System for thermal comfort monitoring in working and living environment

Uros Pesovic[1], Dusan Markovic[2], Zeljko Jovanovic[1], Sinisa Randjic[1]

Abstract – **Thermal comfort of working and living space is dependent on a number of parameters, both personal and environmental parameters. Knowledge of index of thermal comfort, helps creating optimal micro-climatic conditions for unhindered work in a workspace, or customizes the way employees dress in accordance with the conditions prevailing in the environment. This paper introduces a system for monitoring thermal comfort in working and living space, based on the concept of smart transducers on IEEE 1451 standard.**

Keywords – **Thermal comfort, IEEE 1451, TEDS, NCAP, Web Service.**

I. INTRODUCTION

Thermal comfort represents set of micro-climatic conditions for which human feels comfortable in its work and living environment. Thermal comfort is dependant both form personal characteristics and environmental conditions [1]. Personal factors are dependent of human metabolic activity, age, sex and human physical condition, as well as type of clothing. Environmental conditions which affect feeling of thermal comfort are not directly related to human. These conditions include air temperature, relative humidity, air speed and radiant temperature. Air temperature is parameter, which is most usually related to human feeling of thermal comfort since human can easily feel it on their skin. On the other hand, humans cannot detect changes in relative air humidity, which can significantly affect human feeling of thermal comfort. Human body uses perspiration as mechanism for loss of excess heat in order to regulate body temperature. When air has high relative humidity, water cannot evaporate from skin and body cannot lose excess heat so humans feel hotter than usual. When air is dry, humans feel colder since water easily evaporates from skin and cools the human body. Also, air movement increases body heat loss due convection, so in windy conditions humans feel colder than usual. Radiant temperature represents temperature of skin exposed to some radiation source, such as Sun or some artificial heat source.

Humans can in advance adjust their clothing in order to feel thermally comfortable when conducting some activities, by knowing environmental conditions present in certain area. In this paper, we present system for thermal comfort monitoring in working and living environment. System is composed of network of smart transducers which monitors air temperature and relative humidity and web based user application, which is accessible worldwide. Users can select level of clothing and certain activity which they plan to conduct in some area. Based on measured air temperature and relative humidity, system will return information about expected level of thermal comfort which will be experienced in such area.

Paper [2] presents similar solution in thermal comfort monitoring, which collects thermal comfort data by ZigBee network and personal computer, which is later forwarded to handheld PDA device. Such system is intended for localized use because connection between personal computer and PDA device is established using Bluetooth network.

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II. THERMAL COMFORT

Thermal comfort is defined as that condition of human mind which expresses satisfaction with its thermal environment. Thermal comfort scale, defined by international standard ISO7730 [3], has seven point thermal comfort states which are shown in Table I.

TABLE I
THERMAL COMFORT SENSATION SCALE

Value	Description
+3	Hot
+2	Warm
+1	Slightly
0	Normal
-1	Slightly
-2	Cool
-3	Cold

Standard defines PMV (Predicted Mean Vote), average vote of thermal comfort on seven point thermal comfort sensation scale. Average vote of thermal comfort is created when heat balance of human body is achieved, which represents difference of created metabolic heat MW and sum of heat losses $\sum H_i$ which human body emits into environment Eq. (1).

$$PMV = T_S \cdot \left(MW - \sum H_i\right) \quad (1)$$

In order to create PMV from heat balance, transformation coefficient T_S is used, which is obtained by Eq. (2).

$$T_S = 0.303 \cdot e^{-0.036M} + 0.028 \quad (2)$$

Metabolic heat is difference between power of metabolic activity M and external work W. Heat losses originate from set of thermodynamics processes which can be classified into six categories:

1. Heat loss by skin conduction H_1
2. Heat loss by sweating H_2
3. Latent respiration heat loss H_3

4. Dry respiration heat loss H_4
5. Heat loss by radiation H_5
6. Heat loss by skin convection H_6

Metabolic power M is dependent of level of physical activity. Standard ISO8996 defines typical levels of human physical activities where some of them are presented in Table II. It defines metabolic index Met, which represents metabolic power relative to sitting as reference metabolic activity.

