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Interfacing External Sensors with Android Smartphones Through Near Field Communication

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Abstract. In this paper, we present and evaluate a new approach to communicate with inter-integrated circuit (I2C) enabled circuits such as sensors over near field communication (NFC). The NFC-to-I2C interface was designed using a non-standard NFC command to control the I2C bus directly from a smartphone, which was controlling both, the read and write operations on the I2C bus. The NFC-to-I2C interface was reporting back the data bytes on the bus to the smartphone when the transaction was completed successfully. The proposed system was tested experimentally, both, with write and read requests to a commercial microcontroller featuring a hardware I2C port, as well as reading a commercial I2C enabled humidity and temperature sensor. We present experimental results of the system which show that our approach enables an easy interface between smartphones and external sensors. Interfacing external sensors is useful and beneficial for smartphone users, especially, if certain types of sensors are not available on smartphones.

Keywords: embedded systems, inter-integrated circuit, near field communication, NFC interface, protocols, sensors, wireless interface. Submitted to: *Meas. Sci. Technol.*

1. Introduction

Near Field Communication (NFC) is an increasingly popular technology, which lately became a common feature in most of the medium and high-end Android smartphones. In smartphones, the technology is most used for Bluetooth pairing to share data between devices. Recently, NFC payment systems have been developed which can be embedded in credit cards or accessed using smartphone applications. Furthermore, NFC tags can be used for *e.g.* smart poster applications and for ticketing systems [1, 2].

Recent research has been exploring the possibility of using NFC as a measurement system. The NFC enabled sensors are usually dual-interface devices, embedding an NFC proximity inductive coupling card (PICC) core at one end and an inter-integrated circuit (I2C) slave core on the other [3, 4]. Another approach is to emulate the NFC PICC with an NFC proximity coupling device (PCD) circuit, and then control the circuit through a microcontroller at the sensor side [5]. Both of these approaches have the draw-back of requiring an active master device on the sensor side for controlling both the sensor and the NFC circuit.

In [6], the NFC frequency is used for temperature measurements, but not the NFC digital protocol itself. Thus, this approach cannot be used to read temperature sensors with the help of smartphones or other devices through NFC. The use of a NFC sensor platform with commercial components reduces the flexibility for possible modifications to the system [7]. Reading sensors through NFC can be useful in various different types of applications, for example, in medical applications for obtaining information from blood sugar sensors [8, 9, 10].

The proposed system in this paper can be useful for obtaining data wirelessly from different types of embedded sensors which can be integrated, for example into bicycles, and wearable sensors which are placed on top of the human body [11, 12]. The aim of this research is not development of new sensor technologies. The main focus lies on wireless data collection and using the smartphone for the visualisation of the collected data. At present, this type of data is often collected by a data acquisition (DAQ) module and then visualised on a computer [13].

In this paper, we present a new approach of using the NFC circuit as a bridge between a I2C slave and a smartphone acting as the I2C master. This

method removes the need of an active master device between the NFC circuit and I2C slave circuits such as sensors. This approach also allows more flexible solutions. For example, with the help of our system, firmware updates are simplified and can be done purely in the smartphone software.

The proposed system was experimentally verified and the experimental results are presented in this paper. The verification of the data transaction was done in two ways. Firstly, sensor readings were verified with the help of a commercial microcontroller which featured a hardware I2C port. Secondly, sensor information was read through a field-programmable gate array (FPGA) development platform on which the NFC-to-I2C interface was implemented. The results of both tests are compared with each other to verify if the data transmission through the NFC-to-I2C interface was successful.

Analyzing indoor environment conditions can be one of the possible application fields for the developed NFC-to-I2C interface. Here, in a typical use case scenario, a mobile application on a smartphone can be used for uploading measurement data to a cloud service. Monitoring and evaluating ambient conditions such as the humidity and temperature levels can be helpful to provide users feedback on the indoor air quality (IAQ) of their living and working environments [14, 15, 16]. Similarly, the air quality inside and outside a car can be analysed with the help of different air sensor modules [17].

The structure of this paper is as follows: First, the similarities and differences between the NFC protocol and the I2C protocol are elaborated as well as the opportunities for controlling the I2C bus over NFC. Secondly, the configuration of the implemented NFC core and the I2C core are described and discussed. Then, the experimental set-up is described and the experimental results are presented. Finally, the results are summarized and the paper is concluded.

