Internet of Things in Geotechnical Engineering – An example of application

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Advanced research equipment is an essential part of the experimental cognitive process, both in research and development work. Utilizing the latest advances in measurement technology is often an indispensable tool for ensuring the reliability of the results of scientific research. The twenty-first century abounds in modern electronic-information technologies, which are applied in many areas of life. Amongst many modern technologies there is also the Internet of Things (IoT), that is the concept of incorporating objects and devices equipped with a communication interface into the telecommunication and IT networks. This particular feature makes IoT a paradigm that can be successfully applied to measurement systems used in research in geotechnical engineering, especially using a wireless sensor network deployed in scattered research locations. The main purpose of this paper is to present the IoT concept with particular emphasis on its application in Geotechnical Engineering including the author's own system to measure the temperature distribution in ground.

INTERNET OF THINGS

The IoT concept has been developing for several decades, although its distinctive name was adopted only a few years ago. In 1991 Mark Weiser from Xerox PARC (see [19, 20]) introduced the term "ubiquitous computer" to describe a number of smart and interconnected devices, as well as the applications that these devices could connect. It was only in 1999 that Kevin Ashton proposed the "Internet of Things" phrase, noting that although he was the originator of the concept, it did not give him the right to control how others use the notion conceived by him (see [1], he often cited many misconceptions regarding the use of the new naming).

Continuous improvement of IoT devices provides increased performance and memory as well as energy efficiency, not to mention a lower price. In turn, the development of wireless communications enabled these devices to communicate much more effectively with each other.

The IoT has many definitions (see [2, 3]). The most common known definition of IoT is the inter-networking of physical devices, which have embedded electronics equipped with sensors, actuators and managing software. In turn, the most elegant definition was proposed by Atzori et al. [3], it can be presented in the form of the following equation (Fig. 1):

Services + Data + Networks + Sensors = Internet of Things

Taking into account the above definition of this paradigm, IoT system design must meet certain requirements, which are [3]:

- the presence of global network infrastructure, which is necessary for effective interoperability of IoT components and their collision-free integration and unique addressing system (Internet Protocol address – IP, International Mobile Subscriber Identity – IMSI, etc.);
- the main component of the system is the object (thing) that should be readable, recognizable, locatable, addressable and controllable (i.e. physical objects, like sensors and actuators, should have embedded interface to enable them to operate through their virtual representations within a digital information system);
- the objects populating the IoT system should have the autonomy to control the complexity of the system itself by achieving a self-management ability;
- due to heterogeneity of technologies applied in the IoT objects, the structure of the system requires appropriate solutions that enable the coexistence of these technologies within the interconnection platform;
- services need to be strictly associated to the objects, they should be built upon the information (sensing, identification, data interpretation etc.) associated to each object.

As can be easily seen, the IoT paradigm offers unlimited possibilities for constructing remote metering network systems that can be successfully used for research data collection, especially

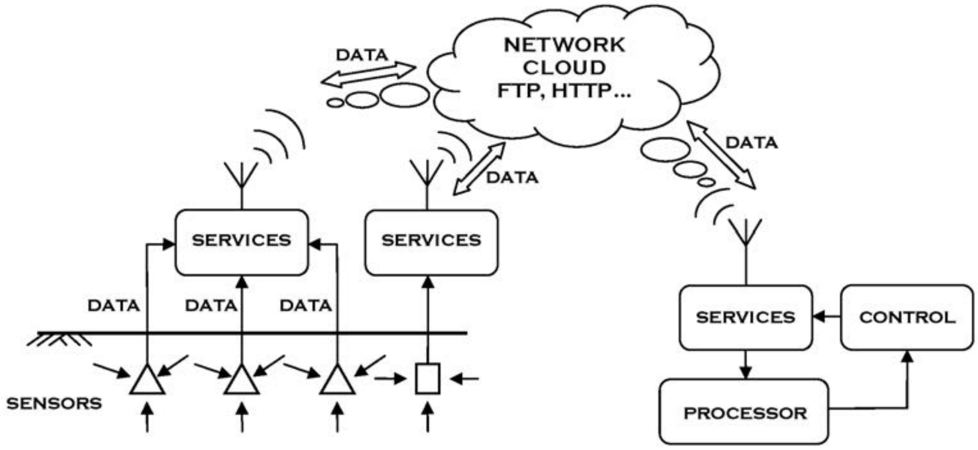

Fig. 1. The Internet of Things concept

in situations where long-term remote monitoring is required. On the other hand, special attention should be paid to the security that should be provided to the designed system (see [16]). It is also worth mentioning that for the success of IoT the most important means are mechanisms to overcome the uncertainty of any kind (see [10]). An interesting discussion concerning detailing aspects of intrusion detection systems taking into consideration development of attack detection strategies for IoT threats is presented in [23].

