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Infrared Detection of Elevations in Mobile Phone Temperatures induced by Casings †

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Abstract: The design and utility of mobile handheld devices have developed tremendously, from being initially intended for audio calls only to the recent incorporation of augmented reality in smartphones. Recent smartphone functions are power intensive, and cause excessive heating in phone parts, primarily batteries and processors. Left unmanaged, phone temperatures would exceed the threshold temperature of discomfort, negatively affecting user experience. The use of phone casings has simultaneously become common in recent years. They form an additional barrier to heat dissipation from mobile devices, which has not been considered in existing studies. In this work, the thermal profiles of two identical smartphones were assessed during common tasks, including music playing, voice calling, video streaming and 3D online gaming. One of the phones (the test case) was operated while enclosed in a plastic phone casing, while the other (the control case) was bare. Transient surface temperature distributions were obtained with infrared imaging and thermocouple sensors, while processor and battery temperatures were obtained from inbuilt sensors. Test results showed that casings generally redirect the dissipation of the heat generated within the phone. For tasks involving contact with users' hands, this will protect the user from high phone surface temperatures. However, the processor and battery temperatures are increased as a result. This user protection was not achieved in the online gaming task, for which the heat generated exceeded the insulating capacity of the plastic casing. The range of protection offered to phone users could be extended by using phone casings which incorporate phase change materials.

Keywords: infrared thermography; smartphones; phone casing; thermal management; mobile device

1. Introduction

In today's world, mobile phones have become a basic necessity, almost indispensable in everyday living. Their usage has grown tremendously in the past decade as manufacturers integrate more functionalities while reducing their sizes. The high-performance processors required for these new tasks have come with a price: increased chip temperatures which give rise to thermal management related issues. The heat generated by the processors travel via heat transfer paths to the phone surfaces [1]. And because these surfaces come in contact with the user's skin, they need to be maintained below 45°C, which is the threshold temperature of pain for mobile usage [2,3].

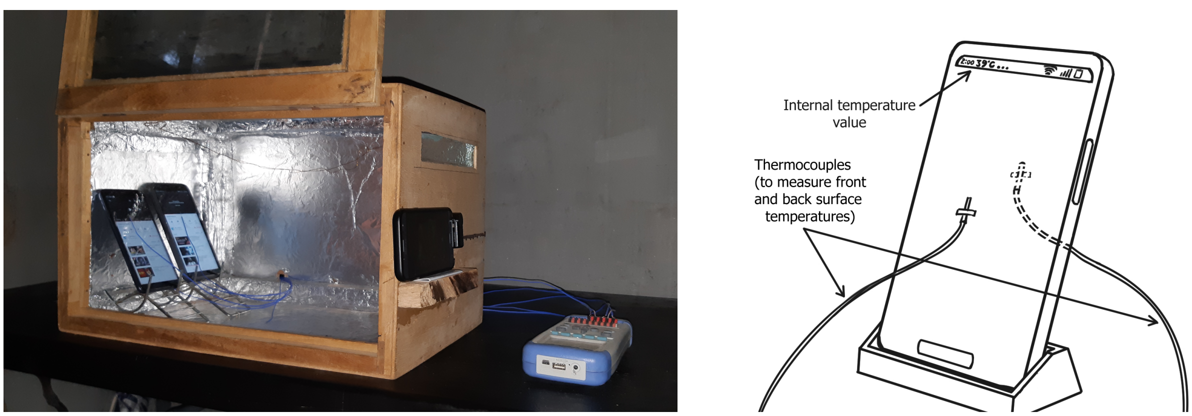
Kang et al. [4] studied several energy-intensive mobile phone operations to obtain temperatures and phone surface thermograms. A component-specific thermal analysis revealed that the power management circuit and camera chip were the major heat sources in the smartphones. Gurrum et al. [5] performed a tear-down analysis of a popular smartphone and measured rises in temperature, which were used to develop a smartphone thermal model. It was shown with the model that the presence of metallic spreaders and gap filler pads within the smartphone helped to establish contact between surfaces within the mobile phone. This facilitated heat flow via conduction to the outer surfaces of the phone in contact with the atmosphere; cooling the internal parts of mobile phones thereby and preventing any deteriorations.

Phone casings have become an important aspect of mobile phone technology in recent years. They are procured majorly to prevent damages to the screens due to falls or sudden impacts. But casings can also serve aesthetic purposes, be used as wallets or integrated with external batteries, etc.

Casings introduce an additional barrier in the heat dissipation route of mobile devices, and this has not been considered in existing studies. Hence, this study investigates the changes in phone temperatures that are caused by a plastic casing when the phone is performing common tasks.