2. NFC and I2C protocols

The NFC and I2C protocols are similar in many aspects. Both protocols have a very strong master-slave relationship, in which the master always controls the bus and the slave only responds to the master commands. NFC slaves (PICCs) only respond when they are in their active state, while I2C slaves only respond if the command includes the correct address.

This feature enables multiple slave buses for both technologies.

However, NFC is a single master multiple slave technology, while I2C is a multiple master multiple slave technology. In addition, I2C devices can switch between being a master and a slave on the I2C bus, which is not possible for NFC devices with the exception of the peer-to-peer mode (a dual master no slave system) [18, 19].

2.1. The used NFC protocol

The PICC core which is used in the proposed system is a NFC Forum type 2 tag and a subgroup of the NFC-A standard [20]. The PICC core features 7 unique identification (UID) bytes and 48 user memory bytes, and all standard NFC Forum commands for type 2 tags including read and write capability.

NFC-A, as well as other NFC technologies, is a short-range radio-frequency technology using an amplitude modulated 13.56 MHz electromagnetic field for communication. The range of NFC technologies is up to 10 cm, typically a couple of centimeters for NFC readers in smartphones [4]. PCD to PICC (reader to tag) communication is carried out with modified Miller encoding, and PICC to PCD communication is established with Manchester encoding on an 848 kHz sub-carrier. The bit rate for NFC Forum type 2 tags is 106 kHz [21].

2.2. The I2C protocol

Basically, the I2C protocol is a two wire communication protocol in which the data transfer is synchronized on the clock line (SCL), and the data is transferred on the data line (SDA). For standard low-speed I2C systems (up to 400 kHz), the SCL and SDA lines are pulled up using 4.7 kΩ resistors, and the clocking of the bus as well as the data transfer is done by actively driving the lines to ground [19].

The I2C anti-collision is achieved by sending a start condition to the I2C bus. Hereby, the first one sending a start condition obtains control over the bus until a stop condition is sent. If another master attempts to use the bus in the meantime, this master has to wait until the bus is again free [19]. When the master is sending data over the I2C bus, the master has to first send the I2C slave address (usually 7 bits) and RW flag indicating a read or a write request. Reading data over the I2C bus is done by first writing a command to the I2C slave, and then reading the requested data [19].

Figure 1: The NFC I2C request used to initiate the I2C serial communication. CMD is the command code, A+RW is the 7-bit address and the RW flag, NBYTES is the number of bytes, MSB is most significant byte, LSB is the least significant byte, and CRC1 and 2 are the cyclic redundancy check bytes.

Figure 2: Response to the NFC-I2C request. MSB is most significant byte, LSB is the least significant byte, and CRC1 and 2 are the cyclic redundancy check bytes.

Figure 3: Timing of the NFC-I2C request and response, and the I2C transmission. S is the start condition, MSB is most significant byte, LSB is the least significant byte, and P is the stop condition

Table 1: Description of the NFC-I2C request and response

Byte	I2C request	I2C response
CMD	Command code	
A + RW	Address and RW flag	
NBYTES	Number of bytes	
MSB	MSB of data	MSB of data
LSB	LSB of data	LSB of data
CRC1&2	CRC bytes	CRC bytes

2.3. Controlling the I2C bus over NFC

A non-standard command has been implemented in the NFC Forum type 2 core described above, exclusively to control the I2C bus. This command includes the I2C address, the RW flag, as well as the number of bytes to read or write over the I2C bus, before the actual data bytes can be transmitted. The PICC then responds with the actual bytes on the I2C bus, used to verify the data written or to return the data read over the I2C bus. The non-standard NFC I2C request is shown in figure 1, the NFC-I2C response is shown in figure 2, and the timing is shown in figure 3. Table 1 presents a description of each byte in the NFC-I2C request and response.

3. The digital design of the NFC-I2C interface

3.1. The NFC core

The NFC core is based on the NFC Forum type 2 PICC described in the NFC Forum standard documents [20, 21]. For this tag to work, several sub-modules are needed including a modified Miller demodulator, a CRC generator, request and response logic, as well as a Manchester code modulator [21]. The sub-modules are connected as shown in figure 4. Furthermore, as we are dealing with type 2 PICC with 7 UID bytes, we need to design the core around a finite state machine with the states IDLE, READY 1, READY 2, ACTIVE and HALT.

