Efficient External Sensors for Smartphones through Near Field Communication (NFC)

Christian Schuss, Tore Leikanger and Juha Häkkinen
Circuits and Systems (CAS) Research Unit
Faculty of Information Technology and Electrical Engineering
University of Oulu, Finland
Email: firstname.lastname@oulu.fi

***Abstract*—This paper evaluates the opportunity to utilise external sensors through near field communication (NFC) for smartphones, both, in terms of energy consumption from the smartphones' battery and time consumption of the smartphones' user. Our developed sensor card enables external sensors to obtain information, for example, on the current temperature level, humidity level, UV level, and amount of ambient light. We demonstrate that our approach requires significantly less energy and time compared to alternatives which users of smartphones have. Furthermore, we analyse the impact of heat sources present in smartphones on the readings of temperature and humidity level sensors. We propose to externalise sensors in order to minimise the negative impact of temperature on sensors readings and, thereby, improving the accuracy of the measurements and the acquired sensor data.**

***Index Terms*—Bluetooth, external sensors, heat sources, humidity level, Internet of Things (IoT), near field communication (NFC), smartphone, temperature, weather information.**

I. Introduction

The forthcoming Internet of Things (IoT), in particular IoT related to healthcare as well as the Industrial Internet of Things (IIoT), has the potential to transform our daily lives [1]. It is worth noting that sensors are one of the key elements of IoT devices and, thus, receive enormous interest from the research community [2], [3]. Sensor data, which is collected by IoT devices, will allow us to improve the quality of our daily life significantly and, furthermore, will increase our awareness and understanding of our environment. Moreover, sensor data obtained with the help of IoT devices can lead to exciting new applications in the future, for example smart healthcare. In addition, the potential is given to dramatically reduce the costs of healthcare [3].

Sensor data can be used to improve people's health and wellbeing in various ways [1]–[3]. In these days of a fast-changing environment, people are worried and curious about the conditions of their surrounding environment. The environment plays a crucial role in people's physical, mental and social wellbeing. Thus, people are seeking for more information, for example, about their current ambient conditions in order to improve their health and wellbeing [1]–[3]. At present, people are missing the opportunity to obtain information directly, for example with the help of their smartphones and tablets due to the lack of sensors on their mobile devices [4].

The degradation of the environment, for example due to air pollution, increases the risk of diseases and cancers within the cardiovascular and the nervous systems. Today, these diseases are major public health problems for Europe's population [5]. Reproductive and mental health problems are also on the rise. Furthermore, asthma, allergies, and some types of cancer related to environmental pressures are of particular concern for children [5]–[7]. The focus of this research is to enable external sensors for smartphones and other portable electronic devices through NFC. In particular, we focus on sensors which are not available smartphones nowadays. In this way, we developed a sensor card which allows users utilising new types of sensors in order to measure the temperature and humidity level, the UV level and the light intensity, as shown in Fig. 1. Measuring the temperature and humidity level allows to analyse indoor and outdoor environmental conditions, for example in terms of indoor air quality (IAQ) [8].

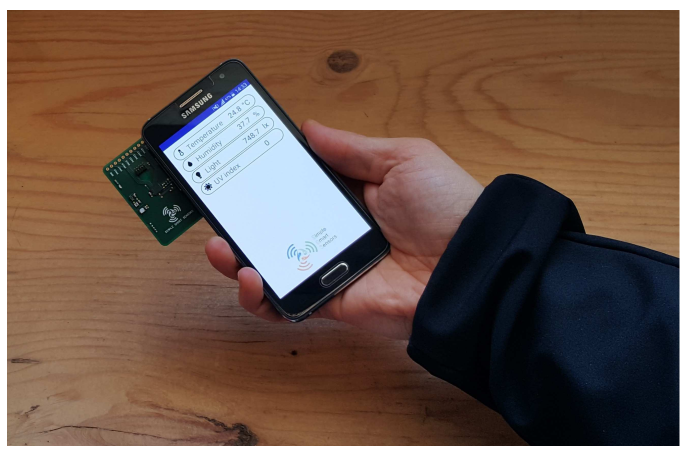


Fig. 1. Obtaining data with the help of the sensor card on a smartphone

II. Background and Motivation of the Research

A. Research background

In previous studies, we have analysed the performance of ambient light sensors (ALSs) in smartphones [9]–[11] in addition to presenting the opportunity to enable external sensors for smartphones [4], [12]. The focus lied on sensors which are not available on smartphones on the one hand

