

11th International Conference on Modern Building Materials, Structures and Techniques,
MBMST 2013

Distributed Ethernet Based System of Measurement and Visualization for Buildings Monitoring

Juliusz Walaszczyk^{a,*}, Piotr Batog^b

^{a,b}Department of Heating and Air Conditioning, Faculty of Environmental Engineering, Wrocław University of Technology, Wybrzeże Wyspiańskiego St.,
50-370 Wrocław, Poland

Abstract

Despite advanced facilities and sophisticated control algorithm which are available in engineering practice, heating, ventilating and air conditioning system (HVAC) constantly works not properly in many buildings. Despite that control loop normally works without any faults, an air quality is often measured in non-representative way. Finding a reason of any defect in HVAC and efficiency assessment is a common task nowadays. Although new buildings are often monitored by building management system (BMS), the extensive analysis involves additional measurements. In this paper authors describe a developed from scratch, distributed measurement and visualization system, which consist of measuring devices with Ethernet connectivity and visualization software. Designed solution seeks to be scalable, flexible and user-friendly. Developed visualization system can operate with different external data sources. Visualization system performance was tested by connecting to heating plant and its usability was assessed. The results show that online visualization rationalizes maintaining of monitored system.

© 2013 The Authors. Published by Elsevier Ltd.

Selection and peer-review under responsibility of the Vilnius Gediminas Technical University

Keywords: measurement; visualization; digital sensors; microcontroller; fault diagnostic and detection; building monitoring; Ethernet.

1. Introduction

A significant share of the world's energy usage belongs to buildings. International Energy Agency (IEA) assessed that buildings account for almost 40% of total end use of energy [1]. It is generally agreed that most of buildings have a potential for energy conservation. Even traditional heating, ventilating and air conditioning (HVAC) systems the energy consumption can be reduced. The right way for energy efficiency optimization of such HVAC systems may be tune-up or redevelop a control system [2], [3], [4]. Furthermore there is a strategy of developing advanced control algorithms and harvesting more information from building than is necessary in traditional systems. Lawrence et al. [5] claimed, that the technology for more efficiency building control system is now available, but there is lack of a good process for developing the "smart" aspect of "smart building energy management". This process involves finding out a connection between particular factors, such as air condition, weather, energy consumption and occupants' activity. When the quantity of measured information grows, building control system will be more complicated, but control process may be more efficient. Similar way to optimization control process was shown by Huang et al. [6]. Authors designed chiller control system which operates on data from direct and indirect measurements together. Method based on heat balance transfer, where total energy was calculate with water flow rate and temperature of the return/supply water was called a direct measurement. Second method, based on electrical

* Corresponding author.

E-mail address: juliusz.walaszczyk@pwr.wroc.pl

power input and the evaporating/condensing temperature was called an indirect measurement. New designed data fusion algorithm based on merged measurements significantly improved building cooling load.

Growing amount of measured variables need to be managed properly. Several methodologies of ontology development and frameworks for building monitoring were described by Dibley [7].

One of the important aims of collecting measurement's data is fault diagnostic and detection (FDD). Traditional FDD in building control system base on compare the value of the control variable with the setpoint. If the values differ more than predefined threshold, alarm will be activating. Despite this method is relative fast in fault detection, there are investigated more sensitive methods, for example cumulative sum (CUSUM) or it's extend proposed by Zhengwei Li et al. [8]. Except algorithms which automatically deliver response where the possible problem occurs, there are some methods based on human decision. Human based approach assumes that people can conclude in more advanced way. In this approach data must be prepared in specific, user-friendly form, e.g. as graph, chart or any other kind of visualizations. Despite that these methods have limited usage, the visualizations systems make possible to localized potential accidents [9]. Except FDD, visualization can present selected scientific data in easy way to understand [10]. The data understanding and analysis efficiency is affected by technique of presentation.

Contemporarily, in many domain of human life there are requirements to share information. Similar expectations are in building industry, even inspired by authorities. Thomas-Alvarez et al. [11] tested web-based portal, which was developed for builders, contractors and homeowners as a one standardized system for collecting information about projects. This kind of web portal is also useful for building inspectors, who can have an access to up-to-date data about buildings projects.

Measuring several different factors in building is necessary for assessment occupants' comfort, proper control strategy development and for FDD. Large amount of information should be shared for entire user's group, who maintain the building. Conventional control system can be enhanced by using Internet architecture [12].