SELECTED EXAMPLES OF IOT APPLICATIONS

The concept of the Internet of Things is very important in civil engineering (including geotechnical engineering) for many reasons. This issue was nicely described by Leonardo Todisco in his PhD dissertation "Funicularity and equilibrium for high-performance conceptual structural design" [18]: ."*Built-in actuators, sensors and internet connection make responsive structures a very attractive alternative to conventional structural systems. In this scenario, the ongoing revolution of Internet of Things would be exploited for a dialogue between structures and their surroundings creating unexpected opportunities for increasing the structural efficiency of buildings.*"

The most obvious examples of the IoT concept are applications in mechatronic systems (see [5]) used for intelligent energy control in buildings for smart cities [11], taking into account factors that can determine the uncertainty and ambiguity of such systems in the context of intelligent building [13]. The IoT facilitates remote real-time monitoring of the processes taking place in the recycling centers of end-of-life vehicles [21]. It is used in the field of public safety [9], including human detection system for disaster situations [6], early warning systems for accident prevention and improved safety management in underground constructions [7, 24] and early warning systems capable of anticipating the maximum seismic peak in the epicentre zone through smartphones [22]. Nowadays, most of systems improving prefabrication production management and traceability of elements in prefabricated construction are based on the IoT solutions [12, 25]. The tailings dam safety, a tailings dam monitoring and pre-alarm system with the abilities of real-time monitoring of the saturated line, impounded water level and the dam deformation are based on the IoT network [17]. However, most of the publications concern the IoT itself, such as Bluetooth Low-Energy innovations [14].

Despite so many areas of IoT application, it is really difficult to find publications describing such applications in geotechnical engineering in the world literature. Simple search in Google Scholar for publications using the phrase "Internet of Things" gives in the years 2015-2016 57000 documents, 964 results for publications with the keywords "civil engineering" and "Internet of Things", but only 10 documents with the keywords "geotechnics", "geotechnical" and "Internet of Things" in the same time period. Among these 10 results, only 2 are closely related to the use of the IoT in geotechnical engineering (see [4,15]). In [4] the authors presented a methodology for measuring sensor orientation in a geotechnical centrifuge on the plane of reactive centrifugal acceleration and Earth's gravity with a single-axis microelectromechanical system (MEMS) accelerometer, which is a part of the IoT technology. In [15] a geo-monitoring system is presented. The described system was using sensors for observation of the geological, geotechnical and hydrogeological environment. The authors stated that the technological advance can be almost directly translated into a better understanding of the geo-environment, more accurate prediction, and reduced risks and costs associated with investments. Taking this into consideration, the author of this paper has decided to construct a simple IoT system that provides data on selected geo-environmental parameters. This preliminary version of the system is intended to provide the basis for further development of the geotechnical measurement network.

EXAMPLE OF GEOTECHNICAL IOT – TEMPERATURE RECORDING SYSTEM

Selection of parameters for geo-environment monitoring was influenced by currently conducted research in the Geotechnical Team employed in the Institute of Civil Engineering, at the University in Olsztyn. In connection with the dissertation work related to the study of phenomena accompanying frost on ground substrate, it was decided to build a system for monitoring the temperature distribution in the ground. The design assumptions of the system were as follows:

– number of temperature sensors – 10,
– type of data transmission – wireless,
– reading frequency – 1 reading per hour,
– internal memory capacity – data recorded by min. 3 months,
– power supply – 12 V lead-acid battery or 3.6 V Li-ion 18650 cell.

Hardware – functional orientation

Application layer

The application layer is a platform of services which provide users with information collaboration, sharing and other special functional services. It also includes planning capabilities for allocating available resources, evaluating general faults, logging commands, and summing up events [9]. In the project, the service platform is a program that handles all events related to external requests and commands as well as internal, programmed tasks. Software (created in C++) was installed on a hardware platform equipped with a microcontroller. Due to the low requirements for computational power and the strictly defined range of processed numbers (mainly integers, without floating point numbers), the implementation of the hardware platform could be based on 8-bit microcontroller. In view of the above, the IoT system design concept was based on Atmel Microcomputer System MCS-51 (AT89C4051) and Advanced RISC Architecture AVR (ATmega328P).

