the y-axis, as shown in Figure 2. In order to enhance the system's field of view, a motor is used to rotate the sensor platform along the y-axis, which will yield a matrix of temperature blocks over the course of a full sweep angle.

To find the angle of rotation needed, it is first required to find the optimal height to place the sensor above the infant such that the utilization of the pixel that contains the child body is over 50% to be able to detect the child temperature and not the surrounding temperature as shown in 3. The equations we formulated to relate these parameters are as follows:

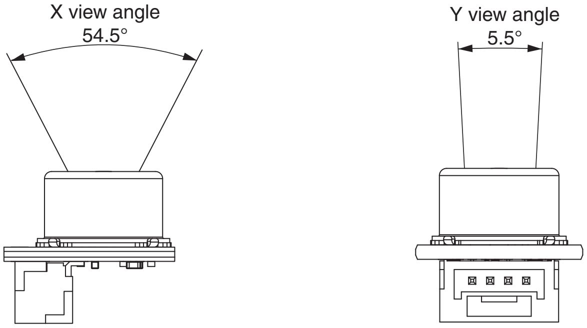

Fig. 2. The Omron D6T-8L-09 sensor's field of view

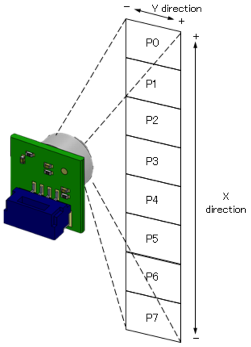

Fig. 3. Distance as a factor of fluctuations in temperature values for each of the temperature pixels measured by the infrared sensor.

$$h_s = \frac{4h_o}{\tan(\theta/2)} \tag{1}$$

$$h_y = 2h_s \tan(\beta/2) \tag{2}$$

where h_s is the height of the sensor, h_o is the size of a single recorded unit within the 1×8 array of temperature values recorded by the D6T sensor in the x-axis, h_y is the size of the field in the y-axis, θ is the field of view angle in the x-direction, and β is the angle in the y-direction. Using Equation 2 after estimating the required height of the infrared sensor with Equation 1, it is possible to estimate the actual size of the field subtended in the y-axis direction (h_y). The size of the area needed to cover in each sweep is divided by h_y to obtain the integer number of steps needed, while tilting in the y-direction 5.5° each step.

IV. DESIGN

Our prototype design consists of seven main parts: a D6T infrared temperature sensor, Raspberry Pi microcontroller, camera, thermistor, passive buzzer, LCD display, and stepper motor with a corresponding controller. (see Figure 4). Additionally, a platform holding the circuit containing the buzzer, thermistor, and LCD display also secures a stepper motor. The axle of the stepper motor turns a smaller platform that includes the D6T sensor and the camera. This allows the system to perform a temperature scanning sweep and capture images along the same direction as the viewing angle.

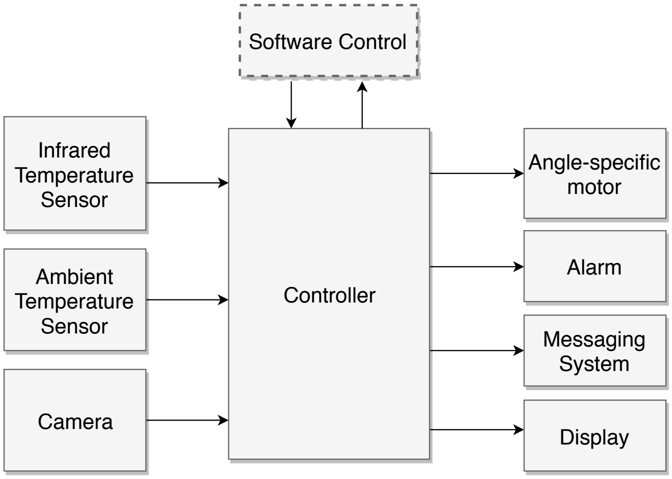

Fig. 4. Block diagram of the proposed system showing the main hardware components, showing input devices (sensors) on the left and output devices on the right.