In present paper authors describe developed data acquisition and visualization system. The distributed measurement solutions are nowadays increasingly used [13], [14], [15] and the Ethernet connection is usually applied in such systems [16]. It was assumed that easy to configuration devices with network connectivity can be a proper tool for creating or extending building information system, especially for assessment indoor air quality (IAQ) or diagnosing existing HVAC systems. Specified data handling frameworks are necessary in online remote monitoring [17], [18]. Several kinds of software to support our devices, range from web-based to pc's application were prepared. Moreover visualization system consists of large display with remotely managed content was presented. Some practical experiences in this field were also described.

2. 1. System architecture

Defining a proper architecture of system plays crucial role in process of developing informatics solution and can improve the future system performance and stability [19]. Designed lightweight universal measurements and visualization system is expected to provide following capabilities:

- measurements of microclimate parameters, such as temperature, humidity, and optionally others, e.g. atmospheric pressure, carbon dioxide or volatile organic compounds concentration,
- storage of data,
- easy access to data, e.g. from mobile devices,
- data visualization.

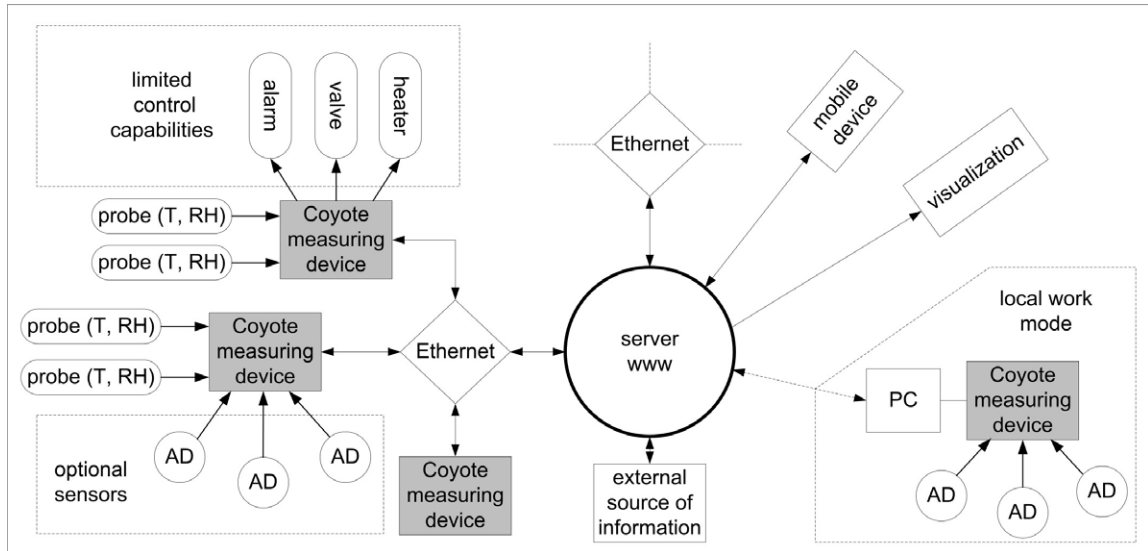


Fig. 1. Overview of system architecture. (AD - Additional Device)

Scalability and flexibility were assumed as two main goals to achieve in this project.

Scalability means that solution proposed in this paper can be used in small buildings with one or a few measuring points, e.g. in detached house, as well as in big buildings demanding multi-point measurements, e.g. in big shopping centre.

In chosen situation temporary measurement can be sufficient for user. Flexibility in this project was considered as ability to easy change the system organization, e.g. adding or subtracting devices, or measurement system transfer from one building to another, therefore measuring devices should be small and portable.

The presented system was based on the sensor net approach and web solutions [20], [21]. The system scheme is shown in Figure 1. Three functional layers, which are: measuring devices, data collecting servers, and visualizing devices were distinguished. Each measuring device is fully independent and consists of sensors, power supply, microcontroller and three different data transmission interfaces. Because of using integrated microprocessor, the device is able to data filtration, fusion and errors compensation, therefore it can be named as intelligent sensor [22]. Measuring devices can upload data through USB or RS232 interface to local computer, and also through Ethernet to remote data server, so the two storage modes can be distinguished:

- data storage on local computer, when device is connected to local computer, and
- data storage on external server, when device is connected by Ethernet.