[4] and the calibration of existing sensors in smartphones on the other [12]. The target was to enable external sensors which can be connected to the inter-integrated circuit (I2C) bus. Theoretically, up to 127 sensors can be used with the help of the I2C bus but generally speaking, the focus lies on interfacing sensors which can be used to obtain ambient conditions such as temperature, humidity level, UV level and amount of ambient light, for example.

In this paper, we concentrate on the energy consumption of our credit card-sized sensor card, which is shown in Fig. 2. We present experimental results, in which we measured the power drained from the smartphones' battery which is needed, both, to run the mobile application on the smartphone and to power the electronics and sensors through near field communication (NFC) to obtain information on the current ambient conditions, more precisely the temperature and humidity level.

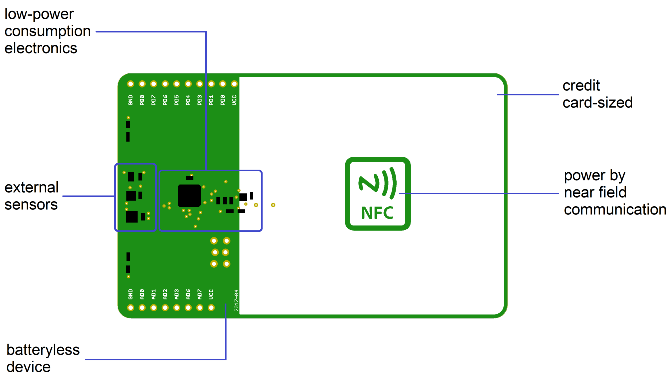


Fig. 2. Concept and components of the sensor card

B. Background of internal smartphone temperature sensors

In this paper, we also demonstrate how internal smartphone sensors which allow measuring the temperature and humidity level are affected by heat sources in smartphones. In experiments, we recorded infrared (IR) images with the help of the Flir ONE in order to show the temperature distribution in smartphones. As a result, we are able to evaluate the impact of the central processing unit (CPU), the graphics processing unit (GPU), and the battery as potential heat source on sensor readings.

The capability of smartphones increases constantly, especially in terms of processing power. Table I presents some of the specification of earlier flagship devices from Samsung, such as the Galaxy S3, S4 and S5. As seen in Table I, the performance of the CPU and GPU has significantly increased, while the amount of memory has remained constant. Furthermore, the size and capacity of the battery has increased. When comparing the different smartphones with each other, it is worth noting that the Samsung Galaxy S4 is the only device of the Galaxy S series which features a temperature (T) and relative humidity (RH) sensor, the Sensirion SHTC1 (measuring range for T: – 30 °C to 100 °C ± 0.3 °C and measuring range for RH: 0 %RH to 100 %RH ± 3 %RH), as summarised in Table II.

TABLE I
COMPARISON OF DIFFERENT SAMSUNG SMARTPHONES

	Samsung Galaxy S3 (GT-I9305)	Samsung Galaxy S4 (GT-I9506)	Samsung Galaxy S5 (SM-G901F)
CPU	Quad-core 1.4 GHz Cortex-A9	Quad-Core 2.3 GHz Krait 400	Quad-core 2.5 GHz Krait 450
GPU	Mali-400MP4	Adreno 330	Adreno 420
RAM	2 GByte	2 GByte	2 GByte
Memory	16 GByte	16 GByte	16 GByte
OS	4.4.4 (KitKat)	5.0.1 (Lollipop)	6.0.1 (Marshmallow)
Battery	2100 mAh	2600 mAh	2800 mAh

