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HEATGUARD: AN ULTRA-LOW-COST 3D PRINTED SENSOR FOR BODY TEMPERATURE ALERT & REPORTING SYSTEM

Rui Li
School of Electrical and Computer Engineering,
The University of Georgia
Athens, Georgia, USA

Aaron A. Smith
School of Electrical and Computer Engineering,
The University of Georgia
Athens, Georgia, USA

Harshitha S. Tadinada
Department of Computer Science,
The University of Georgia
Athens, Georgia, USA

Zion T.H. Tse
School of Electrical and Computer Engineering,
The University of Georgia;
Thermochrome
Athens, Georgia, USA

ABSTRACT

The thermochromic device is a low-cost 3D-printed bracelet. It has the function of reading body temperature and warns individuals of the potential risk for heat related illnesses. The product is created from a thermochromic resin that is sensitive to temperature. This product can be customized to fit different age groups such as children and elders. Combined with the smartphone application, the device can provide real-time body temperature monitoring and alert to people who are vulnerable to heatstroke.

INTRODUCTION

There is a persistent need for treating heatstroke effectively. To solve the problem, an ultra-low-cost, easy-to-wear, and easy-to-use device is developed and its functionality has been tested. Heatstroke is a serious condition caused by the body's failed cooling mechanism due to prolonged exposure to or physical exertion in high temperatures. This is a leading cause of death in sports for both players and fans.

From 2001 to 2010, a recorded 28,000 people have experienced heat related hospitalizations in the United States [1]. Most of these victims were older adults aged 65+, young children, and people with mental or chronic illness. People at higher risk for heat stroke include those who work in outdoor environments such as construction sites (often males), and people who participate in summertime activities such as sports (often young children) [2]. Heat related illnesses can be easily prevented if people are aware of the current temperature in the local environment and take precautions, such as hydrating the body and avoiding strenuous physical activities during hot weather. A practical solution is to transform the unseen rising temperature into a visible physical phenomenon for the people to take quick action. Therefore, a customizable bracelet was 3-D printed from a new type of low-cost thermal sensitive resin that exhibits a physical phenomenon of gradual color change from pink to clear as temperature increases. This light-weight device can be used with a smartphone application that alerts and reports the real-time temperature of the environment. This application incorporates a camera that captures an image of the temperature sensitive bracelet and returns the body temperature based on the RGB values of the color pigmentation of the

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bracelet. This is a low-cost and efficient product that captures the user's attention of the commonly omitted rising heat levels in their surroundings and ultimately prevents heat strokes.

The bulldog is the mascot of the University of Georgia. Our team has set up a promotional campaign in the university which gives out free bulldog models to students and staff during outdoor sporting events. In this way, we will be able to receive continuous feedback from the end-users.

A smart phone application is developed to display the temperature in the surrounding area based on the 3D printed bracelet. The IOS mobile application is a camera app that is written using the Swift programming language. The camera in the app has a built-in outline that aids the user to accurately capture a photo of the bracelet. The pixels within the outline is used to analyze the object's color. The program accesses the device's camera by using IOS API calls from the UI image picker class. The app features an autofocusing camera that utilizes the device's back camera. The camera resolution, saturation level, and lighting effects is dependent on the type of phone. An iPhone 6 with a camera resolution of 4032 x 3024 pixels (12 MP) was used to test the product. The saturation hue and brightness were set to 0.0 on a scale that ranges from -1.0 to 3.0. Additional features of the app include a map based on the device's current location. The map view displays the current address and temperature reading while a time stamp is recorded after the picture is taken.

KEY WORDS

Heatstroke, 3D-print, Thermochromic, Temperature-sensitive

METHODOLOGY

System Overview

Figure 1 shows the working principle of the temperature sensing and alerting system. The system consists of a hardware component—the 3D-printed temperature-sensitive sensor -and a software component—a smartphone application [3]. The color change of the bracelet is recorded by the smartphone camera and processed by the application. The user receives the feedback information of body temperature, the real-time location and time. The application will warn the users if the body temperature exceeds the threshold value which could result in heatstroke.