2. Materials and Methods

Temperature monitoring tests were conducted in a cuboid wooden test chamber (Fig. 1(a)). To prevent radiant heat exchange across the walls of the test chamber, five of the inner surfaces of the chamber were lined with a reflective aluminium foil, while the sixth was made of a glass sheet. Other materials for the experiments included two smartphones of the same model, a plastic casing for the test phone, the *Seek Compact* infrared thermal camera, k-type thermocouple sensors and a digital temperature logger.



(a) Test chamber with the mobile phone setup. **(b)** Measurement setup for each mobile phone.

Figure 1. Test setup

The two smartphones were placed side by side on an inclined stand as shown in Figure. 1(a), and their front and back surface temperatures while performing similar tasks were simultaneously measured with thermocouple sensors Figure. 1(b). For the back surface temperatures, the temperatures of the control phone's back surface were measured whereas the temperatures of the casing's outer surface were measured for the test phone. Another thermocouple placed within the test chamber recorded the ambient temperature. The entire test setup showing the smartphones within the test chamber is as shown in Figure. 1(a). The test smartphone was covered with a casing while the control phone was left without any casing. The IR camera was fixed in an opening in the test chamber to obtain IR thermograms of the smartphones at fixed time intervals. These showed the temperature distribution on the phone screens during the tests. The internal (processor and battery) temperatures of the phones were obtained from of measurements made by the inbuilt sensors within the phones, which were recorded and displayed by the *Cpu Monitor* mobile phone application (found on the Google Play Store).

The test operations carried out by the smartphones included: (i) Online gaming, for which the popular *PUBG MOBILE* game was used. (ii) Audio voice calling, for which the default application on the phone was used. (iii) Video streaming, for which the *YouTube* video streaming application (on Google Play Store) was employed. (iv) Music playing, for which the *Deezer* song streaming app was used.

To ensure regular thermal readings and minimize errors, the batteries of the phones were fully charged before starting each experiment. To ensure identical operations in both test and control phones. all background apps were disabled, including auto-update, adaptive screen brightness and battery saving features and Wi-Fi was used for all processes that required internet access. The duration of each test was 30 minutes to ensure that the phones had reached steady state.

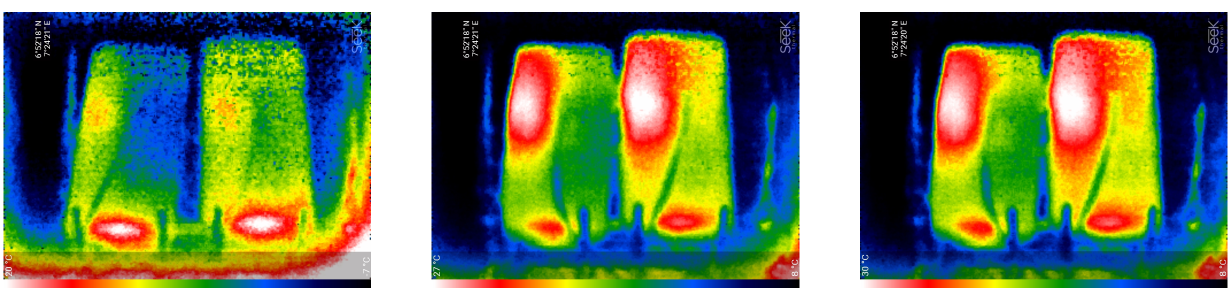
3. Results and Discussion

3.1. IR thermography of casing effects on phone surface temperatures

The IR thermograms of the phone screen surfaces at the start of the tests, after 15 and 30 minutes were obtained. The test phone is on the right while the control phone is on the left of the IR images presented in this section.

3.1.1. Online gaming

The IR images in Figure. 2 reveal changes in the temperature distributions on the phone surfaces during the online gaming operations. Surface temperature rose as the test proceeded as indicated by the general change in the IR thermograms from being generally blue/green to being largely red/white. The gaming application is very power intensive and resulted in much heat generation over the test duration.



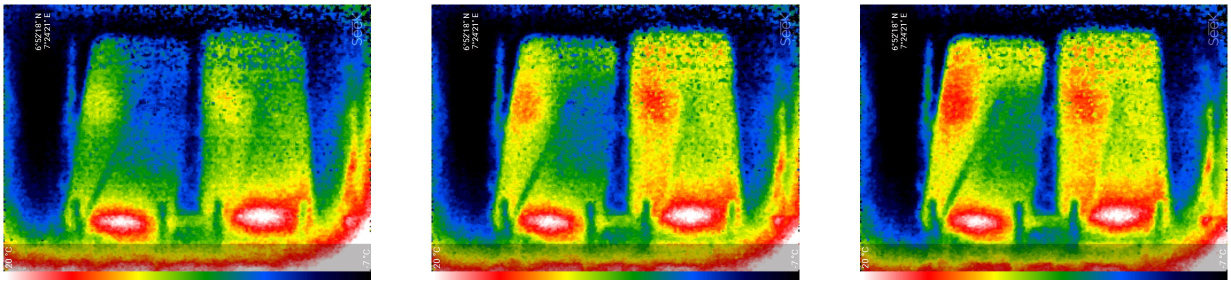
(a) 0 minutes **(b)** 15 minutes **(c)** 30 minutes

Figure 2. Phone surface thermograms during online gaming operations.