A. Sensors

Our selection of the Omron D6T-8L-09 infrared sensor [11] was mainly a budget-oriented decision. This unit senses temperature using a silicon lens that focuses far-infrared rays onto a 1×8 thermopile array, each of which produce an electrical signal proportional to the heat differential that is created across the thermopile junctions. This electrical signal is first converted to a digital value and then translated to a temperature value in Celcius using an internal lookup table and a reference temperature of the device. The sensor communicates with the microcontroller using the I2C protocol. To read the temperature from the device, a stream of bytes is read which provides 8 upper bits and 8 lower bits of the estimated temperature for each pixel, scaled by a factor of 10. An inherent property of detection is that the sensor only updates its readings once every 300 ms. Therefore, the rotation of the sensor platform in our prototype is not continuous, but rather delayed by this factor in between each rotation step of 5.5°.

The thermopile reference temperature of the D6T was not consistent with the room temperature during testing, therefore it was not used for this. To provide a reliable room temperature measurement, we used the DHT11 temperature and humidity sensor. This device uses a proprietary one-wire communication protocol for relaying measured values to the microcontroller. As an additional function for this monitoring system, it has a camera to provide images as a means of subject verification by the administrator. Because the infrared sensor only provides temperature information, the camera will establish greater practicality for the monitoring system. It is used when the infrared sensor reading possibly indicates a fever state for the human subject.

B. Output Devices

The main actuation device is the stepper motor, which rotates the platform containing the infrared sensor and camera, We utilized the ROHS model 28BYJ-48 stepper motor for this purpose. To display the measured room temperature and the maximum temperature pixel value recorded from the infrared sensor for convenient testing and verification purposes, we utilized an LCD display. When dangerous room or subject temperatures are detected, an audible alert is provided by a simple passive buzzer.

C. Software Control

The microcontroller is responsible for communication with the other components in order to receive and process the data from the sensors (DHT11 temperature sensor, camera, and D6T infrared sensor), control the output devices (stepper motor, buzzer, and LCD display) and transmit alert information using its internet connection. We programmed most of the control code in C, with the exception of the camera/email alerts module which is implemented in Python. The control loop flow is as follows:

1) Update the room temperature reading from the DHT11 sensor and print to LCD display. If this reading is inside the established danger range, the buzzer is actuated and an email alert template is sent to the designated recipient.
2) Begin sweeping motor in the opposite direction as the last iteration. Rotation is performed the size angle steps dictated by the infrared sensor design (5.5°).
3) Update the temperature reading from the infrared sensor as the maximum of the 8 pixel values, scale by 0.1, and display on LCD. If the reading is within the range designated as a fever state, the buzzer is activated, the camera captures a photo, and an email alert template with the photo attachment is sent to the designated recipient.

D. Prototype Implementation

The original design concept for our prototype specified an overhead placement of the rotating sensor platform. In other words, the platform would have been mounted above the subject facing downward and it would have rotated around the x-axis. In order to facilitate both the implementation and testing phase of this project, we opted to instead place the platform along a horizontal rather than vertical plane and have it rotate around the y-axis. The sensor platform is large enough to accommodate both the camera and the D6T infrared sensor. The mounting platform houses the stepper motor and circuit board along with extraneous sensors and output devices. Mainly due to physical constraints of the hardware, we decided to limit the sweep angle of the sensor platform to 90°. This provides 16 steps of $\approx$5.6° each, which were implemented using the full step mode of the stepper motor. A depiction of our prototype is shown in Figure 5.

V. PERFORMANCE ANALYSIS

The evaluation of our prototype involved measuring the error of the central unit of our design, the infrared sensor. This was important to establish the feasibility of the design.