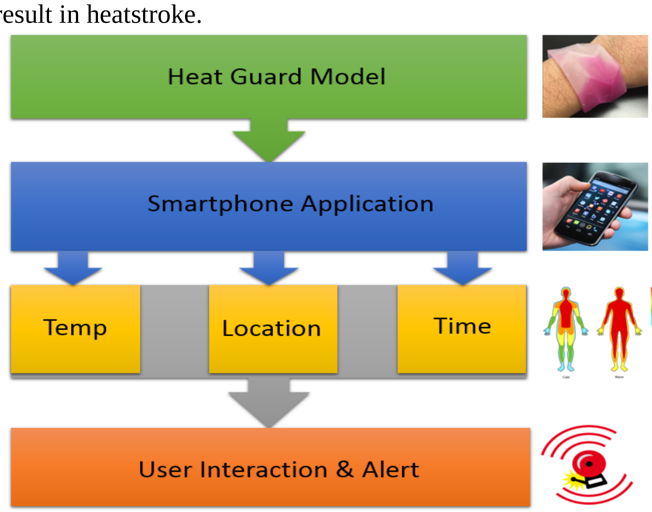

Figure 1: The working principle of the system

Thermochromic Material Development A bracelet prototype has been printed out to demonstrate the feasibility of the color change and temperature display. **Figure 2 (a), (b)** and **(c)** show the development process from the production of the temperature sensitive material to the bracelet. The temperature sensing steps shows the bracelet changing color while in contact with the user's skin. The corresponding temperature is displayed on the screen.

3D Fabrication Steps

(a)Step 1: Temperature sensitive material developed by our team | (b)Step2: Bracelet CAD model | (c)Step 3: Final product

Temperature Sensing Steps

(d)Step 4: Body temp sensing | (e)Step 5: Smartphone App | (f)Step 6: Temp display

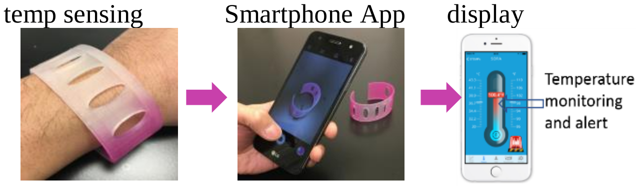

Figure 2: Temperature sensor development and operating demonstration: (a) the resin used to create the temperature sensor, (b) bracelet-shaped sensor model, (c) 3D-printed sensor, (d) demonstration of sensor changing color with body temperature, (e) and (f) smartphone app for temperature measurement and alerting.

Smartphone Application The application has a total of four views. In **Figure 3**, (1) is the initial camera view. The user can use the outline to focus on the object of interest. The circular button captures the image and transitions into (2) view. This view displays the picture the user captured with the option to analyze the picture. The analyze data button calculates temperature based on the object in the outline. Then the view transitions to (3) where the temperature of the surrounding area is displayed. In addition, there are two buttons: 'Send to

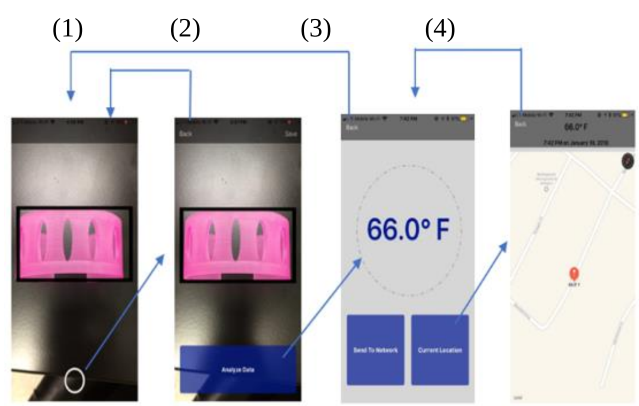

Figure 3: the workflow of the application

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Network' and 'Current Location'. The send to network button sends the picture, time the picture was taken, location, and temperature to a cloud network. The current location button transitions the view to (4). This is a map view with the temperature, time stamp, and location based on the photo captured. The map shows the current location and the temperatures measured.