The IDLE state is the initial state, *i.e.* the state which the NFC core enters during a reset or a power on. The READY 1 and 2 states are the handshake/anti-collision states used by the PCD to initialise the PICC. The ACTIVE state is the main state of the core, in which the actual data transfer between the PCD and PICC is realized, such as reading from the memory on the one hand and writing to the memory on the other. The HALT state is used for putting the PICC to an inactive state while the PCD is communicating with other PICCs, for the case that other PICCs are present in the field [20].

The demodulator is regenerating the data bits and is shifting them into a data byte, before forwarding the byte to the request and response logic. When the request is completely sent, *i.e.* all request bytes including the CRC bytes are received, they are shifted into the CRC generator to confirm that the request is free of errors. The request and response logic then continues to interpret the request.

Now, if the request is valid, the request and response logic must decide whether the PICC should respond or not depending on the state of the PICC. More details about the requests to which a PICC is responding and more information on the possible states of a PICC can be found in the NFC Forum standard documents [20, 21]. In addition to the functionality which is described in the NFC Forum documents, the I2C request is added into the NFC core, as described above. If a response needs to be sent to the PCD, the response is shifted into the Manchester code modulator.

The NFC-I2C request becomes available when the PICC enters the ACTIVE state. When the request is received, the NFC core initiates an I2C transfer (read or write) in the I2C core, and then responds to the NFC-I2C request and transfers data bytes accordingly. The connection between the NFC core and the I2C core is shown in figure 4.

Figure 4: The NFC core and the I2C core, showing the connection between the two cores.

3.2. The I2C core

The I2C core features a shift register for shifting in and out data through the SDA line. Furthermore, a clock generator is embedded in the core for controlling the time and pace of the data shifting and for generating the clock signal on the SCL line. The shift register was slightly modified in order to send a start signal at the beginning of a data transfer and a stop signal at the end of the data transfer. In addition, the modification allowed us as to send an acknowledgement (ACK) signal as well as a negative acknowledgement (NAK) signal between data bytes when the I2C core is reading over I2C.

Both, the SDA and the SCL line are dual direction lines, with internal pull-down transistors and external pull-up resistors. The data lines allow data transfer in both directions and also allow the I2C slave to delay the data transfer by pulling the SCL line down. The connections between the different parts of the I2C core are shown in figure 4.

The data shift register, as shown in figure 4, latches data from the I2C logic when requested, and shifts out this data on every falling edge on the SCL line. Moreover, the data on the SDA line is shifted into this shift register on every rising edge on the SCL line. It is worth noting that data in the shift register is stationary when the SCL line is pulled low by a I2C slave device. Between each byte, *i.e.* during the ACK/NAK time, the data in the shift register is made available to the I2C control logic while the next byte is latched in from the I2C control logic.

Figure 5: The waveforms at the NFC and I2C pins during an NFC-I2C request and response as measured by a logic analyzer.

3.3. Waveforms at the inputs and outputs of the NFC and I2C cores

The waveforms at the NFC and I2C pins during an NFC-I2C request and response were measured by a logic analyzer and are shown in figure 5. In this example waveform, the NFC-to-I2C interface requests to write a data byte with value 0xE3 to an I2C slave with address 0x40 by the Samsung Galaxy A3 smartphone. This is the same command to initiate a temperature measurement with the SHT21 humidity and temperature sensor [25].

As can be seen in figure 5, the I2C core initiates the I2C communication at once when the NFC-I2C request has been received, and initiates the NFC-I2C response immediately after the I2C communication is completed. Because the maximum number of bytes in the I2C communication has been set to 16, in this NFC-to-I2C interface, the time between the NFC-I2C request and response is within the limits in the NFC Forum standard [21].

3.4. Sources of error in the NFC-to-I2C interface

NFC data is hard to corrupt due to its data integrity checks, including both cyclic redundancy check (CRC) and parity bits. Also, NFC modulation is hard to modify by a man-in-the-middle attack, because of the used modulation scheme [21]. The I2C protocol standard, however, does not include data integrity checks [22]. Of course, it is possible to include CRC if the slave circuits supports this feature. Since the

NFC data is hard to corrupt, one possible source of error is the implementation of the I2C master and the I2C bus, as well as the data transfer between the I2C master and the NFC core.