TABLE II
LEVELS OF METABOLIC ACTIVITY

Metabolic activity	W/m^2	Met
Reclining	46	0.8
Sitting	58	1
Office work	70	1.2
Standing	93	1.6
Light work	116	2.0
Walking 3km/h	140	2.4
Walking 4km/h	165	2.8
Walking 5km/h	200	3.4

Clothing can significantly affect human thermal comfort sensation. Standard ISO9920 defines thermal insulation coefficient index (Table III) for various types of clothing. Thermal insulation coefficient index is referenced to thermal insulation coefficient of human body without clothes.

TABLE III
CLOTHING THERMAL INSULATION INDEX

Clothing	m^{2}K/W	CLO
Without clothing	0	0
Summer clothing (shorts, T-shirt, sandals)	0.05	0.3
Summer clothing (trousers, shirt, shoes)	0.08	0.5
Spring clothing (trousers, shirt, jacket, shoes)	0.11	0.7
Winter clothing (trousers, sweeter, jacket, shoes)	0.2	1.3

PMV present mean value of the votes of a large group of people exposed to the same environment. Votes are scattered around the mean value where certain percentage of group will feel uncomfortably hot or cold in given conditions. PPD (Predicted Percentage Dissatisfied) represents percentage of people who will vote hot, warm, cool or cold on the 7-point thermal sensation scale, and it's obtained by Eq. (3)

$$PPD = 100 - 95 \cdot e^{-0.03353 PMV^4 - 0.2179 PMV^2} \quad (3)$$

III. IEEE 1451 SMART TRANSDUCERS

Sensors are used in wide range of applications, such as industrial and home automation, military, healthcare, security, agriculture and environment monitoring. Their basic function was transforming physical value into the measuring signal. According to rapid technological development transducers in addition to its basic functionality got other functions like self-calibration, self-description, self-initialization and some signal processing. All these functions contribute to certain independent processing or intelligence so they get name smart transducers. Connecting these transducers in the network is very important because of the fact that, in this way, collecting of measured signal was facilitated. First networking of transducers had difficulty due to different communication standards that is used in different producer's devices. This problem is solved with standards of IEEE 1451 family which gave standardized way for implementing components of smart transducers.

Concept of smart transducers introduced by IEEE 1451 standard consists of Transducer Interface Module (TIM) and Network Capable Application Processor (NCAP) (Figure 1.). A TIM interacts directly with environments and contains sensors that are used to get measured signal or actuators to control specified activities. Part of the TIM is Transducer Electronic Data Sheet (TEDS) with data, which is used to define characteristics of measurements. These data in TEDS were specified according to standard IEEE 1451.0 [4] which is also used to define commands that could be executed on TIM. NCAP is module that has function of gateway between TIMs and user application. NCAP has interface TSI (Transducer Services Interface) which is used by user application for direct access to function defined by this standard (Figure 1).

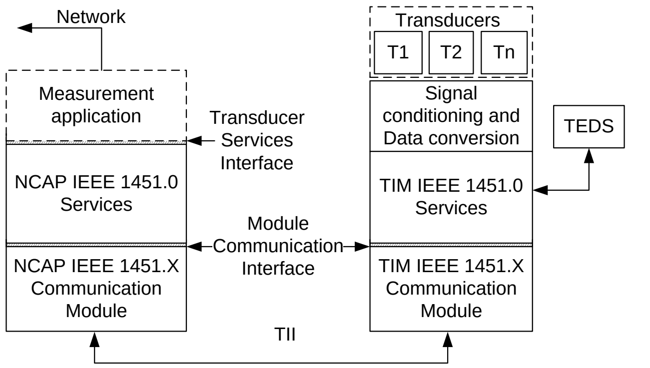

Figure 1. IEEE 1451.0 Reference model

Depending on the type of request from user application transducer services module is subdivided into five services: *TimDiscovery*, *TransducerAccess*, *TransducerManager*, *TedsManager*, *CommManager*, *AppCallback*. If there is a need for obtaining measured value from specific transducer channel *TransducerAccess* service could be used with his methods for accessing transducer channels, where the most common methods are read and write. TSI represents API used by user application to access IEEE 1451.0 layer via HTTP. User send HTTP request to NCAP where it is processed and call appropriate service of 1451.0 API. Service of TSI then call IEEE 1451.X API to establish communication with TIM and get result of measurement. HTTP server on the NCAP receives result from TIM and forms HTTP response that would be returned to end user. Response could be specified in HTML, XML or TEXT format.