Figure 4 shows calibration process for the smartphone application.

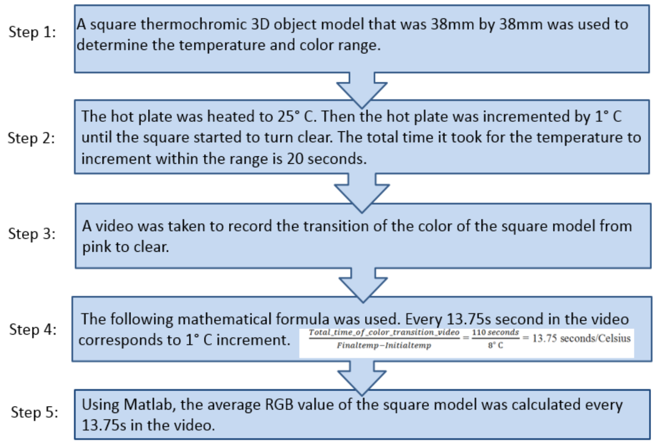

Figure 4: the calibration process

Temperature Sensitivity Testing

Activation Temperature Testing A water bath experiment was designed to discover the activation temperature of the thermochromic material in order for it to change color. The water bath was preheated to a certain temperature before the thin 3D printed block was submerged into it. The selected initial temperature ranged from 25- 40 ºC. The color of the block was recorded for each temperature until it completed its color change from pink to clear. (**Figure 5(a)**)

Color Change Rate Testing It is hypothesized that the physical volume of the object is one of the key factors to determine the speed of color change for the thermochromic material. A set of thin blocks were printed and the surface area to volume ratio will vary by stacking them on top of each other. The time for color change was recorded (**Figure 5(b)**).

Diversified and Ergonomic Design Testing

Different kinds of models have been printed to show the flexibility of the design.

Accuracy of the Temperature Readings

Experiments with the water bath were repeated 10 times where the mobile phone app was used to obtain the temperature reading. The reading was then compared with the laser thermometer. The readings from the laser thermometer was used as a standard to compare with the mobile phone app to determine the accuracy.

(a) Activation temperature testing

(b) Color change rate testing

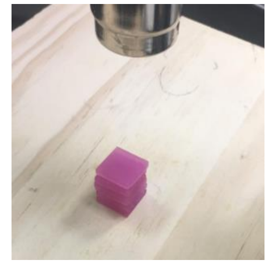

Figure 5: experimental setup for (a) activation temperature determination and (b) color change rate of the thermochromic material.

RESULTS

Temperature Sensitivity Testing

Activation Temperature Testing The block changes from pink to clear once the temperature reaches 31 °C. The color change phenomenon continues after 31 °C. This means the activation temperature for this specific type of thermochromic material is 31°C. Once the external heat input is cut, the color of the block returns back to the pink color at room temperature.

Color Change Rate Testing Duration time for color change versus different surface to volume ratios are plotted below.

(a) Color change rate result

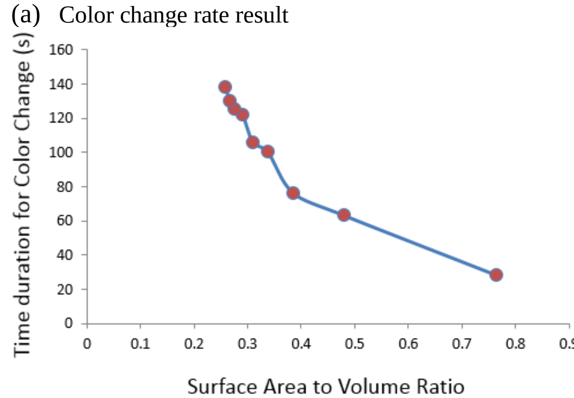

Figure 6: (a) the time duration for color change when the number of block decrease from 9 to 1 in (b).

Table 1 shows the experimental data collected.