When data is stored in local computer, it can be also visualized by PC application.

When data is stored on server, which is common to every measuring device all results of measurements are collecting and storing in one network unit and therefore they are available for all users. Data servers can be connected not only to presented measuring devices, but also to other external sources of information and also to controllers. The data can be downloaded and processed by any visualizing device from net.

3. The "Coyote" measuring device

In recent years continuous process of lowering microprocessors price is observed. The intelligent sensors are becoming more popular thanks to powerful and non-expensive, advanced single-chip microcontrollers. Central processing unit of developed measuring device is low cost and efficient 32-bit STM32f103rht6 microcontroller, with following features: 72MHz maximum frequency (1.25 DMIPS/MHz), 20KB SRAM memory, 128 KB Flash memory, 12 bit Analog-to-digital converter (up to 16 channels, up to 2MHz sampling rate), numerous hardware communication controllers (I2C, SPI, UART, USB, CAN) [23].

The scheme of functional blocks of measuring devices is shown in Figure 2. The sensor probes are connected to CPU by serial peripheral interface (SPI). Up to three additional devices can be connected by Universal Asynchronous Receiver-Transmitter (UART). Communication by Ethernet is handled by programmable Tibbo203a module [24]. Each measuring device has own, configurable IP address.

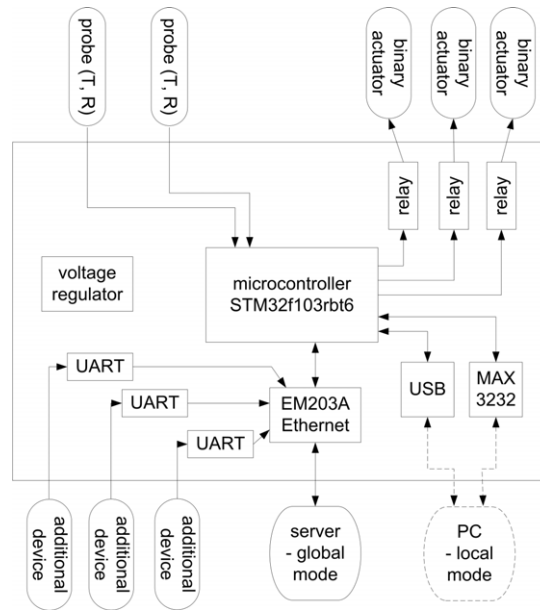


Fig. 2. Scheme of Coyote device functional block

3.1. Temperature and humidity sensor probe

The basic version of measuring device contain two humidity and temperature probes with digital SHT15 sensors. In case of digital sensors, analog to digital converter is integrated in one chip with sensor, so there is no additional errors connected with transmission of analogue signals, and sensor can be placed in relatively distant place from the main board. Thanks to small dimensions (7,5×5×2,6mm) of sensor chip, the sensor probe (Fig. 3.) also can be very small, and therefore easy to install almost everywhere. The sensor provides good accuracy and low power consumption [25].

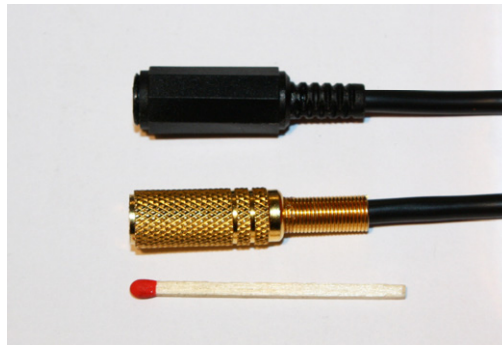


Fig. 3. Probes with temperature and humidity sensors

3.2. Additional devices - optional sensors

For achieving good flexibility it was decided to provide the possibility of connecting additional sensors by serial digital interface. Each base measuring device has three host for additional devices. System is configurable according to user demands by connecting proper sensor in standardized way. The additional device contain microcontroller and one or more specific sensors, for example:

- low differential pressure for flow measurements;
- atmospheric pressure;
- NDIR CO₂ sensors;
- semiconductor gas sensors for VOC measurements;

- additional temperature or humidity sensors;
- other sensors for customer demand.