4. Experimental verification of the proposed system

4.1. Experimental set-up

For the implementation of the NFC forum type 2 core, we chose an FPGA development platform with specific features for NFC development such as a NFC analog front end (influenced by the Chameleon mini project [23]), a power circuitry, an electrically erasable programmable read only memory (EEPROM), and an Altera Max 10 FPGA. The development platform also features 16 general purpose in-out pins available on the circuit board on which I2C bus is included. Figures 6 and 7 show a block diagram and a picture of the designed device.

In this paper, the presented design works as a prototyping platform for an application specific integrated circuit (ASIC) which features the NFC-to-I2C interface. The current requirement of an external power supply can be a limiting factor in certain application scenarios. It is worth noting, that the presented system in this paper includes components for development purposes which are not needed in a design for commercial applications. Furthermore, we also designed an energy harvesting circuit so that the ASIC works as a batteryless passive NFC tag. The

To read the humidity, `init_humid = {0x34, 0x80, 0x01, 0xE5}` was used [25].

Table 2: I2C echo test. A random data byte is sent to the microcontroller, and then read by the phone. The phone reports the value of both the sent and the received data byte, and the microcontroller reports the received data byte.

Sent (phone)	Received (phone)	Reported (MCU)
0x3A	0x3A	0x3A
0xE6	0xE6	0xE6
0xCD	0xCD	0xCD
0x84	0x84	0x84
0xC2	0xC2	0xC2
0x20	0x20	0x20
0x49	0x49	0x49
0x5A	0x5A	0x5A
0xCC	0xCC	0xCC
0xD8	0xD8	0xD8

4.2. Measurement results

In the echo test, one data byte is written to the microcontroller before reading the same data byte through the NFC-to-I2C interface. The data byte is randomly generated by the Android application which is controlling the NFC-to-I2C interface. The Android application then reports the transmitted data and the received data as hexadecimal values.

Furthermore, the microcontroller reports the value of the data byte to the host computer via the USB connection. The test was repeated 10 times, and the result of each test was evaluated. The results of the data reported by the Android application and the microcontroller controller (MCU) are shown in table 2. As seen in the table, the system passed all tests which means that the data transmission was successful in both directions.

In the second test, the task was to read the sensor information by using the NFC-to-I2C interface on the one hand and the microcontroller on the other. In order to be able to compare the results, we programmed the microcontroller to read the sensor 1.5 s after a specific request was sent from the smartphone (through the NFC-to-I2C interface). We chose 1.5 s, because Sensirion recommends a delay of at least one second between each time the sensor is read.

In the test scenario, the smartphone reads the sensor, and then requests the microcontroller to read the sensor after a delay of 1.5 s. This test was also repeated 10 times, with random delays of much more than 10 s. Tables 3 and 4 present the obtained values for the temperature and relative humidity, respectively.

Only minor differences can be noted in the

Table 3: Temperature readings by the smartphone through the NFC-to-I2C interface and by the microcontroller. The raw data in hexadecimal are listed in parenthesis.

Temperature readings	
NFC-I2C interface	Microcontroller
21.59 °C (0x63B4)	21.60 °C (0x63B8)
21.59 °C (0x63B4)	21.59 °C (0x63B4)
21.59 °C (0x63B4)	21.59 °C (0x63B4)
21.58 °C (0x63B0)	21.58 °C (0x63B0)
21.58 °C (0x63B0)	21.58 °C (0x63B0)
21.58 °C (0x63B0)	21.59 °C (0x63B4)
21.58 °C (0x63B0)	21.59 °C (0x63B4)
21.58 °C (0x63B0)	21.58 °C (0x63B0)
21.57 °C (0x63AC)	21.57 °C (0x63AC)
21.57 °C (0x63AC)	21.58 °C (0x63B0)

Table 4: Relative humidity readings by the smartphone through the NFC-to-I2C interface and by the microcontroller. The raw data in hexadecimal are listed in parenthesis.

Relative humidity readings	
NFC-I2C interface	Microcontroller
27.47 %RH (0x448E)	27.47 %RH (0x448E)
27.71 %RH (0x450A)	27.94 %RH (0x4586)
27.31 %RH (0x443A)	27.27 %RH (0x4426)
27.51 %RH (0x44A2)	27.51 %RH (0x44A2)
27.47 %RH (0x448E)	27.51 %RH (0x44A2)
27.51 %RH (0x44A2)	27.67 %RH (0x44F6)
27.87 %RH (0x455E)	27.82 %RH (0x4546)
27.74 %RH (0x451E)	27.74 %RH (0x451E)
27.47 %RH (0x448E)	27.67 %RH (0x44F6)
27.47 %RH (0x448E)	27.67 %RH (0x44F6)

obtained results which are present due to noise and small fluctuations in ambient conditions. The range of measured values is $21.58^{\circ}\text{C} \pm 0.01^{\circ}\text{C}$ and $27.6\%RH \pm 0.4\%RH$ measured by the smartphone through the NFC-to-I2C interface, and $21.58^{\circ}\text{C} \pm 0.02^{\circ}\text{C}$ and $27.6\%RH \pm 0.4\%RH$ obtained with help of the microcontroller.

