Mobile Embedded Climate Sensing 2.0

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1 ABSTRACT

Mobile technologies and communication techniques are developing rapidly. Mobile information systems offer access to information resources and services via “end-user terminals,” which are mobile (e.g. cellphones, netbooks, notebooks, PDAs, etc.) and can work in nearly every location. These techniques have a huge influence on the relationship of time and space. We are more and more surrounded by computers which we do not even notice anymore. While driving we are e.g. assisted by a brake assist system, or by intelligent trash cans. These small computers which are built into everyday items are called “embedded computers” and are often interconnected with each other. In literature they are also called “ubiquitous computing” and “pervasive computing”. These “embedded computers” can be used to gain knowledge and gather data. Because of the amount of the individual measurement stations it would be possible to gain exceptionally precise and special data without ignoring the valid concerns for information privacy. Cellphones are widespread in the population. These mobile devices already have various sensors. For example, most cellphones have sensors for location, temperature, speed and acceleration, brightness, and many more. Furthermore, it is possible to save permanently various data. Additionally, it is possible to connect a computer or microcontroller in order to increase the amount of sensors or to design them individually. Dreams, as they are presented to us by science fiction literature, like the “Tricoder” (Star Trek 1966), are already realizable.

The aim of this paper is to present the possibilities of smartphones for climate research. It should offer the notable capabilities of smartphones to gather climate data only by using the standard built-in equipment and sensors, which applications can handle these data and how the data can be processed further. Besides, it will be demonstrated how smartphones can be enhanced with the help of microcontrollers in order to create various “sensing scenarios.” So a prototype of a microcontroller will be introduced, which was especially developed and adjusted to gather data of the urban climate. Additionally, the accuracy and validity of the data gathered by these microcontrollers will be compared to the data from common measurement instruments in order to analyze how useable they are.

2 INTRODUCTION

The climate, the weather, the city, and the human organism are complex interconnected systems. Though, research is required to analyze the relation between the city, the climate, and the physical health of human beings. Various single measurements try to establish a connection between the influencing factors. “Urban sensing” and crowdsourcing are means to gather various novel and special data. “Urban Sensing” as a new type of measurement could be a very good method of observation for planners. The individual human being or his or her carried equipment can be used as a measurement instrument for “Urban Sensing.” A combination of stationary and mobile sensors is also possible [cf. Campell 2006]. “Urban Sensing” in combination with Web 2.0 or Web 3.0 respectively, is a new possibility to gather and analyse data. These data, which can be determined actively as well as passively, have a yet an unpredictable value for urban design and climatology. The possible usage could be separated into three fields: personal scenarios, social scenarios, and public scenarios. A personal scenario could be the monitoring and analysis of one’s own vital functions. In a social scenario, data of a fixed group of people could be gathered and handled by social networks like “Flickr”. In a public scenario, there is not be any limit and the whole population could take part of it [cf. Srivastava; et al., 2006:1F]. One advantage of this data collection is the possibility of monitoring huge areas over a long period of time [cf. Hof, 2007:1]. Mostly, out of financial reasons, this is not possible with the classical methodology of counting or measuring. Also the already existing ubiquiority of mobile devices is important for the accuracy of data [cf. Goldman; et al., 2009:4FF]. Several microclimatic factors could influence the well being of the people and out of this reasons they are an important basis for urban planning. Numerical simulations such like “ENVI-met” coould help to gain a better understanding of microclimate. It allows to analyze and anticipate various planning scenarios and their

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consequences for the microclimatological aspect. Data required for the simulations are mainly determined by means of field surveys and measurements at certain locations by various individuals. Out of this reason, data collection of an urban area is expensive as well as time consuming [cf. HELDENS; HEIDEN, 2010:170F].