Network layer

The network layer should be based on the available mobile communication network. It should provide the transmission of various types of information obtained from sensing layer through the application layer to all request centers. It should have high reliability and high security [9]. In the first prototype of the device a Bluetooth transmission was used (HC-05 module) – the connection required early pairing of all devices with a password. Due to the widespread availability of the GSM mobile communication signal, it has been decided to use it as a trusted and secure medium for transmitting information at any distance. In this case, the IoT data security is provided by the subscriber identification module (SIM) that was purchased from local GSM/GPRS provider (the SIM card contains the IMSI number and its related key). The project uses the SIM800L hardware communication module.

Sensing layer

The main task of the sensor layer is to handle physical events and obtain data from the physical environment, including the recording of various physical quantities (e.g. temperature, humidity, displacement, acceleration, etc.) [9]. The sensor layer consists of a set of temperature sensors - this is a key element of the measurement system. As the temperature transducer, the digital sensor DS18B20 was selected. It can measure temperatures to an accuracy of 0.5 degrees in 12-bit resolution in the range of -55 to 125 degrees.

In total, four versions of the IoT system were designed and manufactured. The modular scheme of the system is shown in Fig. 2. A general view of assembled IoT boards are presented in Fig. 3 and 4.

The tested units were installed in a geotechnical research field located near the Geotechnical Laboratory in the university campus Kortowo (Fig. 5). Temperature sensors have been deposited in a natural non-cohesive soil (fine sand) with a depth of 1 m below the ground level at intervals of 20 cm. The system started to work when the power was turned on. The use of the system with Bluetooth interface consisted of cyclical loading of data to a laptop computer at least once every three months. A serious disadvantage of this solution was the lack of measured information made available remotely in real time – a download of data was available only when laptop computer was in range of Bluetooth interface (10-100 m). The next version of this IoT project had a built-in GSM/GPRS interface, which allowed for communication with the FTP server via the Internet and retrieving data at any time intervals controlled remotely by the user.