The bright (white) coloured portions represent the highest temperature region on the surface of the smartphones. They are initially at the lower end of the phones, where the battery contacts are located, because the phones had just been fully charged before starting the test. As the test proceeded, these hottest locations were found on the top left side of the phone surfaces where the processors are located. The thermograms show that the heated region is larger in the test phone (with casing) than in the control phone. The high surface temperatures indicated by this will usually cause discomfort on the hands of the user while gaming with these phones.

3.1.2. Audio calls

The thermograms for the phones during audio call tasks are shown in Fig. 3. As observed in the online gaming case, the test phone temperatures generally appeared elevated compared to the control phone. However, the temperatures are more evenly distributed across the phone surfaces as the 15 and 30 minutes thermograms show. The surface temperatures do not experience significant elevations as the hottest locations remain at the bottom of the phone surfaces.

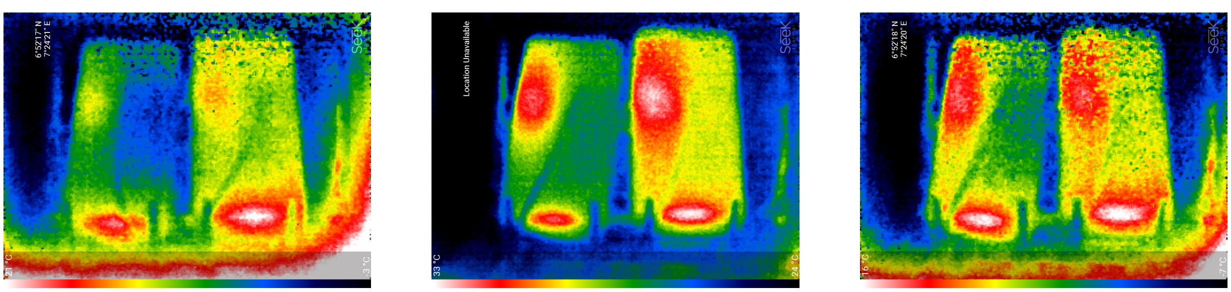


(a) 0 minutes **(b)** 15 minutes **(c)** 30 minutes

Figure 3. Phone surface thermograms during voice calls.

3.1.3. Video streaming

Figure 4 shows thermograms for the video streaming operation. The position of the heat generating wireless network chipset on the phone processors are indicated by the regions of elevated temperatures. The network chipset is actively in use during this task, and its temperature initially rises fast from the start of the operation till 15 minutes into the operation, and reaches steady state between 15 and 30 minutes (since there is slight reduction in the intensity of the white colour on the screens between these periods). However, this operation will degrade user experience because it generates a lot of heat in a short period, which the user would feel on his/her palm.

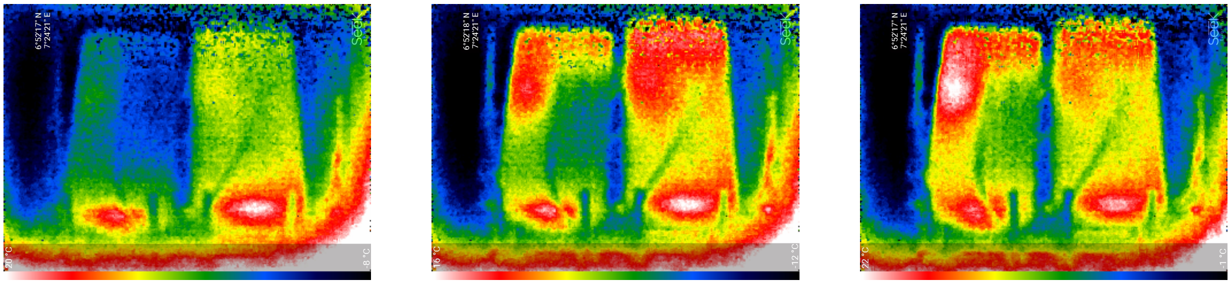


(a) 0 minutes **(b)** 15 minutes **(c)** 30 minutes

Figure 4. Phone surface thermograms video streaming.

3.1.4. Music playing

A slow rise in the surface temperatures was observed during the music playing operation as shown in Figure. 5. The thermograms indicate that the heat generated during this task is not significant as the patterns of the thermograms are not significantly altered.