Nowadays, cartography and planning is widely influenced by the internet. The users as well as the creators of maps are affected. The net-based cartographical data processing is only just developing and can be regarded as the beginning of a new era in the field of cartography [cf. HERMANN; ASCHE, 2001:3FF]. In 2006 a new trend emerged: Neogeography. Typical areas of this new geography are the geotagging of videos and photos, e.g. by uploading them to “Flickr”, and the “Open Streetmap Project.” The radical change in cartography is supported by the absolute availability of the technologies, the possibility to include geodata of various sources, user participation following the Web 2.0 idea, and grassroots and free democratic geodata [cf. Unigis, 2010]. New technologies like smartphones, mobile internet, embedded systems, and augmented reality (AR) offer an enormous potential for this kind of monitoring. The gathered data can be digitalized and processed, e.g. by a Geographic Information System (GIS), and new types of maps could be created. Augmented reality (AR) can also be used for urban sensing. Exemplarily, the diploma thesis “Augmented City Kaiserslautern” by ALLBACH (2010) describes how virtual tags can be blended into the real world as an information carrier. The active tagging of objects in the real world offers a comprehensive database for planners and scientists. New projects and their acceptance can be analyzed. Nuisances like noise, dirt, heat, problems with a special type of ground covering, or insufficient accessibility could be identified in a new way and through the uploading of pictures and voice recordings be further documented [cf. ALLBACH 2010, 2011]. A lot of different phenomena, e.g. the rising emission of carbon dioxide and its effects on the global climatic system or the distructive consequences for the ozone layer due to the anthropogenic emission of FCKW, are only discovered after new measurement techniques have been field-tested. Furthermore, weather and climate monitoring has probably been established just as long as humankind. It has constantly developed alongside with other technologies and the human society. Because of the importancy, climate monitoring must always be adapted to the current state of technology.

So, a next step in this development is using the availability of mobile phones and tablet computers for the climate monitoring. Due to the low costs of the so-called microcontrollers, it is possible to improve one’s own devices or even develop completely new ones.

3 SMARTPHONES AS SENSOR UNITS

Depending on the technological area, new products are developed and updated at a very high level. We are surrounded by computers which support and guide us. And because of a permanently increasing processing power the barrier, which was again and again prophesized by Moore’s Law, was never met up to now. Every year the producers of smartphones create new devices and the scope of operation of these is steadily increasing. Networks and clouds have a huge significance, but have not yet reached the peak of their development. For instance, the changes in the Middle East (Arab Spring) had shown the power and potential of Web 2.0/Web 3.0. As an example, “Facebook” was used as a kind of navigator device for the revolution. The Tunisian online activist “FOETUS” stated in an interview for Technology Review that a revolution always takes place on the street, and the street offers a huge potential in combination with “Facebook” [STIELER, 2011].

Though, it could be interesting to measure and monitor the environment with daily carried gadgets. One of these gadgets is a mobile phone or a smartphone respectively. These modern phones have a variety of sensors. They can be used to monitor the movement of the users (tracking), which is done via GPS or wireless LAN. Additionally, there are sensors for acceleration and absolute positioning as well as a compass and they can determine the altitude via GPS. User can save pictures, audio recordings, and texts and enhance them with their current position (GeoTagging). Since ambient noises can be recorded it is possible to conduct noise measurements. There are already projects which try to use “Urban Sensing” and indicate what can already be done by smartphones. “Noisetube” (http://noisetube.net) is a system for the monitoring of noise. “Waze” (www.waze.com) is a mixture of crowdsourcing, geotagging, traffic information system, and real time map. Users are enabled to inform each other about traffic jams, accidents, and other problems. Because data could be collected in real time and it is also possible to send the data directly to the system, this program is interesting for planners. Another aspect which might be fascinating for planners is the possibility to monitor areas like nature protection areas or new development sites. Many new phones offer the possibility to adapt the brightness of the screen automatically to their surrounding. This sensor could be used to measure brightness. In combination with the absolute position sensor it is possible to identify how the phone is positioned and why a certain amount of light is registered by the sensor. After the nuclear catastrophe of Fukushima, Japan, the company SoftBanks developed a smartphone with an integrated Geiger tube (Pantone 5 Softbank 107SH). The camera and the included sensor is also an interesting device and it was already attempted to create a Geiger tube by using this sensor. Since the light consists of photons and since gamma rays are photons which have a higher energetic value, the sensor in the camera can detect them if one covers the lens with black adhesive tape. The application “Thermos” (http://www.thermos-app.com/) makes it possible to measure the air temperature by covering the lens. It might also be possible to use the internal temperature sensors of the cell phone measuring the air temperature. At the moment, producers consider to add an infrared sensor next to the camera sensor which could make various tasks possible, e.g. taking someone’s temperature.