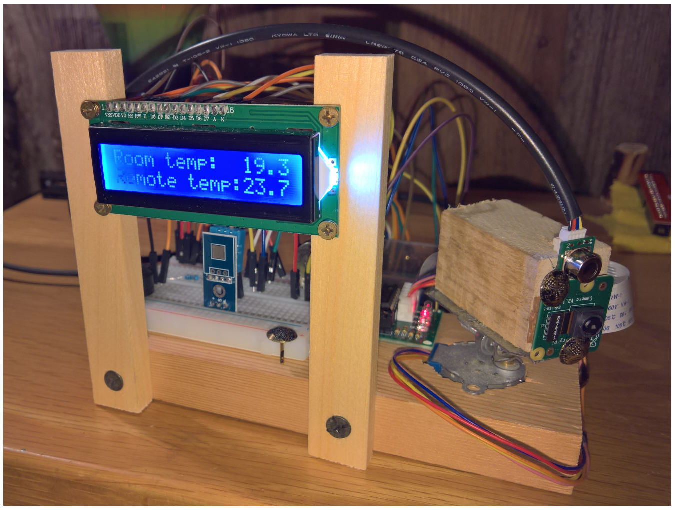

Fig. 5. Our implemented prototype has a modified platform origin and axis of rotation to simplify the testing and analysis phases of the project.

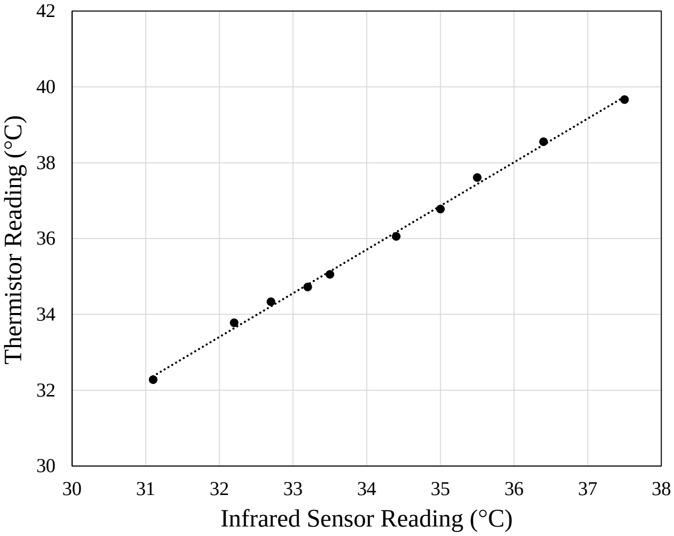

Fig. 6. Measured temperature discrepancies between those measured with a contact thermistor and the D6T-8L-09 infrared sensor using water heated to various temperatures. This fitted linear equation was used to provide a rudimentary type of calibration of the recorded values from the infrared sensor.

A. *Error Modeling for Single Distance*

The analysis of our infant monitoring prototype included estimating the accuracy of the infrared sensor for an object placed statically in front of the sensor; well within the optimal detection distance. This was done by by comparing measurements with those of a contact thermistor. This was done by placing water in front of the sensor and heating it to various temperatures within our specific range of interest, namely a range slightly larger than that of human body temperature. Obviously, an inherent assumption with this analysis is that the accuracy of the contact thermistor was significantly greater than that of the infrared sensor. The recorded values for this temperature discrepancy analysis are shown in Figure 6. Because the D6T-8L-09 infrared sensor has no inherent calibration support, the linear equation fitted to these experimentally determined values,

$$y = 1.152x - 3.462, \tag{3}$$

was used in a simple calibration scheme that used this equation to translate raw values output from the infrared sensor into the values used for prototype testing.