In order to avoid additional heat production and affecting the measurements results only low energy consuming components are used in additional devices.

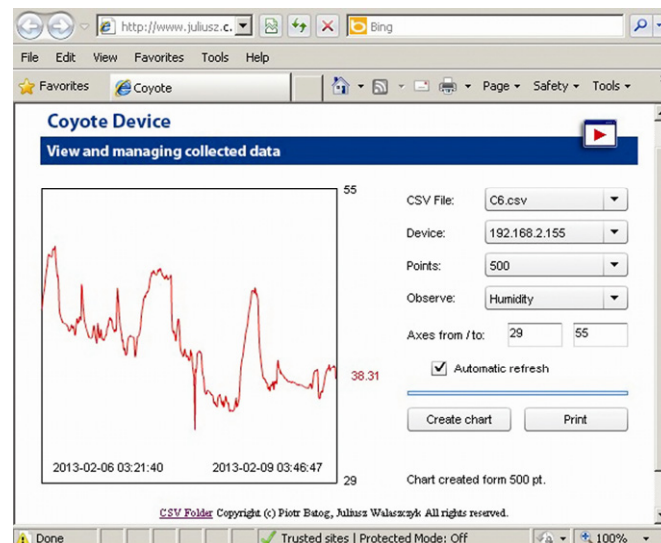


Fig. 4. Measured values available on the web page

3.3. The limited control capabilities

The possibility of controlling up to three binary actuators is provided thanks to three relays on main board. Device can turn off/on heaters, fans, lights or activate/deactivate alarm, etc. The output state can be changed independently by internal decision algorithm stored in microcontroller memory, or as a result of order from server or PC.

4. Data collecting and visualizations

Three independent platforms for collecting the measured values were developed. In one of them it was emphasized on compatibility not only with Coyote devices but it was created a visualization system which is able to cooperate with any other data source. Remaining two platforms are destined for Coyote devices. Chosen platform for collecting data determine maximum speed of refreshing measured data. Also each platform has some individual practical features.

4.1. Data storage on external server

First solution assumes direct data exchange between web server and Coyote device. It was prepared a software pack which can be uploaded to any HTTP server. Therefore each existing webpage can be extended by data acquisition mechanism. Software pack consists of regular webpage files which mean each web browser allows viewing and managing the collected data (see Fig. 4.). Data storage direct on web server is the best practice when ease of use has the priority. It will be enough fill servers' parameter into Coyote memory and the measured data will be sending repetitively to the web. Everyone who has web page address get data access. Predominantly, user can carry Coyote devices into new place without any reconfiguration. Just after connect, it starts work and new data will be available under the same web address. There is one practically reason to limit potential of this approach. If the quantity of devices grows up or data transmission frequency pick up, communication with server may be more fallible. It is hard to assess maximum data transfer frequency, because it depends on servers permit policy.

Also in some situation the topology of network has big impact on transmission's reliability. For example if Coyote are connected to adverse point in network, other devices or computer can trammel its data sending. It was prepared a transmission control mechanism and user has always information about connection status, but it is hard to eliminate

potential future problems. The big advantage of Ethernet using is existed, popular infrastructure, but also measuring system coexist in the same network with many other commercial devices, what sometimes prompt to fail.

4.2. Data storage on local computer

This solution was called Coyote Reader and it is dedicated pc's software which guarantees additional connectivity options. Program can download measured data from many Coyote devices, negligible kind of interface (RS232, USB, Ethernet).

Frequency of refreshing data is adjustable and repeating for 1 second over Ethernet is maximum value. Coyote Reader loads the same chart plotter from previous solution, where data was collected directly on the web server. This time, charts are creating based on local storage data. Also software has build-in full screen version of chart plotter, which can start just after computer starts. Thus local computer may by simple visualization system. Data storage on local computer is independent from storage on external server, described in previous section. In that, distributed measure network can have redundantly data storage systems.

4.3. Visualizations system

Based on the assumption, that collecting data in large databases is not sufficient in many practical situations, a continuous working visualization system was developed. People don't often analyze process variables in daily life because they don't have much time for such activities. Measured values from database are analyzed only if obvious fault occurs. Meanwhile, just casual charts' analysis inform about quality of any physical process.