Following a concluding research it is verified that nearly all included sensors can be activated and read-out. Partly, this is prevented by the producers and has to be bypassed. However, smartphones lack crucial sensors for the complete measurements of climate parameters. Additional devices have to be connected via USB, Bluetooth, or wireless LAN. But these additional devices allow the execution of new sensing scenarios in order to measure the local climate. Even human biovital functions and medical conditions could be measured, e.g. blood sugar level, pulse rate, temperature, blood oxygen, air humidity, and skin temperature. Since 2012, the company Netatmo advertises the development of the first personal weather station application which includes a sensor for air quality (www.netatmo.com). This includes various climate sensors and connects them to a smartphone which allows a rudimentary urban sensing. However, this product has different flaws and a multitude of needed sensors are missing. A huge flaw of the available products is that measurements cannot be conducted simultaneously and the sensors are not interconnected. Most of the available “single sensing solutions” do not offer the possibility to access the measured data. Out of this reason, it is not possible to merge the data with the data measured by additional devices and process them in a single application. At present most producers favor their own closed system. It is not possible to combine the single devices into one specific system. Meanwhile, it is detectable that the sharing of crowdsourcing or biovital data in social media networks is appealing to the users (e.g. covered distance, energy consumption, time needed, overcome altitude). Nevertheless, it would be desirable that the producers enhance their closed systems for the possibility of exporting data.

4 A MICROCONTROLLER AS A CENTRAL UNIT FOR CLIMATE MONITORING

In order to overcome the described weaknesses of the available products, especially for the measuring climate parameters, the idea for the development of a new measurement device was born. Basicly, this will be a microcontroller and the various sensors, connected to it. Of course, the idea for a stationary weather station in combination with a microcontroller and sensors is not really new. There are a lot of projects [e.g. HAAKE-ERFURT.DE; CAMPBELL SCIENTIFIC; PRODATA] monitoring the weather. Commercial weather stations are using sensors and some kind of microcontrollers measuring the meteorological conditions. However, the weakness of all products is that they lack at least in monitoring the urban environment or special sensors are missing and cannot be connected to the base unit of the controller. These requirements are: simultaneous measurements of different weather values and biovital functions at the same time, transportable, battery powered, low cost/affordable, modular built and expandable. This is why a a new measurement device is still needed for a urban climate monitoring and for analysing the relationship between the urban area, the climate, and the physical health of human beings. If it could be possible to create one device which measures all climate data and biofital function at the same time, this would lead to a faster, more accurate, cheaper, and easier way for monitoring the connections of the urban ecosystems complex. The measuring of climate conditions and immediate bodily reactions could lead to new insights into the complex urban ecosystem which might change the planning process.

So two alternatives emerged: How should the device be constructed and how could data be stored and processed controlled?

The smartphone will be the central unit, controling and regulating the single sensors as well as the storage of the data and its localization. Furthermore, it should transmit and visualize the data. An application will be created to serve as a graphical interface. This system must be regarded as cost-effective, because the storage unit, data connection, and sensors are already part of a smartphone.

The other possibility is that a microcontroller could be the central unit and the different sensors will directly be connected to it. Likewise, the microcontroller is responsible for the storage of the data. By means of various enhancements the microcontroller will be able to send the data to a smartphone, to another system, or the possibility for an upload to the internet. A SD card could be used as a storage unit and data could be exported to a GIS. Of course, the usage of a microcontroller as the central unit does not exclude the usage of a smartphone for the controlling and storage of the data.

The prototype of the climate measurement instrument will follow the second possibility and uses a microcontroller as a central unit. The main function of this new device is measuring climate data (figure 1). Additionally, it will be able to record various biovital functions. This combination of detecting climate as well as biovital data could help to analyze the urban ecosystem more precisely. Because the weather ist permanently changing, it is hardly possible to process and present these data statistically correct and to gain how far these are influencing the human body. Important data of the body are the age, the adaptability of the organism, illnesses, gender, and stamina. Both, the human body and the climate system are so complex that it is complicated to conduct a scientific researches of them [cf. TRENKLE, 1992:21].