Since the measurement results of the NFC-to-I2C interface and the microcontroller are nearly identical, it can be stated that the type of interface does not have an influence on measurement results. Furthermore, the uncertainties in the readings of the sensor ($\pm 0.3^{\circ}\text{C}$ and $\pm 2\%RH$ in the datasheet [25]) are significantly

higher than the difference in the obtained measurement results.

4.3. Practical application of the proposed system

Nowadays, smartphones contain a remarkable amount of embedded sensors. For example, the Samsung Galaxy S7 Edge features sensors which allow users measuring their heart rate and the oxygen saturation degree of arterial blood (SpO₂). Data obtained by these types of sensors is then used by mobile applications such as Samsung S Health to provide users valuable information of their health and well-being.

Recently, light sensors available in smartphones were used to estimate the amount of daily illumination in order to investigate the circadian rhythm and influences on the sleep-wake cycle of humans [26]. However, even though the amount of sensors of smartphones has increased over time significantly, yet, not all types of sensors are available on mobile phones.

In addition, significant errors can be present in the readings of integrated smartphone sensors such as the ambient light sensor (ALS). A calibration can be required to lower measurement errors [2]. Generally speaking, it can be helpful and beneficial for smartphone users to obtain data from external sensors such as ambient light sensors and temperature sensors, for example.

In our proposed system, external sensor data can be read in a simple way via NFC with the help of the smartphone. In this way, information on the conditions of the surrounding environment can be obtained with any type of smartphone which includes NFC. As a result, the smartphone can act as a measurement instrument and collected data can be used by various different types of mobile applications directly.

For example, the Vernier Sensor data acquisition module (DAQ) allows interfacing with over 60 different types of analog and digital sensors. In a similar way, our interface can be used to allow smartphones communicating with a large number of different types of external sensors via NFC.

In this part of our research work, the focus lies again on temperature sensors. At the moment, mobile applications are available which display information from different sensors in smartphones free-of-charge. These applications are helpful to display the current value, for example the light intensity (in lux) measured with the help of the ALS.

Figure 9 shows one of the typical applications which can be found in Google Play. It is worth noting that only the Samsung Galaxy S4 features a temperature/humidity sensor, while successors of the S4 such as the S5, S6, and S7 do not contain an ambient temperature sensor. Similarly, the predecessors such as the S2 and S3 do not have a temperature/humidity

Figure 9: Example for a mobile application on a Samsung Galaxy S3 for obtaining sensor information.

sensor. However, if the application is installed, for example on a Samsung Galaxy S3, information on the available temperature is presented to the user.

It is worth noting that the displayed temperature is actually not the ambient temperature. Instead, the smartphones' battery temperature is displayed by the application. The question is how suitable the smartphones' battery temperature is for providing information on the ambient temperature. In our experiments, we used two Android smartphones, a Samsung Galaxy S3 (1) (GT-I9305) and a Samsung Galaxy S3 (2) (SCH-L710) as well as a conventional temperature meter from Voltcraft DT-300 (tolerance ± 1 °C by the manufacturer).

The Voltcraft DT-300 temperature meter was used as reference in the experiments. We built a test environment, shown in figure 10, for comparing the results of temperature readings between Android smartphones (T_{phone}) and a conventional temperature meter (T_{ref}). Here, the temperature meter was placed as close as possible to the smartphone. The test environment allowed us to control the temperature increase inside. A digital temperature sensor (Maxim DS18B20) connected to a microcontroller was used as additional reference as well as for controlling the temperature inside the test environment. Experiments were repeated several times in order to conduct a statistical evaluation of the measurement results.

