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IoT Based Indoor Personal Comfort Levels Monitoring

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***Abstract*—We present a low-cost IoT based system able to monitor acoustic, olfactory, visual and thermal comfort levels. The system is provided with different ambient sensors, computing, control and connectivity features. The integration of the device with a smartwatch makes it possible the analysis of the personal comfort parameters.**

I. Introduction

During last years there has been an increasing demand by buildings occupants for the continuous monitoring of all indoor comfort related parameters. In this context the Internet of Things (IoT) promises a new era in ambient monitoring since the amount of smart devices and accessible data is constantly growing. Although comfort is a subjective concept composed by many factors (i.e. acoustical, visual, thermal and olfactory comfort) most of the recent works focus on thermal aspects only [1] and assess comfort condition by the use of the Predicted Mean Vote (PMV) formula [2]. Since it can be extremely expensive to gather real time measures of some variables involved in PMV formula (i.e. metabolic and clothing personal parameters), assumptions are made in order to use this index [3]. Different approaches can be found in [4], where authors proposed the monitoring of temperature, humidity and light in order to control appliances. In [5] authors monitored and controlled the visual comfort by using a LED system. Finally in [6], the authors developed a Wireless Sensor Networks (WSNs) to monitor temperature, humidity and concentration of gases (i.e., CO and CO_2). The solution presented in our paper, namely ComfortBox, is an open hardware and open software IoT based platform, which allows to monitor the four personal comfort parameters. The acoustic, olfactory, visual and thermal comfort levels are evaluated according to the international ISO, American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and Environmental Protection Agency (EPA) regulations (standard EN15251 [7]). The platform is provided by a LightWeight Mesh 802.15.4 communication module able to manage a mesh network and interact with objects equipped with the same module. Thanks to the internet connectivity of the ComfortBox, each object connected to the mesh network (e.g., distribute sensors or actuators) can be remotely controlled. Data received from sensors are stored both locally and in a cloud server. One of the key findings of this work is the integration of a smartwatch in the platform that allows us to estimate the variables involved in the PMV formula, thus making possible its use in a real-world scenario.

II. System Architecture

The whole system is composed by a low cost programmable small single-board computer, namely Raspberry PI, an Apio Dongle [8] and different environmental sensors. The so-called Apio Dongle is a USB stick that integrates an Atmel microcontroller with a Lightweight Mesh communication module. The sensors integrated in the ComfortBox are: a digital temperature and humidity sensor, an Indoor Air Quality (IAQ) sensor measuring carbon dioxide (CO_2) level and the concentration of Volatile Organic Compounds (VOCs), a light sensor and a microphone. The software platform is built using *Node.js* for both the server side and cloud synchronization while the client side is based on *Angular.js*. The non-relational database is built using *MongoDB* (the whole hardware and software structure is depicted in Figure 1). Thanks to the communication module, any object equipped with a Lightweight Mesh can be connected to create a mesh network. Since the ComfortBox is connected to the internet

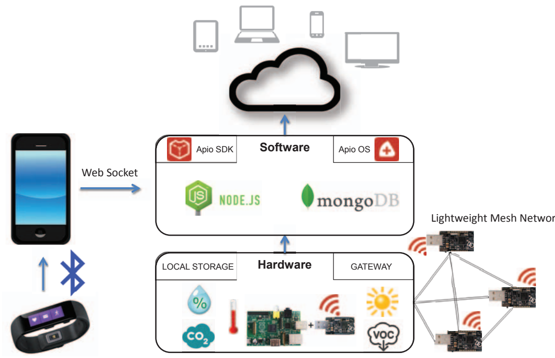

Fig. 1: *Hardware and software architecture of the ComfortBox and smartwatch communication procedure.*

(via ethernet or wi-fi) any object of the mesh network can be managed via software, thus becoming remotely accessible, monitorable and/or controllable automatically through its network address and the ComfortBox IP. The smartwatch has been integrated into the system via a mobile app through a web socket. The complete source code is available for free on GitHub.

III. Comfort Analysis

In this section we analyze the four different human comfort parameters (thermal, acoustic, visual and olfactory) as well as the default warning levels.