Table 1: Detailed experimental description

SA/V ratio	Time (s)	No of blocks
0.76	28	1
0.48	63	2
0.39	76	3
0.34	100	4
0.31	106	5
0.29	122	6
0.28	125	7
0.27	130	8
0.26	138	9

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Diversified and Ergonomic Design Testing

Figure 7 shows a variety of bracelets being able to fit into a volunteer's arm. The flexibility of the 3D print technology fulfils the needs of the customer-oriented design.

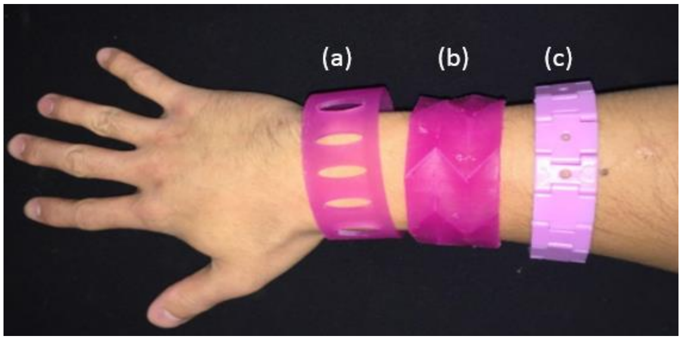

Figure 7: (a) displays a decoration model for daily-wear, (b) displays a durable model for sports-wear, (c) displays a watchband model for formal events. Moreover, the bracelets can be designed to fit for specific age groups such as children. Compared to current wearable device, the greatest advantage is low cost and no battery required.

Accuracy of the Temperature Readings

After processing the RGB values of the image and comparing it to the database, the temperature is calculated and displayed on the screen. The temperature reading is then compared with the results from the laser thermometer. **Figure 8** shows the difference between conventional thermometer and our device.

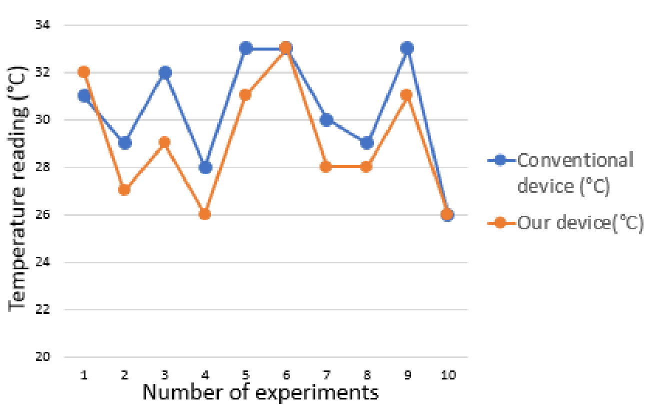

Figure 8: Comparison of temperature measurement between our device and conventionally used thermometer.

DISCUSSION

The traditional thermometer falls into two categories. The mercury-in-glass thermometer needs to be in close contact with the skin for a long time and in a stable environment before it is able to have accurate reading of body temperature. Meanwhile, the new-generation thermometer such as the laser thermometer can obtain temperature reading in a fast manner, however, it requires the users to manually press the start button to initiate the temperature detection, also the accuracy is not as dependable as the traditional thermometer. The new type temperature sensor we propose here can maintain accuracy with a detection rate comparable to the laser thermometer. The transition rate from completely pink to absolute clear takes approximately 1 minute. From the above experiment, the color change is repeatable due to the stable nature of this mixed material. The cost of the device is $0.50 each.

CONCLUSIONS

Temperature sensitive resin combined with 3D printing can detect body temperature to warn individuals of potential risks of heat related illnesses. The product is created from a temperature-sensitive resin. This product can be customized to fit different age-groups such as children and elders. Combined with the smartphone application, the device is able to provide real-time body temperature monitoring and alert people who are vulnerable to heatstroke.

POTENTIAL PITFALLS & FUTUREWORK

Lighting effect could potentially affect the smartphone application performance.

ACKNOWLDGEMENTS

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