IV. IMPLEMENTATION

System for thermal comfort monitoring is composed from smart transducer network and web based user application (Figure 2.). Transducer network, compliant to IEEE 1451 standard, is composed form two TIM modules and one NCAP module. Each TIM module has two sensors, one for air temperature and another for relative humidity. NCAP module acts as network gateway and provides communication interface for entire sensor network. It has integrated Web server, which is accessible via Ethernet network. User application is realized in form of web service and measured data represent to end user in adjustable form.

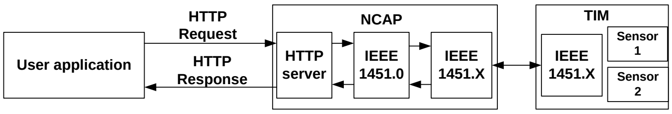

Figure 2. NCAP HTTP access

SHT15 digital sensor is used as a sensor for measurement of air temperature and relative humidity. It’s composed form capacitive sensing element for measurement of relative humidity and bandgap sensor for temperature measurement. Each SHT15 sensor is calibrated in high precision humid chamber, where calibration coefficients are stored in sensor memory. SHT15 sensors communicate with microcontrollers using I^2C digital communication bus. It has low power consumption of 3 mW in operational mode and 5μW in sleep mode with wide range of supply voltage from 2.4 to 5.5 V [5]. Typical measurement characteristics of SHT15 sensor are presented in table IV.

TABLE IV
MEASUREMENT CHARACTERISTICS OF SHT15 SENSOR

Characteristics	**Temperature**	**Relative humidity**
Operational range	- 40 ÷ 124 ºC	0 ÷ 100 %
Resolution	± 0.01 ºC	± 0.05 %
Accuracy	± 0.3 ºC	± 2 %
Repeatability	± 0.1 ºC	± 0.1 %
Response time τ=0.63	5 s	8 s

NCAP module was implemented on *mBed* development board. This board uses NXP LPC1768 microcontroller, which is designed for low-power embedded applications. This microcontroller uses ARM Cortex-M3 uses 32-bit processor core, designed for wide range of application like industrial control systems, wireless networks and sensor integration. Processor has great performances in terms of processing power, fast response and also meets challenge of low power consumption. Besides ARM Cortex M3 core, this microcontroller contains 512KB FLASH memory, 32KB RAM memory, Ethernet, USB, CAN and other peripheral interfaces. *MBed* board was packaged in form of 40-pin DIP footprint which enables easy interaction to its environment. Programming and communication with computer is established via USB interface. Applications development for *mBed* board is possible using *mBed* Online compiler or using standard tools such as Keil uVision or Code Red [6].

Intention of this work was to develop NCAP module on the *mBed* platform for distribution of measuring data via HTTP protocol. In addition, Web service was created that could gather measured data, apply particular programming logic and offer complete results to end users. For NCAP, *mBed* board was equipped with Ethernet connector for connecting NCAP to local computer network. HTTP Web server was started on the *mBed* this HTTP request from outer computer network could be processed and response in one of the possible format could be returned. Method *ReadData* of the *TransducerAccess* interface was realized on the *mBed* board and these methods were used to send new request to TIM for reading measuring values. Measured results were obtained by two SHT15 sensors which are connected to the same *mBed* board, but represents independent logical component forming one TIM. Communication between NCAP and TIM is omitted because it is not part of the IEEE 1451.0 standard, and to facilitate prototype realization both logical module was situated on the same *mBed board.* Request for accessing NCAP on the *mBed* must be in the certain format defined by standard.

http://<host>:<port>/<path>?<parameters>
<host> - domain name of destination
<port> - port number (default value is 80)
<path> - IEEE 1451 path including specified commands
<parameters> - parameters link to command
HTTP request for our NCAP looks like this:
http://192.168.0.33/1451/TransducerAccess/ReadData
192.168.0.33 – IP address assigned to Mbed HTTP server
/1451/TransducerAccess/ReadData – path which indicate to appropriate method of 1451.0 API

When this request is received on the NCAP, measured data are read from TIMs sensors and then it was send back to the requester in structured XML format.

<sensor>
<air_temperature>23.9</air_temperature>
<relative_humidity>36.0</relative_humidity>
<radiant_temperature>23.9</radiant_temperature>
<air_speed>0.1</air_speed>
</sensor>
<sensor>
<air_temperature>-2.4</air_temperature>
<relative_humidity>78.0</relative_humidity>
<radiant_temperature>-2.4</radiant_temperature>
<air_speed>0.1</air_speed>
</sensor>

In presented XML structure, first two parameters, air temperature and relative humidity, are measured value from sensors. Last two values are not obtained by measuring; radiant temperature that is equalized to air temperature and air speed that is equal to constant value of 0.1 m/s.