Each time, the test started at a room temperature of 22 °C. Then, the temperature was increased until 36 °C were reached. Here, the temperature was increased with a rate ($\frac{dT}{dt}$) of about $0.025 \frac{^{\circ}C}{s}$ or $1.5 \frac{^{\circ}C}{min}$. Afterwards, a built-in ventilation system controlled by a microcontroller was used to cool the test environment down until the room temperature was reached again. Similarly, the smartphones were let to rest and to cool down until they reached the initial temperature level again.

The temperature was monitored on a continuous

Figure 10: Test environment for measuring temperatures with Android smartphones and a conventional temperature meter.

basis throughout the whole experiment. For an easier comparison of the measurement results, we show an evaluation every 2 °C. Figure 11 shows the temperature readings of the Samsung Galaxy S3 (1) (GT-I9305), while figure 12 shows the readings with the help of the Samsung Galaxy S3 (2) (SCH-L710).

As seen in figure 11, already in the beginning of the experiment, the smartphone obtained a lower temperature (T_{phone}) of about 4 °C compared to the Voltcraft DT-300 temperature meter (T_{ref}). This obtained temperature difference increased during the experiment. At $T_{ref} = 36$ °C, the difference in measurement results was about 8 °C. A similar situation can be observed in the measurements with the second smartphone in figure 12.

In addition, the spread in sensor readings (indicated as error bars in figures 11 and 12) increased when the temperature was increased in the test environment. Moreover, the dynamic response of the smartphones' sensor was poor. The Samsung Galaxy S3 (1) (GT-I9305), for example, did not immediately respond to temperature changes while the reference temperature meter measured temperature changes with a step of 0.1 °C.

In summary, the temperature readings obtained with smartphones do not provide accurate information on the ambient temperature. Thus, we conducted the same experiment with our proposed system and the Sensirion SHT21 humidity and temperature sensor. The temperature information from the sensor (T_{NFC}) was read through NFC with the help of one of the Samsung smartphones.

Figure 13 shows the obtained measurement results. It can be seen that the temperature readings with the sensor from Sensirion (T_{NFC}) were very similar with the results of the reference temperature meter from Voltcraft (T_{ref}) throughout the experiment. The Sensirion SHT21 humidity and temperature sensor showed a prompt response. Each time temperature information was requested, the current temperature value was available immediately. Furthermore, the

Figure 11: Obtained temperature readings at reference points with the Samsung Galaxy S3 (1) (GT-I9305).

Figure 12: Obtained temperature readings at reference points with the Samsung Galaxy S3 (2) (SCH-L710).

Figure 13: Obtained temperature readings at reference points with the Sensirion SHT21 humidity and temperature sensor read via NFC with a smartphone.

measurement results were very consistent and no significant differences in sensor readings were obtained when the experiment was repeated (indicated as error bar in figures 13).

5. Discussion and Conclusion

In this paper, we presented a new approach for enabling a communication with sensors and other I2C devices with NFC. Our proposed system has been successfully tested and evaluated with the help of smartphones which feature NFC. Our approach eliminates the need of programming microcontrollers on the sensor side of

the system, by implementing an I2C master core in the NFC circuit which can be controlled by a simple non-standard NFC command.

As a result, only the mobile application on the Android smartphone needs to be programmed, which makes the use of the NFC circuit very flexible and easy to work with in practice. In addition, our approach reduces the delay in data transfer from the smartphone to an I2C chip, because the NFC circuit no longer needs to be polled from both sides for the data transmission.

We elaborated the digital design of our system. In experiments, it was shown that the transmitted data and received data through the NFC-to-I2C interface indeed is valid. We conducted our tests with a commercially available humidity and temperature sensor, more precisely the Sensirion SHT21, as well as a microcontroller featuring a hardware I2C port, the Atmel Atmega328P.

Nowadays, the large majority of the Android smartphones features NFC. However, Android smartphones do not feature certain types of sensors such as a temperature/humidity sensor. Generally speaking, sensor data can be helpful especially for improving the living quality and health of humans, for example in indoor environments.

In mobile applications which are available free-of-charge from the application store, the smartphones' battery temperature is read instead of the ambient temperature. Thus, users of smartphones can obtain wrong sensor information about their surrounding environment. We built a test environment to analyze the capability of our system to obtain sensor data from external temperature sensors via NFC.

It was shown that the proposed system provides accurate measurement data instantaneously. Moreover, temperature readings were very consistent with the readings of a conventional temperature meter, the Voltcraft DT-300 which we used in our experiments. Our system can be beneficial to interface various different types of external sensors in a simple way with smartphones via NFC.

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