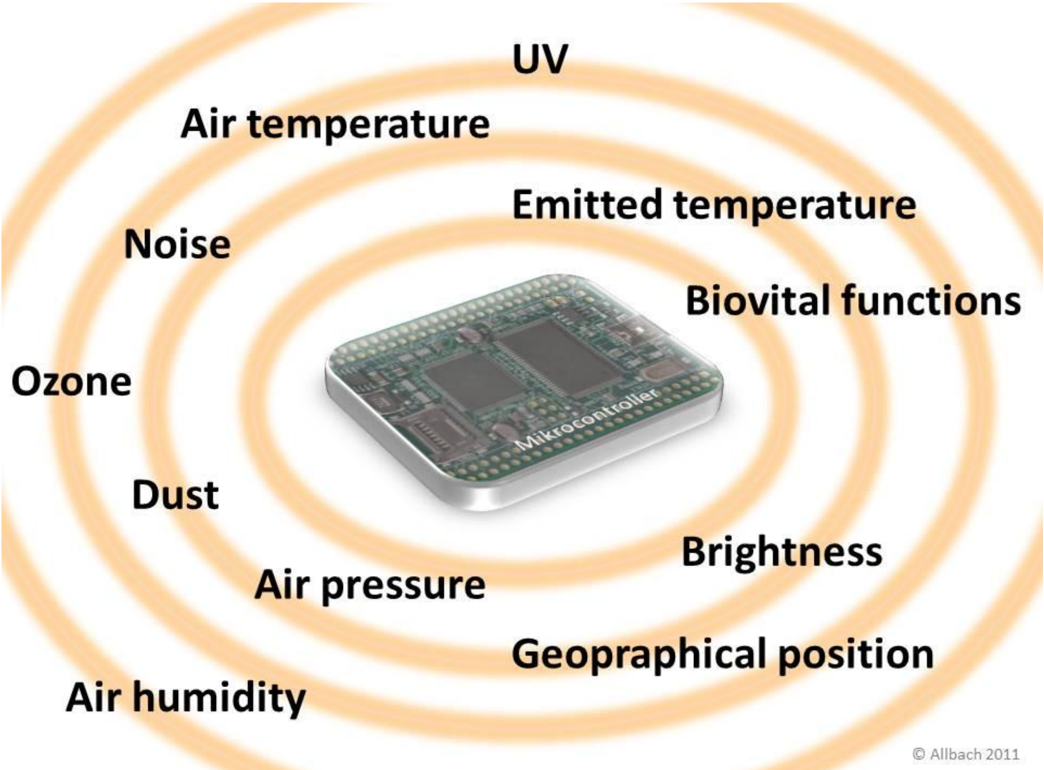

Fig. 1: Microcontroller as central unit.

5 BIOCLIMATOLOGICAL COMPLEXES

In order to have a better understanding of the aspects, which are going to be measured by the microcontroller, a brief description of the humanbiometeorological complexes is given. There are four bioclimatic complexes, which control the function of the human organism and influence the thermal regulation:

1. Thermal complex
2. Photo-actinic complex
3. Air chemical complex
4. Neurotropic complex

The thermal complex deals with the influence of daily and annual impulses (e.g. heat and cold) on the organism and its ability to regulate its temperature independently from outside influences. Physical (blood circulation, perspiration) and chemical (basal energy rate) processes adapt the temperature to the surrounding environment. The thermal regulation of the body is influenced, for instance, by clothes, activity, shade, wind, and indoor air conditioning. Based on the comfort equation by FANGER (1972) a bioclimatic model was developed by JENDRITZKY (so-called Klima-Michel-Modell). This model describes the thermal environment conditions which are important for the human being and includes influences like clothes, activity, heat emission and absorption. A model for the calculation of the body temperature was developed by HÖPPE in 1984 [cf. TRENKLE, 1992:21FF].

The actinic or photo-actinic complex describes the influence the radiation of the sun on the human organism. We can confirm that the visible light, about 46 % of the total radiation, influences our psyche. It influences our activity, efficiency, and mood and is also important for our apperception, our hormonal balance, metabolism, and furthermore influences our biorhythm. Ultraviolet radiation is of crucial biological importance. Ultraviolet radiation can be divided into UVA radiation (315 – 380 nm), UVB radiation (280 – 315 nm), and UVC radiation (100 -280 nm). UVA radiation can lead to a change of the melanin in our skin. For instance, this can be used medically as a cure for psoriasis. UVB radiation also influences the melanin in our skin, but over a longer period of time. It is also responsible for erythema and it has a lethal effect on bacteria. UVC radiation has also a lethal effect on bacteria. However, it also causes skin cancer and the destruction of cells. Infrared radiation only reaches the biosphere with a low intensity with less biological influence.