1) Thermal Comfort: The PMV/PPD model was developed by P.O. Fanger in the 70's using heat balance equations

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and empirical studies about skin temperature to define comfort. Fanger's PMV equations, which can be found in [2], are based on air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation. Zero is the PMV ideal value and the comfort zone is defined within the recommended limits of ± 0.5 on a seven point scale from cold (-3) to hot (+3). According to a sensitivity analysis, the most influencing variables are the metabolic and clothing parameters. To the best of our knowledge no one previously exploited smartwatch measures to obtain these parameters which usually are considered only as constant values. The equations used to compute metabolic rate can be found in ISO 8996 norm:

$$M = \left(\frac{HR - HR_0}{RM}\right) + M_0 \tag{1}$$

where M is the metabolic rate, $[W/m^2]$, M_0 is the metabolic rate at rest $[W/m^2]$, RM is the increase in heart rate per unit of metabolic rate, HR_0 is the heart rate at rest, under neutral thermal conditions. The value of HR_0 and HR are measured by the smartwatch, RM formula can be found in ISO 8996 norm and

$$M_0 = (10.0 \cdot m + 6.25 \cdot h - 5.0 \cdot a + s) \tag{2}$$

where m is the weight $[Kg]$, h is the height $[cm]$, a is the age in years, s is +5 for males and -161 for females (all these parameters can be taken from the smartwatch user's profile). Clothing parameters can be found from the T_{cl} (clothes temperature) formula in [9] by substituting I_{cl} (clothes insulation) with the inverse relation of

$$R + C = \frac{T_a - T_{sk}}{I_{cl}} \tag{3}$$

where C and R are the thermal convection and radiation coefficients (respectively considered 3.8 and 4.7) and T_{sk} is the skin temperature measured by the smartwatch.

2) Olfactory Comfort: Although no standards have been set for VOCs in non industrial settings, alarms are sent to people when VOCs value increases of a 50% with respect to its average value. On the same time it is well known [10] that CO_2 has negative effects on human working performances. It is widely reported by the technical community involved in indoor air evaluations that the ASHRAE has a standard of 1,000 ppm CO_2 for indoor spaces. The same value has been set as the warning level in the ComfortBox.

3) Acoustic Comfort: The noise analysis has been carried out considering the levels suggested by the Environmental Protection Agency [7] and the norm EN15251. These documents identify 55 decibels outdoors and 45 decibels indoors as the levels which will permit spoken conversation and other daily activities. An alarm is sent when the indoor sound pressure level reaches 55 dB (A).

4) Visual Comfort: According to EPA residential illumination standards, warnings are generated when the light level is less than 100 lux.

IV. Web Graphical User Interface

In this section we present the GUI and the main software functionalities of the ComfortBox web application. A screenshot of the GUI main page ("Home") is depicted in Figure 2.

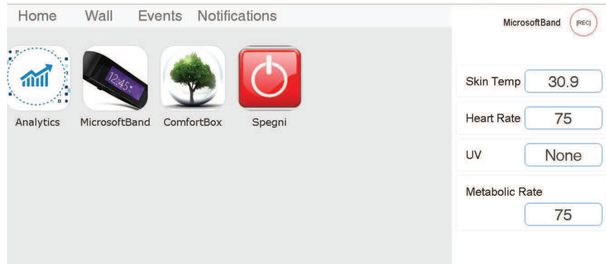

Fig. 2: *ComfortBox GUI.*

Buttons on the left side of the screen represent applications ("Analytics", "Band" and "ComfortBox") while in the right side sensors readings are continuously updated and formulas evaluated. The application named "ComfortBox" contains all the comfort values recorded as well as the PMV value computed thanks to the smartwatch measures (depicted in the figure).

V. Conclusions

In this work we proposed an open hardware and open software platform able to turn an 802.15.4 intranet mesh network into an IoT architecture. The device is able to monitor and analyze four personal comfort parameters. Real time smartwatch data, integrated to compute personal metabolic and clothing indexes, have been used to properly assess thermal comfort according to PMV index.

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