TABLE II
AVAILABLE SENSORS ON SAMSUNG GALAXY PHONES

	S3	S4	S5	S6	S7	S8
Accelerometer	x	x	x	x	x	x
Proximity sensor	x	x	x	x	x	x
Barometer	x	x	x	x	x	x
Gyrometer	x	x	x	x	x	x
Ambient light sensor	x	x	x	x	x	x
Temperature sensor	-	x	-	-	-	-
Humidity sensor	-	x	-	-	-	-
Heart rate sensor	-	-	x	x	x	x
SpO2 sensor	-	-	-	x	x	x

x . . . sensor available
- . . . sensor unavailable

As mentioned above, CPU, GPU and the battery are potential heat sources in smartphones and, thus, can affect the measurements carried out with internal sensors. In future, it is highly likely that the process and graphic power embedded in smartphones increases further and so will the battery power. On the contrary, the thickness of devices will decrease in future. It can be argued that this development is the reason why certain types of sensors such as temperature and humidity level sensors are not included in today's smartphones.

III. EXPERIMENTAL RESULTS

A. Measurement setup for obtaining the energy drain

A Samsung Galaxy S5 (SM-G901F) was used within the experiments. In between the plus terminal of the smartphone's battery, a shunt resistor (R_{sh}) of 10 mΩ was connected. With the help of a data acquisition (DAQ) module, more precisely the National Instruments (NI) myDAQ, we measured the voltage drop V_{sh} on the shunt resistor. The NI myDAQ was connected to a Laptop on which the LabVIEW software was running in order to log the data [13]. Fig. 3 illustrates the measurement setup. The voltage of the smartphone's battery (V_b) was obtained with the help of a mobile application and added to the LabVIEW program to calculate the power drained from the battery (P_d).

The power and, in this way, the energy drained from the phone can then be calculated, as follows:

$$P_d = V_b \times I_{sh} \quad \text{whereas} \quad I_{sh} = \frac{V_{sh}}{R_{sh}} \tag{1}$$

The drained energy (E_d) from the smartphones' battery can then be calculated over the measurement time (t_m).

$$E_d = \int_{t_1}^{t_2} P_d(t)dt \tag{2}$$

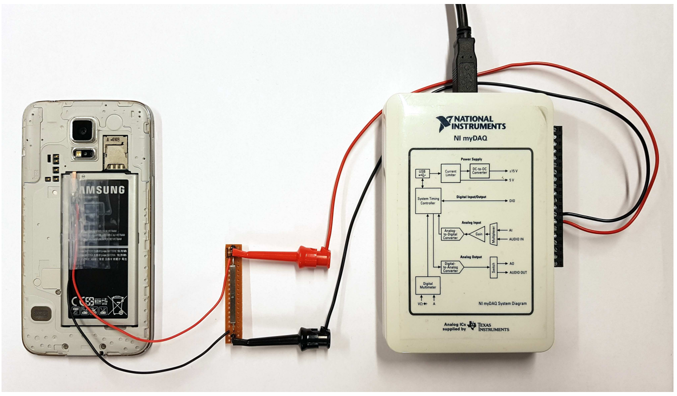


Fig. 3. NI myDAQ connected to the shunt resistor at the battery terminal

B. Energy drain using external sensors through NFC

In the first measurement, the energy consumption is measured in the situation where the sensor information is obtained with the help of the sensor card through NFC. Fig. 4 illustrates the obtained power drain from the smartphone's battery. At first, the mobile application is started (peak at t = 3 s in Fig. 4). Then, the sensor information is read from the sensor card (peak at t = 5 s in Fig. 4) and, right after, the measured data from the Sensirion SHT21 on the current ambient temperature (measuring range for T: – 40 °C to 125 °C ± 0.3 °C) and humidity level (measuring range for RH: 0 %RH to 100 %RH ± 2 %RH) is displayed by the mobile application (peak at t = 7 s in Fig. 4). The measurement time (t_m) was about 6.2 s.