The air chemical complex analyzes the influence and reaction of natural and anthropogenic air pollution on the human organism. Various noble gasses and micro elements are part of the natural air quality components. Carbon hydrate (CH_4), carbon monoxide (CO), nitric oxide (NOx), ammonia (NH_3), and hydrogen sulfide (SH_2) can be emitted during the decay of organic substances. During natural incidents like volcanic eruptions or huge forest fires, the emission of sulfur dioxide (SO_2), nitric oxides (NO_x) and other solid and liquid aerosols reaching the atmosphere. There are also airborne particles emitted by the flora, which can influence the human organism (e.g. pollen can lead to allergic reactions) [cf. TRENKLE, 1992:32FF]. Anthropogenic air pollution like dust, soot, and the waste products of the industry (sulfur dioxide (SO_2), carbon monoxide (CO), nitric oxides (NO_X)) as well as traffic exhaust of carbon monoxide, hydrocarbons, and mainly nitric oxides effect the air quality negatively. The consequences and the duration of the harmful substances within the atmosphere depends upon their physical qualities, disposition to undergo a chemical reaction, concentration, and the atmospheric terms of exchange. For instance, soot absorbs various carcinogenic and toxic substances. Pure sulfur dioxide, if absorbed by the mucosa, complicates the expiration of phlegm, which leads to a narrowing of the bronchia, which, in return, causes tussive irritation. Nitric oxides can also narrow the bronchia and cause nausea, headaches, and exhaustion. Additionally, viruses and bacteria more easily cause illnesses when the defense mechanisms of the organism are weakened due to a limited oxygen supply. Ozone, and other photooxidates can cause headaches and attack the mucosa and complicate the breathing. If during clear and calm weather conditions the air exchange is hindered this results in an accumulation of noxious substances, which lead to serious respiratory and cardiovascular diseases, [cf. TRENKLE, 1992:36FF].

The neurotropic complex analyzes the influence of different climate and weather situations on the human organism. Such influences could lead to neurotropic reactions. All humans are affected by weather stimuli, but only a healthy and adapted organism automatically is able to adjust the metabolism, the temperature, and the circulation to them. The sympathetic and the parasympathetic nervous system are keeping the nervous system in the interbrain in balance. For a long time, physicians have observed that e.g. neuritic or rheumatic are prone to hurt during special weather conditions and it was detectable that under certain conditions physiological and biological reactions were taking place. [cf. TRENKLE, 1992:47FF].

6 MICROCONTROLLER AND SENSORS TO ANALYZE THE BIOCLIMATOLOGICL COMPLEXES

All these complex relations could be analyzed with one device and therefore we defined the following requirements for the device:

- Modular structure and portable format
- Recording of the location of the measurement
- Detecting of local climate data

- Measuring biovital functions
- Selective and constant measurement during movements

Relevant climate parameters are air temperature, air pressure, air humidity, surface temperature, including the distance from the ground, emitted heat to the left and to the right of the device, including the distance to the emitting surface, UV value, brightness (LUX), ozone (O_3), carbon dioxide (CO_2), sulfur dioxide (SO_2), carbon monoxide (CO), nitric oxide (NO_x), and particulate matters ($PM_{2.5}$ and PM_{10}). Relevant data for the biovital functions are pulse and heart rate, airflow, temperature, oxygen level in the blood, and skin resistance. Due to the modular structure and additional sensors it is possible to gather various data in the future. The listed sensors will allow us to create a kind of 'ambient atmosphere'/'ambient climate' which is recorded at a specific geographical position. Because the emission of heat from constructions is of importance in the urban environment, the device will not only measure the emitted heat from the ground, but also from its nearby surroundings. This could be enhanced by measurements to the front and to the back of the device. The measurement of the emitted surface temperature will be enhanced by a sensor to locate the distance to the surface object from where the heat is emitted (Figure 2).

