**Term Paper – Fire in your hands: Understanding Thermal Behavior of Smartphones**

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1. **Introduction**

This term paper is about the MobiCom conference paper: Fire in your hands: Understanding Thermal Behavior of Smartphones[1]. This paper introduces that with the increasing number of reports on smartphones overheating issues, systematic measurement and user experience study regarding the thermal aspect becomes an urgent demand. Toward this end, the authors perform experiments utilizing thermal imaging cameras, as shown in Figure 1, to examine the thermal behavior of various smartphones under different types of workloads. As numerous popular applications would overheat the smartphone and cause thermal pain, the authors further conduct a user study to evaluate how soon would the users be aware of the overheating, and how would the users respond to the heat. The majority of the participants claim to feel uncomfortable because of the heat. To better gain insights into the heating behavior and provide improvement directions for developers, the authors design a model to predict the surface temperature of the smartphone.

**Figure 1: Measurement setup using thermographic cameras.**

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The major contributions of this work are as follows. 1). This paper shows a significant contribution for it systematically studies when and how much heat a smartphone and its components could generate and thus affect user experiences. 2). The experiments cover a broad range of smartphones and components and use thermographic camera measurements to generate quantifiable results under various usage scenarios. 3). A user study is performed and analyzed to learn how overheating would lead to discomfort and affect user experience, revealing users’ concerns on health risks and sweating related problems. 4). A smartphone surface temperature prediction model leveraging easy-to-access system statistics is proposed, which could achieve high accuracy for both real-time and one-minute look-ahead predictions. In the rest parts of the term paper, I will introduce how the authors perform user study and quantify the users’ feedbacks.

1. **Approach and Methodology**

As Section 3 and Section 4 of the conference paper studied, numerous applications could cause the phone to overheat, it is important to understand how much heat would actually cause discomfort to most users and how uncomfortable the users would feel when using the smartphone for a reasonable amount of time. The authors also study the users’ reaction patterns due to the surface heat.

To perform user study, the authors involve 20 participants, with the gender ratio equally divided. It is widely acknowledged that male and female differ in the sensitivity of thermal comfort [2], 10 male and 10 female participants ensure the fairness of subjective thermal feeling. The participants’ ages range between 19 and 26, with an average of 21.45 to represent the thermal sensitivity of the majority people. In order to observe users’ feelings and reactions in response to the overheating, the authors select a popular 3D mobile action game named Yokai Saga [3] as the application scenario. This 3D mobile game could attract participants’ attention to test for a long period of time. Besides, it frequently requires participants’ interaction and results in the smartphone to heat in a consistent pattern. The above properties of this application guarantee each participant focus on operating the smartphone continuously, in the meantime, the phone would generate a similar amount of heat each time. The authors use two smartphones: Nexus 5X and Galaxy S7 to involve the variance of heating patterns among different devices. As Figure 2 demonstrates, the Nexus 5X shows a slightly higher surface temperature and can achieve a stable surface temperature state faster. The experiment lasts for 20 minutes and participants are recommended to hold the phone in landscape mode using two hands to avoid laying the phone down on the table and cause unexpected heat conduction between the table and the smartphone. The order of participants performing **A close up of a map

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**Figure 2: Surface temperature during a gameplay.**

The experiment is a within-subjects experiment approved by IRB. One challenge for performing user study is how to quantify the subjective sensations. To address this, the authors use a 5-point Likert scale as an evaluation metric: 1: Not at all, 2: Little, 3: Somewhat, 4: Very much, and 5: Extremely. The participants are requested to rate the level of heat sensation and discomfort every 4 minutes. The experiments are video recorded to investigate their reactions and grabbing patterns. After the experiments, the authors conduct a follow-up interview to comprehensively investigate user experiences.

1. A screenshot of a cell phone

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**Figure 3: Heat sensation and discomfort during gameplay (error bars denote standard deviation).**

Figure 3 demonstrates the feedback from users regarding the average level of heat sensation and discomfort during the 20-minute game scenario. As can be seen from this figure and Figure 2, the temperature level increases at a similar level as the heat sensation. However, the user experience regarding heat discomfort doesn’t show a similar pattern. The discomfort level increases nearly linearly as the time increases. Based on the Likert scale rating, 75% of the participants rated the discomfort level as 3 to 5, indicating feeling uncomfortable because of the surface heat. As the heat levels up, other corresponding effects such as sweating and fingers get numb also get reported.

In order to examine the time-correlated differences, the authors use paired samples t-tests between neighboring measurements. They found that the heat sensation hugely differs from the 0th minute to the 16th minute, but the latter 4 minutes were not that different. Despite the steady heat sensation after 16 minutes, the discomfort level increases as time grows, which proves that long-period smartphone usage under heavy workload still leads to uncomfortable experiences, even though the temperature is not increasing significantly.