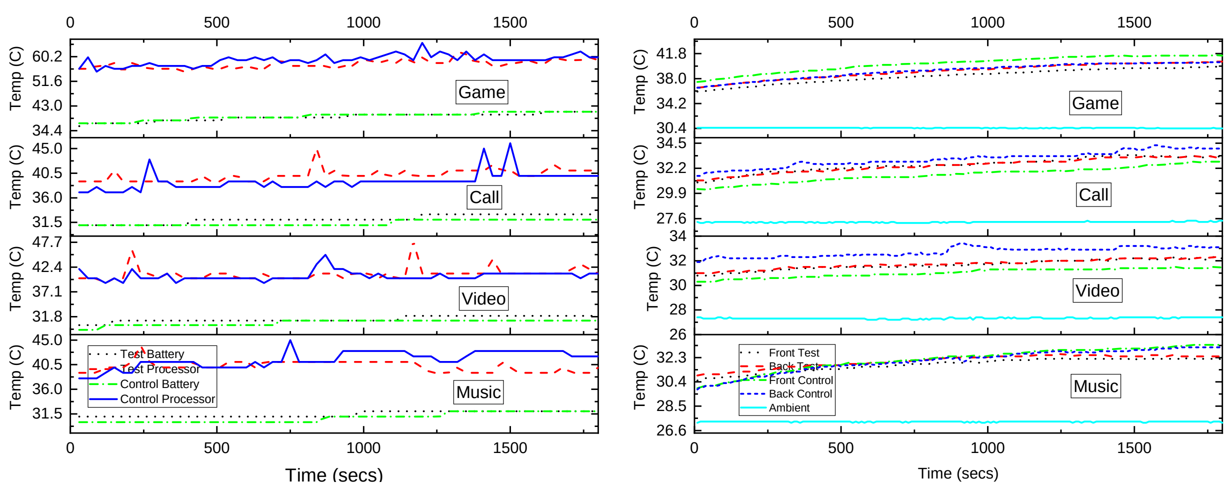


(a) 0 minutes **(b)** 15 minutes **(c)** 30 minutes

Figure 5. Phone surface thermograms music playing operations.

3.2. *Effect of phone casing on phone processor, battery and surface temperatures*

The phone processor and battery temperatures, front and back surface temperatures and ambient temperatures during the test tasks are shown in Fig. 6. Figure 6(a) shows that the test phone battery temperatures are generally higher (by ∼2°C) than those of the control phone. Both phones recorded unexplained peaks in processor temperatures (reaching up to ∼65°C), in the absence of which the test phone processor temperatures were generally higher (by ∼1°C).



(a) Battery and processor temperatures. **(b)** Surface and ambient temperatures.

Figure 6. The effect of plastic casing on transient temperatures in the phones

During the call, video and music tasks, the control phone back surface temperatures were higher than those of the test phone, showing that for these tasks, the plastic casing sufficiently impeded heat flow to the surface in contact with the user's hands. For the gaming task however, the plastic casing was unable to suppress the flow of excessive heat generated, and the back surface temperatures of both test and control phones were effectively equal.

This trend was reversed for the front surface temperatures, revealing that the effect of the phone cover was to redirect the heat flow to the phone's display surface. This effect will be majorly felt during voice calls when user cheeks are in contact with the phones front surface. Prolonged contact between the phones and the human skins during calls are known to cause mild pains on the cheeks because the elevated surface temperatures experienced [6].

As shown from Figure. 6(a), for the less power intensive tasks (call, video, music) for which the casing protects the user's hands from elevations in back surface temperatures, increased internal temperatures (processor & battery) also, which may be detrimental to the internal electronic components of the devices.

4. Conclusions

The gradual spread of heat within the smartphones over the duration of common tasks was observed, being more widespread in the power-intensive gaming operations. The surface temperature distributions in the thermograms were highest for online gaming, followed by video streaming, call making and then music playing, indicating the order of the power consumption by the tasks. The test phones also appeared to be hotter than the control phones.

The measured surface temperatures revealed that due to the insulating property of the phone casing material, it redirected heat flow to the front surface of the smartphones. Consequently, the use of plastic phone casings will improve user experience for tasks involving contact with the users' hands but not for tasks involving contact with the users' faces. These are accompanied by excessive heating of phone internal parts, which is detrimental to the electronic components of the phone, which deteriorate under high temperature conditions.

The protection offered to phone users by the use of phone casings can be extended by using casings which incorporate phase change materials. With these, rather than being redirected, the heat flowing to the phone's back surface would be absorbed by the casing and released later when the phone is not in use [7].

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Conflicts of Interest: The authors declare no conflict of interest.

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