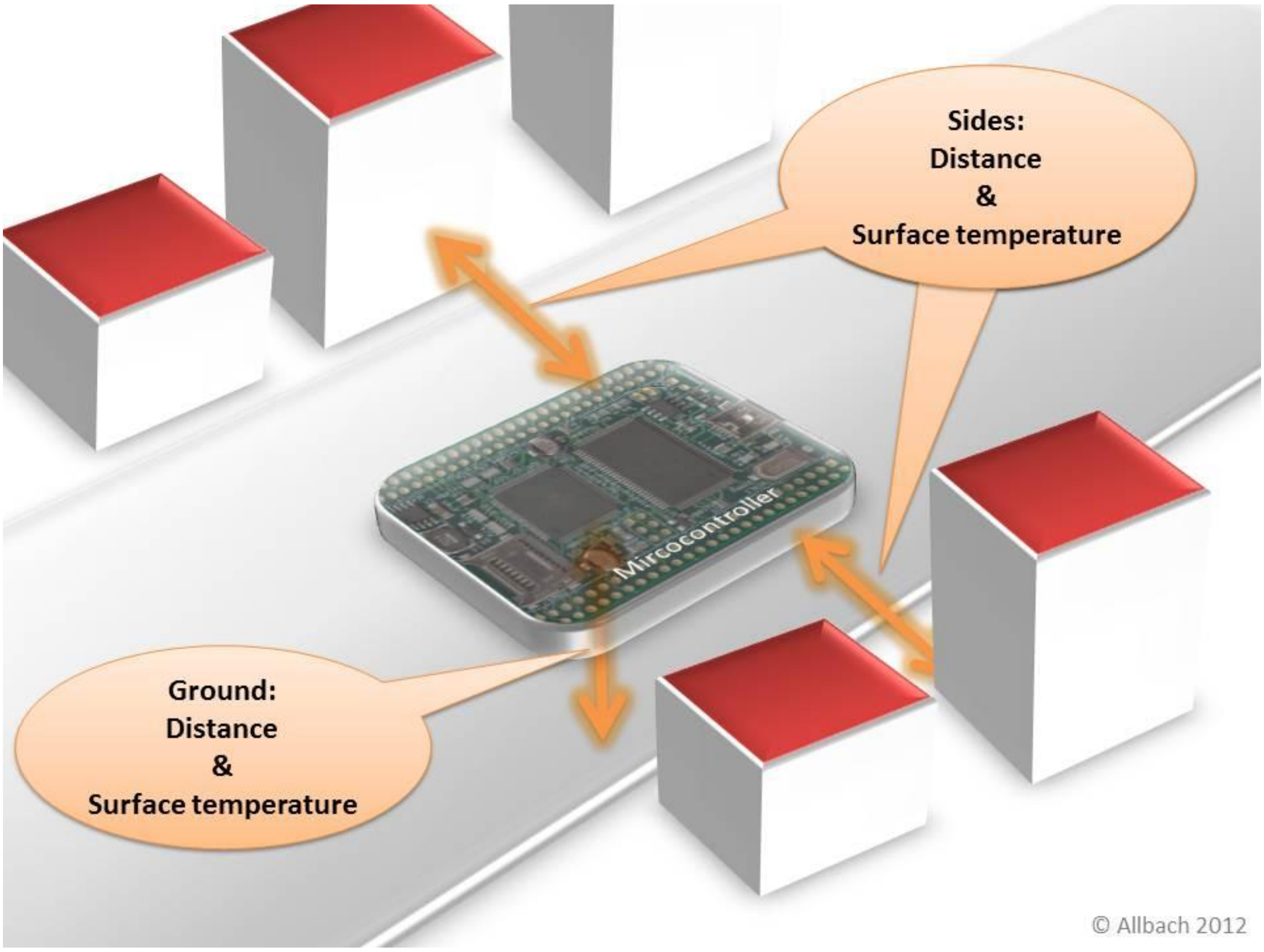

Fig. 2: Microcontroller measurement of the emitted temperature and distance to the surface by the microcontroller.