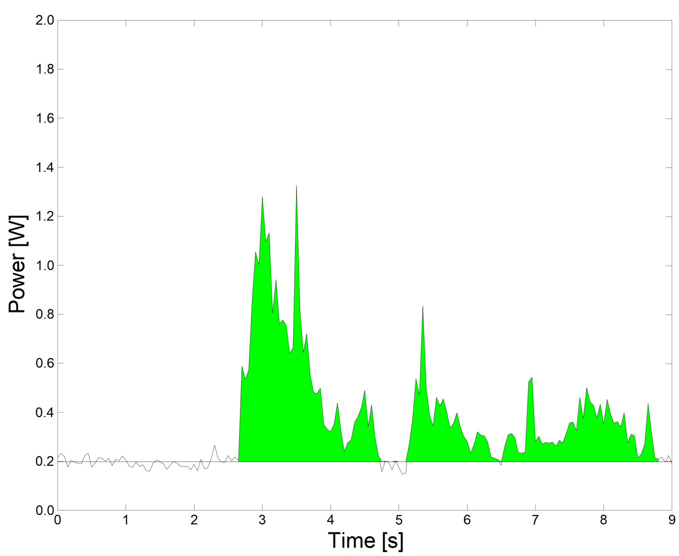


Fig. 4. Power drain for getting ambient data from the sensor card

In the experiments, the smartphone did not have any network connectivity and the screen was used at medium brightness level. The baseline power, in other words the power consumed by the phone left in idle, was about 0.2 W. For simplification, the energy consumed in idle mode is excluded from the calculations. Focusing on the consumed power for obtaining the sensor information, integrating P_d over t_m, gives a total energy drained from the smartphones' battery of E_d = 1.36 J.

C. Energy drain using external sensors through Bluetooth

In the second experiment, an external sensor tag, more precisely the Texas Instruments (TI) SensorTag (CC2650) was read through Bluetooth. The SensorTag obtains the temperature (measuring range for T: – 40 °C to 125 °C ± 0.2 °C) and the humidity (measuring range for RH: 0 %RH to 100 %RH ± 3 %RH) are read with the help of the TI HDC1000 temperature/humidity sensor. The baseline was about again about 0.2 W. The SensorTag was switched on before the application on the smartphone was started.

In Fig. 5, the peak at t = 7 s indicates the start of the mobile application. The series of peaks starting t = 12 s are a result of establishing the connection between the smartphone and the SensorTag through Bluetooth. The remaining peaks are caused by reading from the SensorTag and displaying the obtained information on the screen of the smartphone. The measurement time (t_m) was 19.9 s, while the drained energy was E_d = 11.89 J. Due to Bluetooth Low Energy 4.0, the energy consumed on the sensor side is low. However, the energy consumed on the smartphone is significant.