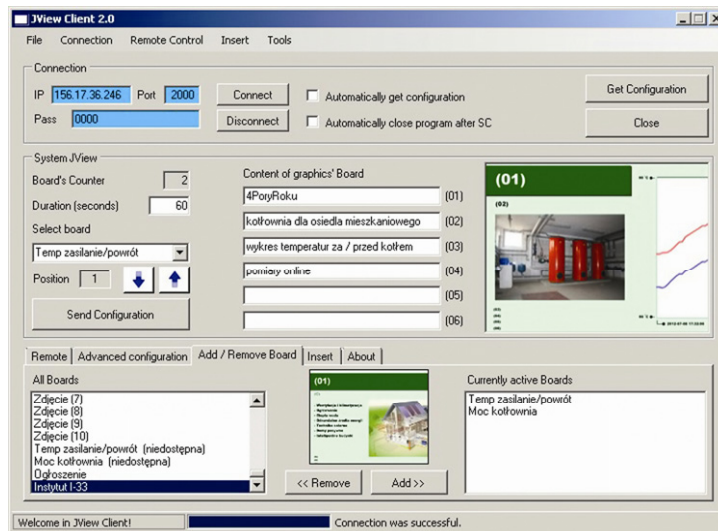


Fig. 5. Remote management software (JView Client) for visualization system

Prepared visualization is a graphical presentation consisted on sequential-changing content – graphical boards are repeating in user predefined time. Each board can contain some charts, texts and other graphical elements. For example visualization can have three independent boards, where first is shows chart of outdoor temperature, second CO₂ level in selected rooms and the last shows sponsor's advertisement. Graphical board mechanism works on open source Linux operating system. Users can write additional scripts or programs in order to download data from different source. Visualization parameters, such as presentation period and boards' arrangement are adjustable by pc's software dedicated specifically for remote management the presented content. The software was called JView Client, see Fig. 5.

5. System utilization

5.1. Coyote device

Measuring device was testing in several residential buildings. Stability and no-break work was assessed, on the assumption that Coyote send data to web server nonstop. It was observed that one Coyote device send data even to strongly limited server without any faults repetitively every 10 minutes. This limit was caused by server security policy. Sending data every 1 second was achieved, but only hour-long. Automatic blocking the IP address which are polling the server too frequent in short time is used to avoid brute force hackers attacks. Nevertheless, 10 minutes is enough in case of processes characterized by slow dynamics - like air temperature or humidity changes in room.

Although quite advanced pc's program was developed, more usable became interactive web page with measured values. Computer's application has more options, but it requires to be switched on 24 hours a day. In addition web content can be viewing in many sorts of devices, e.g. mobile phones and tablet computers (Fig. 6).

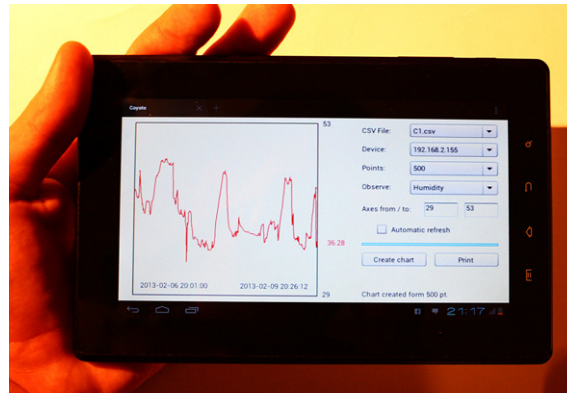


Fig. 6. Tablet computer with preview of microclimate parameters in detached house

5.2. Heating plant's visualization

Visualization was tested with another than Coyote data acquisition system. The key question was, how continuous visualization influence measured system maintaining? Is technical service or common user interested in measured variable from heating plant?

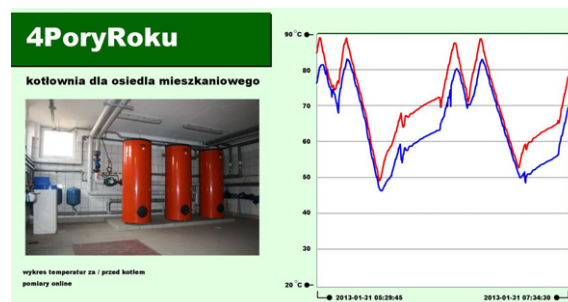


Fig. 7. Element of visualization system. Visualization's screen with return/supply water chart

A visualization platform consisted of huge screen and managing computer was build. Screen was located in university's hall. Also several graphical boards with data from heating plant in residential building in Poland (254 apartments) were developed. Heating plant's boards consist of graphs showing present temperature of the return and supply water (Fig. 7) and separately output thermal power (kW). All of boards were developed follow the instruction from [10], only significant data was presented and level of scientific accuracy has lower priority than understandability of the key concept. System automatically switches off in the night and starts next day. In predefined time system connect with heating plant's data server and download last measured variables. Actual data are shown on the visualization's screen.