7 EMBEDDED SENSING – PROTOTYPE

While developing the prototype various models were conceived:

(1) Developer model

(2) Hand held model

(3) Belt

(4) Backpack

(5) Integrated into the clothes

Fig. 3: Model of the various measurement devices.

The developer model is a connection of microcontrollers and sensors. The second model is a hand held device similar to a remote control or the “Tricoder” from Star Trek. In the future, the hand held model could be used in schools, projects, and workshops in the field of natural sciences. Pupils could be able to discover their environment with such an device and could experience and record nature and the weather conditions as well. The third model is placed in a belly bag. The forth model is carried in a backpack. The fifth model is an integration of the devices into the clothes in order to create a kind of wearable computer. However, also a smartphone and a backpack could be described as wearable. But the best solution would be to integrate all sensors complete and invisible into the clothes. The measurements will be individualized, inconspicuous, discreet, and permanent. As a result, the instruments can offer the most pristine “ambient-climate”/”ambient atmosphere” data. Partly, the equipment even adapts to the shape of body, can be washed and bended. But of course, this model is the most expensive one.

The first measurements with the microcontroller had demonstrated that it can compete with the common measurement instruments (Figure 4). The laggardness of the sensors has to be taken into account just like in any other measurement of the climate. More precise measurements have to be conducted and the spread for standard factory models has to be considered.

All models have their advantages and disadvantages: e.g. costs, portability, and accurateness of the measurement. The belly pack and the backpack are very similar, but the backpack has a higher contact area with the body which could lead to increased sweating at the back and to measureable bodily reaction. A hand held model could also lead to problems during longer measurements, because this might wear out the muscles of the arm.

Problems all models share are the dependence of a power source and the reaction time of the sensors. Some problems are specific for certain sensors. The anemometer, for instance, must record wind speed during a constant movement, but the measurement can be distorted by the movement and the reaction time of the sensors. Though, it might be able that an ultrasonic sound anemometer or a heat wire anemometer could be used to solve this problem. Last but not least, measurements of precipitation cannot be done out of technical reasons.

A major test of the hardware is done during “Projekttage für Schülerinnen” at the University of Applied Science, Kaiserslautern, Germany. For two days, pupils tried to create a simplified weather station out of microcontrollers with identical wiring and sensors. The used sensors are: barometer, light sensor, water sensor, sound sensor, and a combination of air humidity and air temperature sensor [cf. THEATO 2013]. The procedure, programming, electric circuit, management of the individual parts, and wiring was predetermined by the author. The test or workshop, respectively, confirmed that the sensors already work accuratly (even if they are rather cheap and not labeled as very precisely).