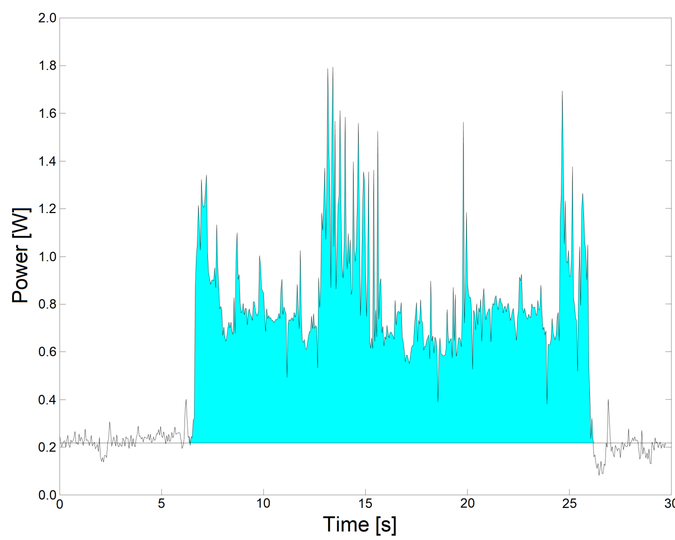


Fig. 5. Power drain for getting ambient data from the local weather station

D. Energy drain using wireless local area networking

In the third measurement, data on the ambient temperature and humidity level was requested from a local weather station with the help of a mobile application (AccuWeather). In this way, the ambient data was obtained with the help of wireless local area networking (WLAN) connectivity. Fig. 6 illustrates the power consumption for requesting the data on the current ambient conditions. A more detailed description about the individual tasks which were carried out is provided underneath Fig. 6. As in the previous experiment, the baseline power of about 0.2 W was not taken into account for the calculations.

When integrating the power consumption from the first peak t = 4 s in Fig. 6, until the time the smartphone returns to idle, we obtain E_d = 14.91 J. In this experiment, the measurement time (t_m) was 33.7 s.

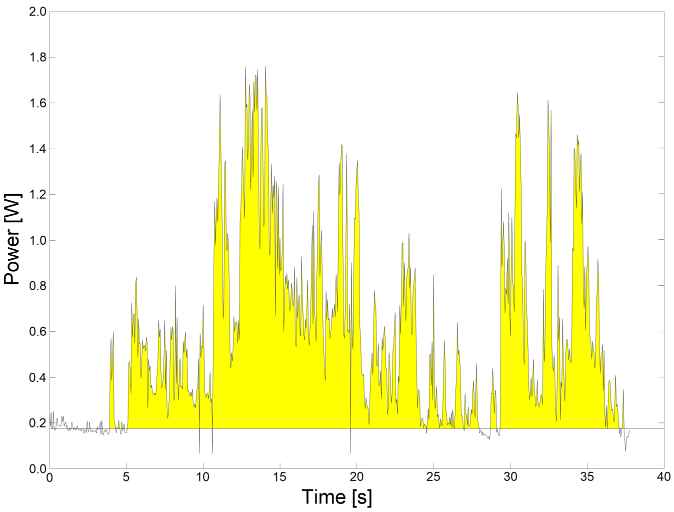


Fig. 6. Power drain for getting ambient data from the local weather station

Individual tasks/events for obtaining the data from the local weather station:

1) The phone is in idle mode.
2) The menu bar is pulled down from the top.
3) WLAN connectivity is switched on.
4) WiFi starts up and connects to a network.
5) The mobile application is started.
6) The application starts to obtain the current data.
7) The application displays the current weather data.
8) The mobile application is closed.
9) The menu bar is again pulled down from the top.
10) WLAN connectivity is switched off.

E. Comparison of the power profiles

When comparing the three power plots with each other, we can see that obtaining information from external sensors through NFC is easy and convenient for smartphone users. Firstly, users are able to receive sensor data from their surrounding environment directly. A local weather station can be dozens of kilometres away, for example. Secondly, the process of obtaining the data on the ambient conditions from the sensor card is about three times faster than requesting data from Bluetooth and about five times faster than requesting data from the local weather station through WiFi. In Fig. 4, the short idle time at t = 5 s is caused due to sweeping the sensor card over the NFC coil of the smartphone.

Finally, and most important, obtaining the ambient data from the sensor card through NFC requires about ten times less power in comparison to Bluetooth and WiFi. In other words, with the same amount of energy, we are able to obtain the ambient conditions from external sensors ten times more often. As a result, users are able to obtain their ambient conditions by obtaining sensor data more frequently.

It is worth noting that keeping NFC activated throughout the day, drains only a small amount of power, which is in the order of about 0.25 to 0.5 % of the battery capacity. The sensor card, on which the external sensors are located, can be designed as a batteryless device. In contrast, Bluetooth connectivity also requires batteries for powering external sensors. Even though Bluetooth has a low power consumption [14], [15], pairing external sensors with a smartphone requires time and, thus, results in CPU activity.