5.3. Benefits of visualization's system

In fact, the user's requirement emerges, and many people, who worked with monitored heating plant, wanted graphical content presented on the screen. Although simplified images has low practical potential (graphs and other data are flattered with background, graphs' axes was not adjustable), in practice just regularly made print screens meet user's expectations. Print screens was collected automatically on the external webpage once a day, and anyone, who has a URL address, can get access to all images.

It was observed that visualization influence the collaboration process between technical service and users. Currently print screens' archive helped to diagnose fault, especially in control loop. On graphics' boards it is easy to find too big temperature difference between supply and return water or for example aberrations form proper heating curve. In short time, heating plant's administrator reconfigured boiler's starting up sequence, because control was much far of optimal control. Regularly made charts are also simplified heating plant work documentation.

6. Conclusions

The flexible multi-purpose, network-based system was presented. System is based on existing infrastructure, and can be installed in fast and easy way in every building with Ethernet. Designed solution is configurable thanks to additional devices with optional sensors and fully adjustable to user demand. The data storage and organization task is performed by remote server or by specific PC application. If Coyote devices work under Ethernet network, data will be obtained by any network device, including tablet computers, smart phones etc. Special means of data visualization for large displays are also provided. In the nearest future the solution presented in this paper will be installed in several places like big commercial center to investigate system reliability and performance.

Because of high flexibility this system has many potential application, not only stationary, continuous monitoring, but it can be also used for evaluation of correct operation of HVAC systems, building energy efficiency testing and other audits.

Practical experiences show that online visualization rationalizes maintaining of monitored system. First of all, continuous visualization system can influence on effective fault diagnostic and detection tool. Online created charts are preview, how does the monitored plant work. Although all data has been collected for long time, in practice anybody didn't regularly analyze measured variables. Even simply visualization force attention and abbreviate in significant level time for preparing data. If visualization's charts are too simple for advanced analysis, technical service will have clever tip, where the possible problem occurred. Print screens of visualization stored on a web page are overall report from monitored system. It is clearly informational tool for discussion between technical service and homeowners.

Acknowledgements



Research is co-financed by the European Union as part of the European Social Fund

References

- [1] Energy efficiency requirements in building codes, energy efficiency policies for new buildings, International Energy Agency, March 2008.
- [2] Wemhoff, A.P., 2012. Calibration of HVAC equipment PID coefficients for energy conservation, *Energy and buildings* 45, pp. 60-66.
- [3] Bai, J., Zhang, X. 2007. A new adaptive PI controller and its application in HVAC systems, *Energy Conversion and Management* 48, pp.1043-1054.
- [4] Mathews, E. H., Botha, C.P., Arndt, D. C., Malan, A., 2001. HVAC control strategies to enhance comfort and minimize energy usage, *Energy and Buildings* 33, pp. 853-863.
- [5] Lawrence, T. M., Watson, R.T., Boudreau, M-C., Johnsen, K., Perry, J., Ding, L., 2012. A new paradigm for the design and management of buildings system, *Energy and Buildings* 51, pp. 56-63.
- [6] Huang, G., Wang, S., Xiao, F., Sun, Y., 2009. A data fusion scheme for building automation systems of building central chilling plants, *Automation in Construction* 18, pp.302-309.
- [7] Dibley, M., Li, H., Rezgui, Y., Miles, J., 2012. An ontology framework for intelligent sensor-based building monitoring, *Automation in Construction* 28, pp. 1-14.
- [8] Zhengwei, Li, Paredis, Ch.J. J., Augenbroe, G., Huang, G., 2012. A rule augmented statistical method for air-conditioning system fault detection and diagnostic, *Energy and Building* 54, pp. 154-159.
- [9] Yo-Ming, Hsieh, Lu, Y., 2012. Visualization system for field monitoring data and its effectiveness, *Automation in Construction* 26, pp. 54-68.