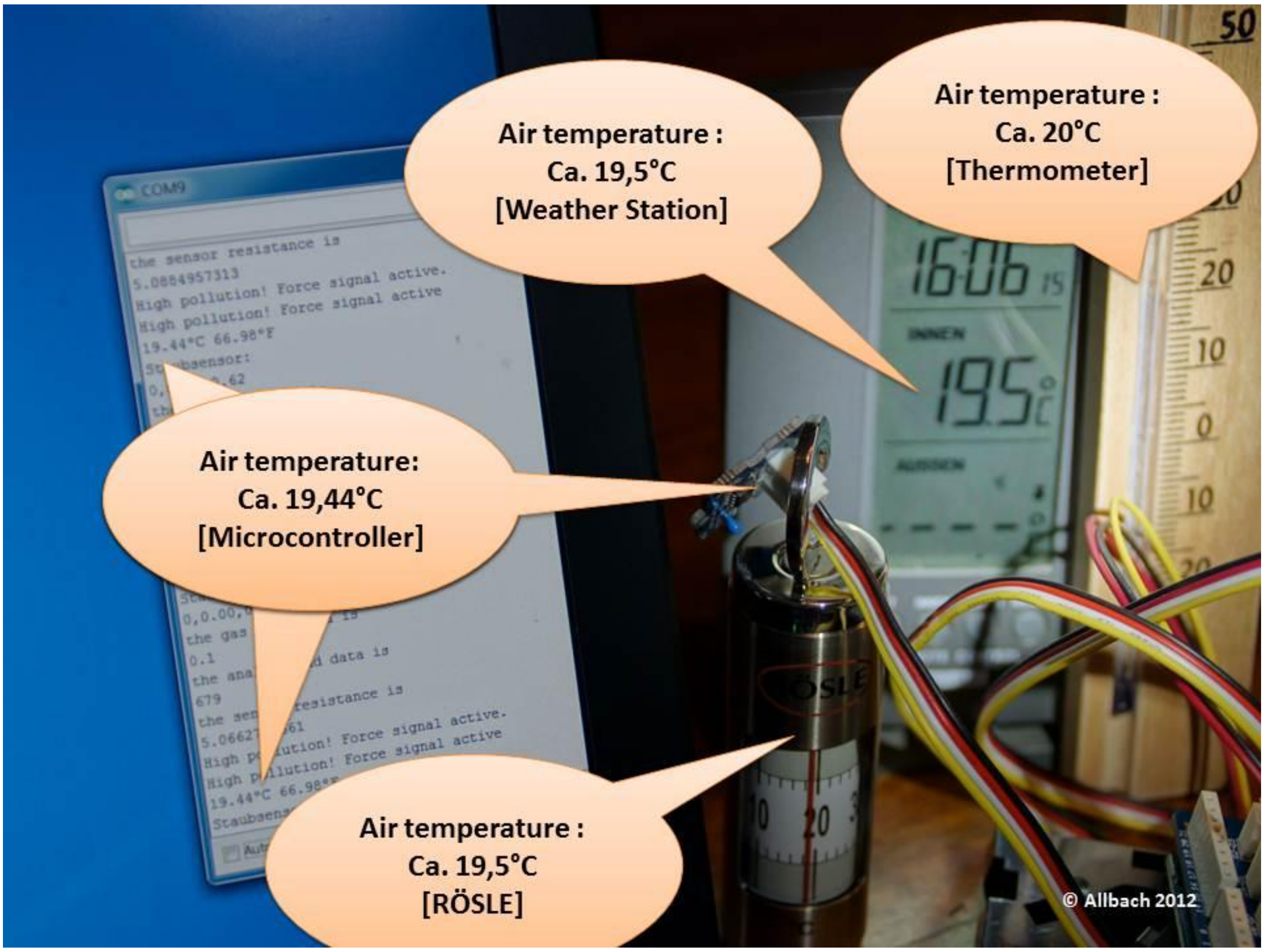

Fig. 4: First measurement results of the air temperature and a comparison to common measurement devices.

8 CONCLUSION

Smartphones, urban sensing, and other new technologies are becoming part of climate monitoring. However, these technologies are still under development and are confronted with various problems and the current measurement results must be regarded with suspicion. Nevertheless, since we have to assume that there will be plenty of measurement stations in the future, it might be possible that the sheer amount of measurements will result in kind of “wisdom of crowds.” Especially, the approach monitoring the climate bottom-up is an interesting alternative to the generally known top down monitoring. It follows the principal of “we are all affected by climate and weather, so we will monitor it together.” At the moment, smartphones are limited in their use as measurement instruments due to the lack of important sensors. But this will change in future. It is already possible to conduct amazing measurements (e.g. the cell phone as a Geiger tube). If the sensors of the smartphone do not suffice, they can be expanded by a microcontroller and its sensors. The new generation of microcontrollers follows the idea of Web 2.0 and appeals to new users due to its improved handling. The new technologies make is possible that a prototype can be created which can easily be expanded and adapted to special purposes, due to its modular design. This device is rather cheap and will allow us to conduct new forms of climate measurement and urban sensing. For instance, the urban area could be explored by groups of people and the gathered data could be analyzed with regard to climate and biovital values. A new possiblity of monitoring climatological effects within inhomogeneous urban structures is using mobile measurements devices. The advantage of this type of methodology is a high density of measurements, which could be mapped spatially. Although, mobile air temperature and air humidity measurements had been practiced for a long time, especially in the field of applied urban climatology. However, most of the mobile measurements are performed by using individual mobile measurement instruments and the results have to be written down manually. Other methods like a special car, which is able to gather various climate values, is very expensive and is also not able to gather biovital functions. A new devise, based on microcontroller, could help planners and scientists. It could close the gap between various single measurements and an expensive professional car. This device uses a new approach to research the interconnections between climate, city, and human beings and might offer new insights, showing us new interdependencies, but it does not replace the traditional measurement methods!

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