F. The CPU and GPU as a heat source

In the first measurement, the phone was left in idle mode on the desk for a few minutes. This is the practical way to obtain the ambient temperature and humidity level, according to the mobile application from Sensirion which is available for the Samsung Galaxy S4. Fig. 7 (a) shows the IR-image of the smartphone with a CPU temperature of 35 °C. For comparison, we also obtained the temperature and humidity level with a reference, the Testo 608-H2, a thermo-hygrometer.

In the second measurement, the smartphone was in light usage e.g. web-browsing but remained lying on the desk. The CPU temperature increased to 50 °C and the related IR-image is shown in Fig. 7 (b). In the third measurement, when the smartphone was in medium usage e.g. watching videos, the CPU temperature increased to 60 °C. The IR-image is shown in Fig. 7 (c). Table III summarises the obtained measurement results for the temperature (T) and humidity level (RH), with the Testo 608-H2, the sensor card and the Samsung Galaxy S4.

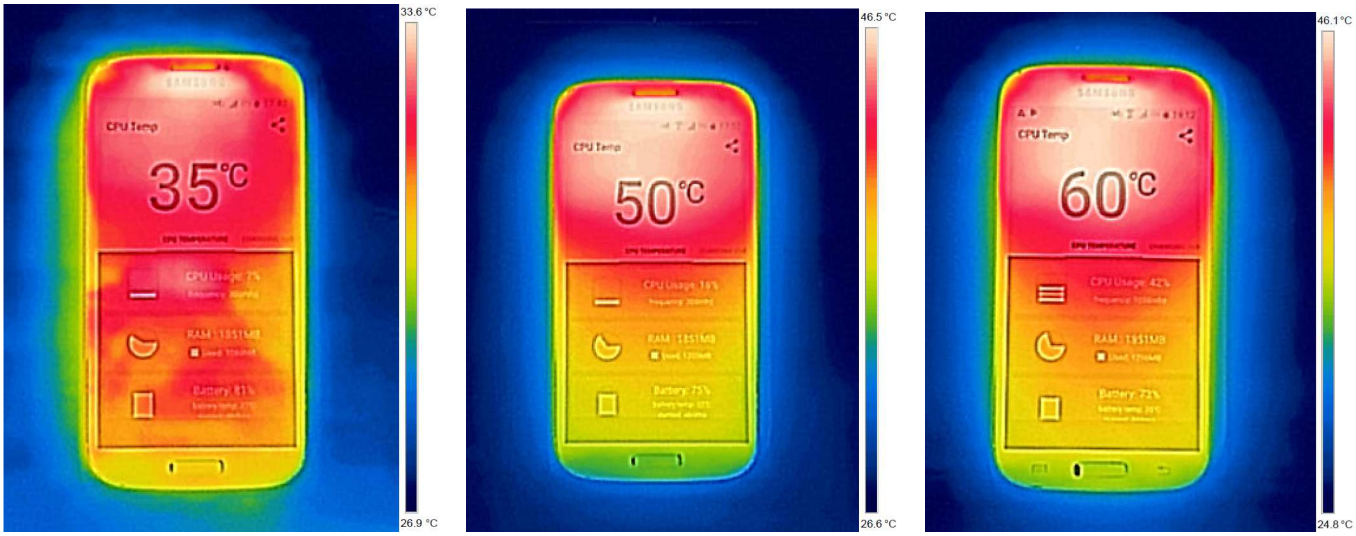
TABLE III
COMPARISON OF MEASUREMENT RESULTS (CPU/GPU AS HEAT SOURCE)

Testo 608-H2	Sensor card	Samsung Galaxy S4	CPU temperature	Samsung S Health
T = 23.8 °C RH = 46.3 %	T = 23.7 °C RH = 46.1 %	T = 24.0 °C RH = 46.0 %	35.0 °C	Good
T = 23.8 °C RH = 46.2 %	T = 23.7 °C RH = 46.0 %	T = 25.9 °C RH = 45.0 %	50.0 °C	Good
T = 23.8 °C RH = 46.3 %	T = 23.7 °C RH = 46.1 %	T = 27.0 °C RH = 42.0 %	60.0 °C	High temperature

As the workload for the smartphone and, thus, the CPU and GPU increases, the CPU and GPU become a heat source. As a result, the sensor data obtained with the internal temperature and humidity sensor are affected. As seen in Table III, an increase in the CPU temperature causes an increase in the measured temperature (T) and a decrease in the measured humidity level (RH). At a measured temperature of 27.0 °C, the mobile application Samsung S Health informs the user about a high temperature, as shown in Fig. 8 (a).