The authors further interview the participants after the experiments to investigate the dominant factors causing thermal discomfort. According to the reports from the participants, the top five reasons are as follows: (1) heat sensation, (2) concerns on skin burn, (3) sweating, (4) sensor malfunction caused by sweat, and (5) slip caused by sweat. Apart from the thermal issues, the authors also find that other factors such as the materials of the smartphone surface would dominant the user experience. For instance, most users rate the Galaxy S7 as more uncomfortable than Nexus 5X for its slippery surface after sweating, despite Nexus 5X actually has a higher surface temperature.

The authors perform a video recording analysis to observe participants’ behaviors in response to the overheating. Since the game application requires landscape mode to interact, 75% of the users hold the phone with two hands, and all users are exposed to areas that could generate the most heat. Based on such baseline posture, almost all participants (95%) frequently adjust the way they grip the smartphone and stretched their hands. 35% of those participants claim this was either because the smartphone is overheating, or their hands are too sweaty. Whereas the rest majority consider this is to relieve the discomfort caused by holding the smartphone for a long time and should be subconscious.

1. **Related Work**

Powerful modern mobile processors have brought more heat to mobile devices and raised broad attention. Many works studied the thermal models and thermal management techniques for mobile devices, which could be categorized into three aspects: smartphone-based thermal management and prediction, thermal models and simulation, as well as the relationship between thermal conditions and user experience.

Existing smartphone-based thermal management and prediction models mainly focus on measuring or predicting the temperature of application processors, underestimating the synthesis of other components such as the Wi-Fi chip, camera, and battery. Moreover, works such as Egilmez et al. [4] propose a model utilizing limited data obtained from kernel-level hardware to predict temperature via basic linear regression methods. The authors propose to leverage various easy-to-access system statistics as the feature and apply preprocessing techniques, such as time lagging, to fit a multiple regression model.

Thermal models and simulators developed for smartphones only focus on hardware-level heat dissipation from the heat source to the surface, without considering the influence of various software applications workloads. The authors select a wide range of application scenarios to mimic different daily usage, making the results practical and instructive.

Some studies also research on the relationship between the thermal issue and user experience, but there is a lack of systematic analysis on surface-level and component-level temperature measurement. Additionally, these studies fail to involve various recent smartphones and evaluate under diverse application scenarios. In this paper, the authors measure the thermal conditions for both the surface and components of the smartphone using diverse application workloads.

1. **Conclusion**

This paper systematically investigated the thermal issues for various recent smartphones by measuring the temperature for both the surface. Diverse application scenarios are selected to study how different software would impact the thermal conditions of smartphone components. A user study is performed to examine when and how much heat would cause discomfort and users’ reactions. The authors found the heat sensation level increases as the surface temperature, but the discomfort level shows a linear trend, which is less correlated to the surface temperature. Besides, the surface material and other side effects of overheating, such as sweating, can also downgrade the user experiences. To better gain insights into the thermal pattern, the authors propose a surface temperature prediction model for smartphones. The surface temperature prediction model takes as input various system statistics and achieves high accuracy.

**Strengths of this paper:**

* This work systematically studies the overheating issues on smartphones, verifying across various recent devices and evaluates under lots of practical application scenarios.
* This work measures not only the surface temperature of the smartphone, but also the temperature of the components.
* The authors perform a user study to investigate the user experience and use the Likert scale rating to quantify subjective sensations.
* The authors further design a surface temperature prediction model based on system statistics.

**Weaknesses of this paper:**

* The proposed surface temperature prediction model needs to be trained again for different smartphones. Therefore, the generalization of this model is not good enough.
* The authors only evaluate running a single application at a time. However, multitasking is a fundamental function and heavily used by users. The authors could further evaluate the thermal conditions under multitask scenarios and study the background application management.
* The authors mainly study the thermal impact from various application workloads without considering different hardware designs and circuits layouts could also have a significant impact on heat dissipation.

**Potential enhancement directions:**

* The authors could study how different background management strategies could influence the thermal management.
* The authors could further investigate the differences between smartphone operating systems. iOS is less likely to overheat comparing with Android-based on their preliminary study. It is essential to study how different resource management in various operating systems could affect the overheating issue.
* The authors could study how the battery saving mode would change the power output and further decrease the surface temperature.
* The authors could extend the user study to include more details, such as which component overheating would bother users most and which is the least component that the users worry about thermal issues. This could provide useful information for software developers and smartphone vendors to improve the software/hardware design.

**References**

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