The role of sender requester in our case has Web service (WS). WS gets the required data from *mBed* over the network, computes necessary values and returns them to end users. WS provide interoperating between software applications implemented in any language, running on a variety of platforms and frameworks. WS and its consumer exchange data using XML over HTTP or SOAP (Simple Object Access Protocol). Besides SOAP, WS uses Universal Description Discovery, and Integration (UDDI) and Web Services Description Language (WSDL) to publish their functionalities to clients.

In this paper, created Web service is used to compute and provide information about thermal comfort according to user selected parameters and measure values. User parameters are clothes (CLO) and metabolic activity (MET) passed to a web service from a client application, and four measured parameters (*air_temperature*, *radiant_temperature*, *air_speed*, *relative_humidity*) parsed from XML data obtained by NCAP. The code shown below represents part of the WSDL file that describes interaction with WS method getComfort and defines return values.

```
<element name="getComfort">
    <complexType>
        <sequence>
            <element name="CLO" type="xsd:double" />
            <element name="MET" type="xsd:double" />
        </sequence>
    </complexType>
</element>
<complexType name="ThComfort">
    <sequence>
        <element name="PMV" type="xsd:double" />
        <element name="PPD"  type="xsd:double" />
    </sequence>
</complexType>
```

J2EE web application, directly designed for client, was developed by Java Server Faces (JSF) framework. Development environment used in its realization was NetBeans 7.1 with Glassfish 3.1.

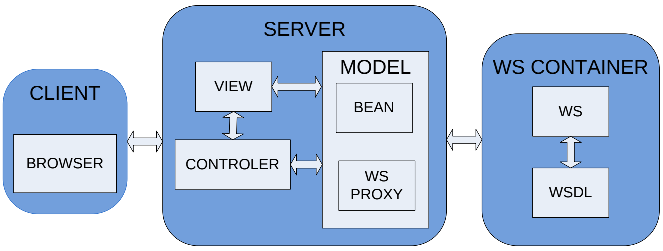

Figure 3. Web service position in client application

According to the structure of the client application (Figure 3.), WS can be easily inserted into logical model of the application. This means that interaction of application with WS was transparent for designer developers and they do not need to deal with that functionality.

Invoking WS functionalities in a web project was done by "*creating new web service client*" option in NetBeans, by pointing to WSDL URL. After this, source classes described in WSDL were created inside a web project. JSF page as a presentation page provides variable value visibility. This means that every presented value to a client in a JSF page is mapped in a managed Bean that creates its value. As a demonstration of WS functionalities, client application presents temperature comfort scale level as position of slider, ranging from COLD to HOT. Meteorological data are provided from two sensors, located indoor and outdoor, with values contained in NCAP XML response. Client application functionalities are shown in Figure 4.

Java framework was chosen for the web service since it offers build-in support by AXIS framework, which enables faster development of web services and web service clients.

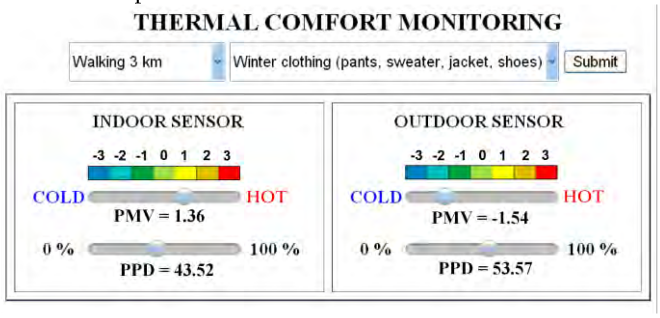

Figure 4. Client application

V. Conclusion

This paper presents system for monitoring thermal comfort in working and living space, based on the concept of IEEE 1451 smart transducers accessible via web service interface. Current system is based on Ethernet connectivity between smart transducer network and web service, which limits its usage to locations with existing Internet infrastructure. System can be upgraded with Wireless LAN or GPRS connection to NCAP, in order to be used in remote locations. Also, smart transducer network can be scalable in number of transducers which can be connected to NCAP either by wired of wireless connection.

Acknowledgement

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