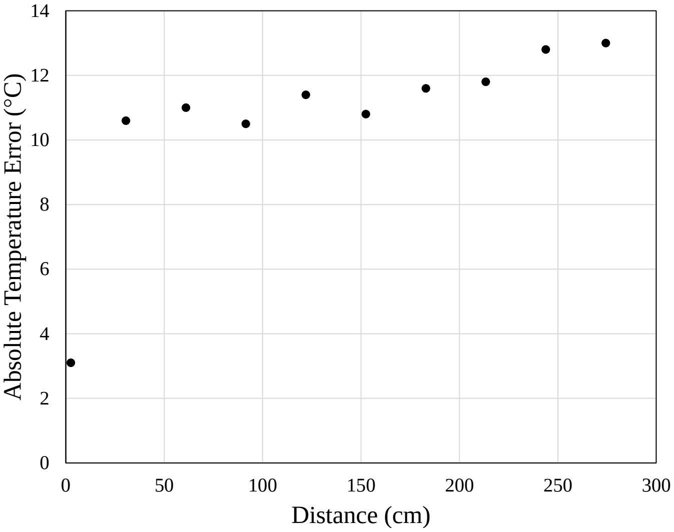

Fig. 7. Absolute values of measured temperature errors using a human subject at various distances from the sensor. These results demonstrate the principal shortcoming of the D6T-8L-09 infrared sensor for reliable fever detection.

B. *Error Modeling for Varied Distance*

Because the most important function of the infrared sensor (for this application) was measuring human body temperature, another experiment involved measuring human temperature at various distances. According to the simple trigonometric model discussed in Section III, an adult human would occupy at least four temperature pixels of the infrared sensor at a distance of 3 m. However, as observed in the temperature reading errors according to various distances of the human from the sensor (Figure 7), the accuracy of the sensor degrades at significantly shorter distances than implied by the naive model. This analysis indicated that the D6T-8L-09 infrared sensor does not provide reliable temperature monitoring in a broad enough range of situations for a practical infant monitoring application.

C. *Testing and Verification*

There were two main methods to test our entire prototype system, albeit at sufficiently short distances between the sensor and the object/subject used for verification. The first method involved simply lowering the programmed threshold of what we designated as a fever state in order to use a healthy human subject to test the prototype. The second method consisted of essentially tricking the system by placing an object of a temperature above the designated fever temperature and below the maximum human body temperature within the effective range of the prototype. The system performed flawlessly in both cases, and immediately paused to capture an image of the object/subject and send it via email before continuing to sweep the area for purpose of temperature monitoring. Our analysis did not differentiate between the use cases of assuming a single subject or multiple subjects. In the case of a single target, the sensor could stop rotating until the subject moved outside its effective field of view, in which case it would re-enter the search state.

VI. SUMMARY OF CONTRIBUTIONS

The details regarding the contributions toward our final implemented prototype are as follows. The prototype platform and the assembly of the hardware components onto the platform were completed by Ethan. The camera activation and email alerts were implemented by Amr. The implementation and testing of the D6T sensor was carried out largely as part of a team meeting in which both members were equally involved. The remaining software design and implementation was similarly a team effort, and not fully the domain of one team member.

VII. CONCLUSION AND FUTURE WORK

In this project, we implemented a prototype for a contact-less temperature monitoring system using an infrared MEMS thermal sensor, the Omron D6T-8L-09, to be integrated in a smart infant monitoring unit. The implemented prototype was able to detect a high temperature situation which can be a fever and capture a photo of the object or subject and send it via e-mail to notify the user. It showed promising results that can be extended to different applications (i.e. security systems or energy management in home appliances). The performance of this proof-of-concept prototype was limited by the accuracy and precision of our infrared sensor.

The results show the need for a more robust infrared sensor that has better accuracy and precision (a tolerance of about ±0.5°C is required). Also, a sensor with a wider field-of-view (FOV) and longer range might be used for a more practical monitoring system. For example, the unit should still perform within specifications even when the subject is approximately 3 meters away.

Artificial intelligence could be utilized in a better prototype in order to differentiate between different children by employing facial recognition algorithms. This would enable the system to provide smarter notifications by only sending alerts once for a particular child. Moreover, integrating a mobile app with a notification system can be used instead of our current e-mail notification system for a better user experience.

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