- [10] Ma, J., Liao, I., Ma, K-L., 2012. Living Liquid: Design and Evaluation of an Exploratory Visualization Tool for Museum Visitors, *IEEE Transactions on Visualization and Computer Graphics* 18(12).
- [11] Thomas-Alvarez, N., Mahdjoubi, L., 2013. Testing the effectiveness of a web-based portal system for the building control sector, *Automation in Construction* 29, pp. 196-204.
- [12] Lakshmi Sangeetha, A., Naveenkumar, Balaji Ganesh, B., Bharathi, N., 2012. Experimental validation of PID based cascade control system through SCADA–PLC–OPC and internet architectures, *Measurement* 45(4), pp. 643-649, doi:10.1016/j.measurement.2012.01.005.
- [13] De la Rosa, J. J. G., Muñoz A. M., de Castro A. G., López V. P., Castillejo, J. A. S., 2010. A web-based distributed measurement system for electrical power quality assessment, *Measurement* 43(6), pp. 771-780. doi: 10.1016/j.measurement.2010.02.009.
- [14] Chen, D., Zhang, Q., Li G., 2012. Distributed On-line Monitoring System Based on Modem and Public Phone Net, *International Conference on Applied Physics and Industrial Engineering, Physics Procedia*, 24(A), pp. 127-132. doi:10.1016/j.phpro.2012.02.020.
- [15] Grimaldi, D., Marinov, M., 2001. Distributed measurement systems, *Measurement* 30(4), pp. 279-287, doi:10.1016/S0263-2241(01)00019-7.
- [16] Ji, Q., Chen, B., 2011. Angle Measurement System Based on Ethernet, *Procedia Engineering*, 15, pp. 3184-3189, doi: 10.1016/j.proeng.2011.08.598.
- [17] Konno, T., Cabrera, A., Ishitsuka, M., Kuze, M., Sakamoto, Y., 2012. Online Monitor Framework for Network Distributed Data Acquisition Systems, *Physics Procedia* 37, pp. 1835-1840, doi:10.1016/j.phpro.2012.03.756.
- [18] Kalaitzakis, K., Koutroulis, E., Vlachos, V., 2003. Development of a data acquisition system for remote monitoring of renewable energy systems, *Measurement* 34(2), pp. 75-83. doi:10.1016/S0263-2241(03)00025-3.
- [19] Bracke, W., Merken, P., Puers, R., Van Hoof, C., 2007. Generic architectures and design methods for autonomous sensors, *Sensors and Actuators A: Physical* 135(2), pp. 881-888. doi:10.1016/j.sna.2006.07.028.
- [20] Song, G., Song, A., Huang, W., 2005. Distributed measurement system based on networked smart sensors with standardized interfaces, *Sensors and Actuators A: Physical* 120(1), pp. 147-153. doi:10.1016/j.sna.2004.11.011.
- [21] Ding, H., Zhang, B., Ding, Y., Tao, B., 2007. On a novel low-cost web-based power sensor via the Internet, *Sensors and Actuators A: Physical*, 136(1), pp. 456-466. doi:10.1016/j.sna.2006.11.036.
- [22] Meijer, G., 2008. *Smart Sensor Systems*, John Wiley & Sons, Ltd, Chichester.
- [23] STMicroelectronics, 2012, STM32F103x8, STM32F103xB-Medium-density performance line ARM based 32-bit MCU with 64 or 128 KB Flash, USB, CAN, 7 timers, 2 ADCs, 9 communication interfaces. [Viewed on 8 February 2013]. Available from internet: http://www.st.com/internet/com/TECHNICAL_RESOURCES/TECHNICAL_LITERATURE/DATASHEET/CD00161566.pdf.
- [24] Tibbo Technology, 2012 Tibbo Programmable Hardware Manual [Viewed on 8 February 2013]. Available from internet: tibbo.com/downloads/open/phm_manual.pdf.
- [25] Sensiron, 2011. Datasheet SHT1x (SHT10, SHT11, SHT15) Humidity and Temperature Sensor [Viewed on 8 February 2013]. Available from internet: <http://www.sensiron.com/nc/en/products/humidity-temperature/download-center/?cid=879&did=66&sechash=911a6914>.