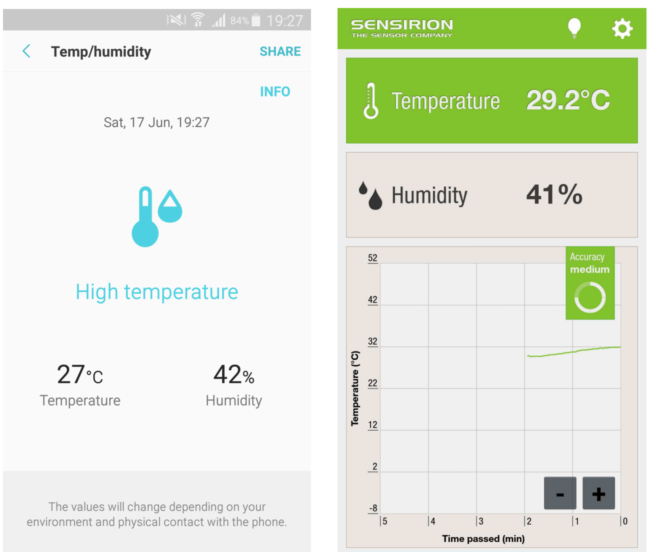
G. Other potential heat sources

The readings of the internal sensors are also affected, when the smartphone is charged by a wall-charger, as shown in the IR-image in Fig. 9 (a). Similarly, as shown in Fig. 9 (b), when the phone is held in the hand, instead of put on the desk, the temperature and humidity readings are affected. Table IV presents the obtained measurement results. As seen in Fig.



(a) Samsung S4 in idle mode (b) Samsung S4 in light usage (c) Samsung S4 in medium usage

Fig. 7. Obtaining IR-images from the Samsung Galaxy S4 under different types of usages: idle mode, light usage, and medium usage



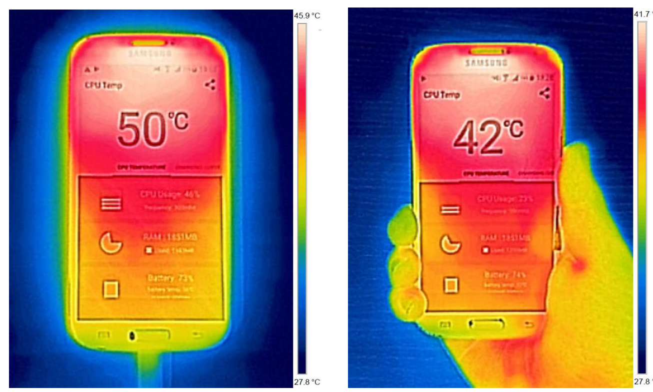
(a) Samsung S Health (b) Sensirion application

Fig. 8. Mobile applications displaying temperature and humidity level

8 (b), the longer the smartphone is hold in the hand, the higher the temperature become. After some time, the Sensirion mobile application shows a decrease in it's accuracy.

TABLE IV
COMPARISON OF MEASUREMENT RESULTS (OTHER HEAT SOURCES)

Testo 608-H2	Sensor card	Samsung Galaxy S4	CPU temperature	Samsung S Health
T = 23.9 °C RH = 46.2 %	T = 23.8 °C RH = 46.0 %	T = 27.7 °C RH = 39.0 %	50.0 °C	High temperature
T = 23.8 °C RH = 46.2 %	T = 23.7 °C RH = 45.9 %	T = 29.2 °C RH = 41.0 %	42.0 °C	High temperature



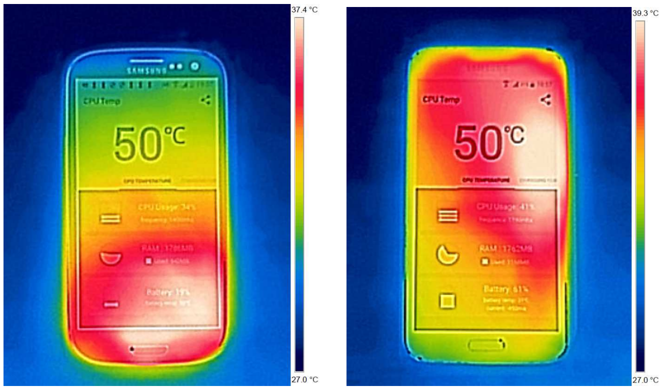
(a) Samsung Galaxy S4 charging (b) Samsung Galaxy S4 in the hand

Fig. 9. IR-images of the Samsung Galaxy S4 under different usages

H. Comparison between different heat sources

It is worth noting that not only the usage of the smartphone affects temperature readings, but also the location of the sensors is crucial. In the Samsung Galaxy S4, the Sensirion temperature and humidity level sensor is located next to the USB connector in the lower right-corner of the phone. Hence, it is difficult to obtain accurate sensors data while holding the phone in the hand. As seen in Fig. 7 (b) and (c), the CPU and GPU are located on top of the phone, while, as seen in Fig. 9 (a), the battery is located in the centre of the device.

The location of CPU, GPU and battery differs between the Samsung Galaxy S3, S4, and S5. Thus, the optimum location of the sensor also varies. In general, users are not aware about the locations of the internal sensors in smartphones. Fig. 10 (a) shows the IR-image of a Samsung Galaxy S3, in which the CPU and GPU are located in the lower half of the phone. In contrast, Fig. 10 (b) shows the IR-image of a Samsung Galaxy S5, in which the CPU and GPU are located on the upper right-hand side of the phone. As mentioned above, both smartphones do not contain a temperature/humidity sensor.



(a) Samsung Galaxy S3 (b) Samsung Galaxy S5

Fig. 10. IR-images of different the Samsung Galaxy smartphones

IV. Discussion and Conclusion

In this paper, we demonstrated that obtaining data from external sensors on the current ambient conditions is both, energy efficient as well as time efficient. In experiments, we measured the power and, thereby, the energy which is drained from the smartphone's battery for obtaining sensor information. Here, the main target was to measure the current ambient temperature and humidity level. We used a Bluetooth sensor tag (TI SensorTag CC2650) and a standard mobile application (AccuWeather) to obtain the same type of information from a local weather station.

We showed that obtaining environmental data with the help of our sensor card is three times faster and requires ten times less energy. It is worth noting that NFC gives the ability to transmit power and data simultaneously. In this way, we are able to design our credit card-sized sensor card without a battery as a power source. As benefit, users do not need to worry about the battery life of their external sensors. Other communication methods such as Bluetooth require batteries on the sensor side.

Furthermore, we verified the impact of heat sources on the sensor readings of internal temperature and humidity level sensors. More precisely, we showed that different types of usages increase the CPU temperature and, thereby, the temperature measured by the smartphone. However, with the increase in CPU temperature, the humidity level decreased. We presented IR-images to illustrate the temperature distribution in smartphones.

In this way, we elaborated that the location of the CPU, GPU and battery can have an impact on sensor readings as well as on the possible location of sensors. We presented results which showed that internal sensors in smartphones are affected by heat sources, while external sensors on our sensor card are not influenced by the potential heat sources in smartphones. It is worth noting that external sensors provided similar measurement results as the reference source.

Environmental data is important for users and patients. For example, when suffering from dry skin, measuring the temperature and humidity level can help to improve the IAQ and, thus, the health and wellbeing of individuals. As internal sensors, which allow obtaining ambient conditions, are affected by different heat sources in smartphones, we recommend using external sensors which are not affected by these heat sources.

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