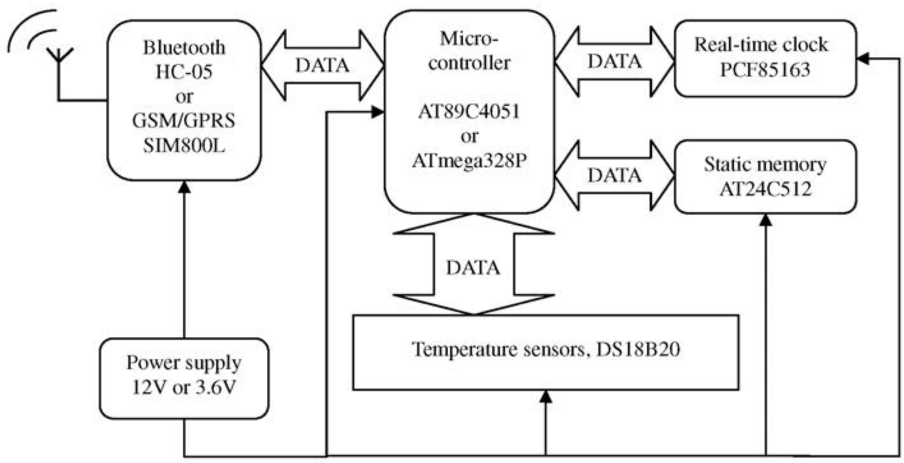

Fig. 2. A block diagram of the IoT system

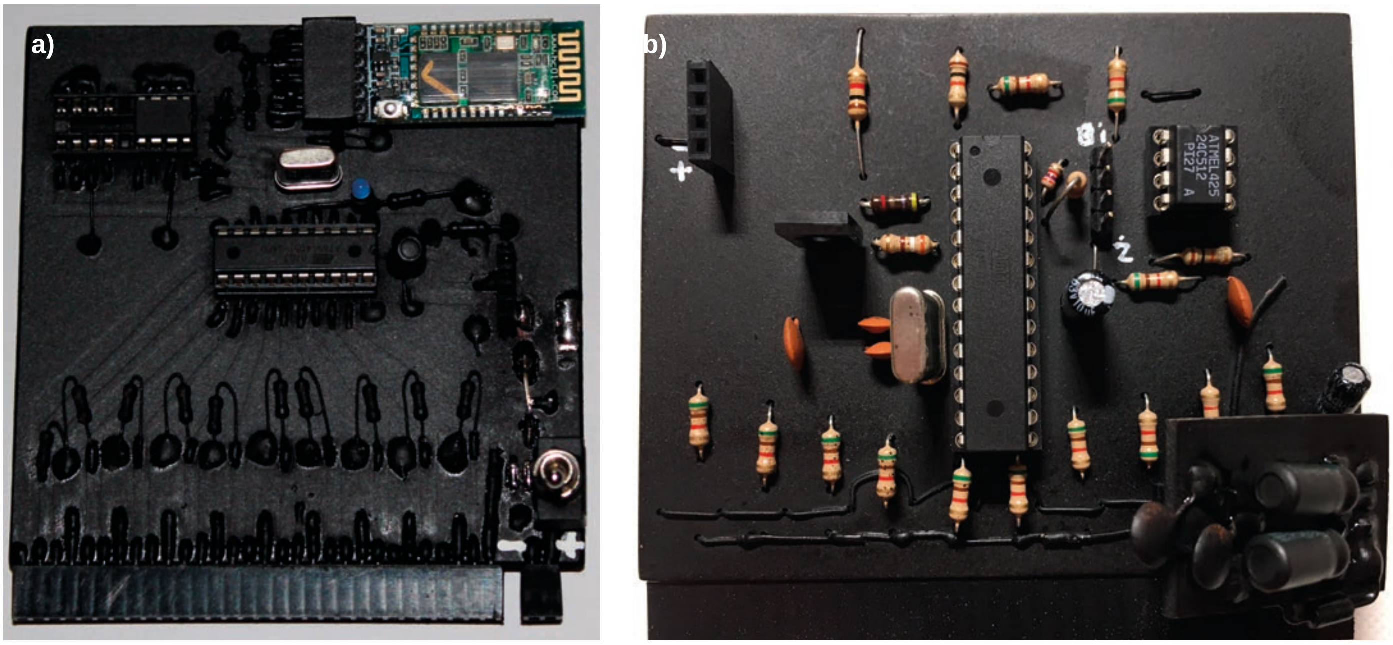

Fig. 3. Microcontroller boards with Bluetooth interface; a) based on MCS'51 CPU; b) based on AVR CPU

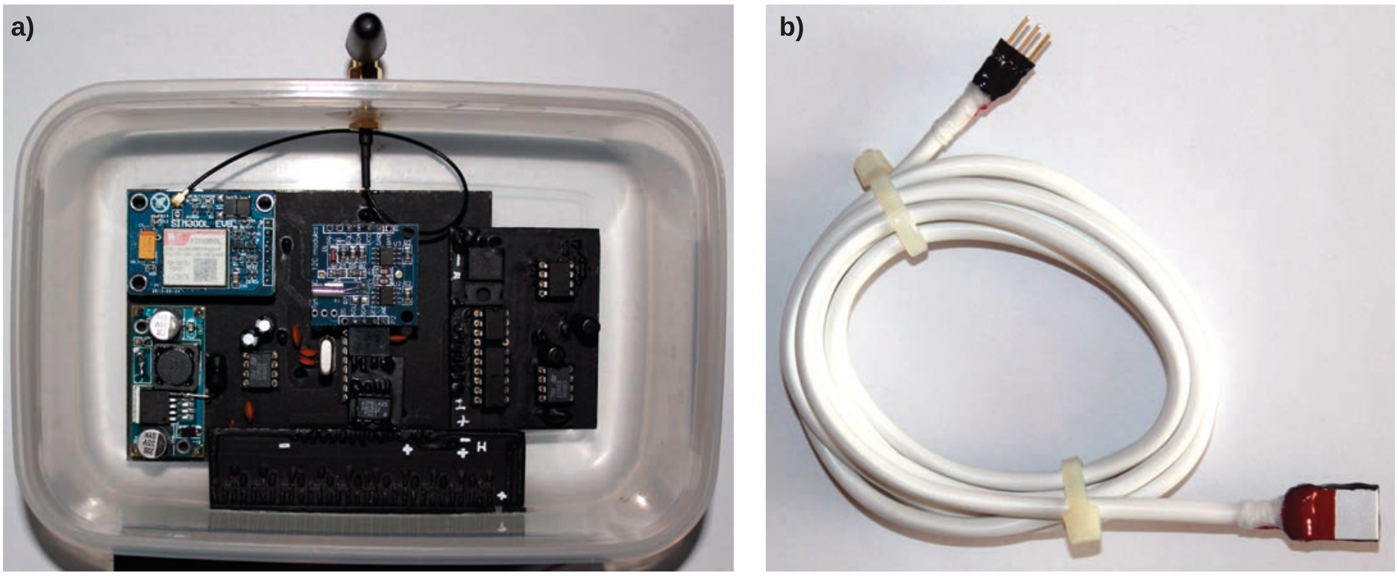

Fig. 4. The IoT system with GSM/GPRS interface; a) motherboard; b) temperature sensor

Thanks to the use of the GSM network, the user can access measurement results anytime and anywhere in the world. An example of measurements updated by IoT on webpage (www.uwm.edu.pl/edu/piotrsrokosz/temperatures.htm) is shown in Fig. 6. The described system has been functioning for five months without any failure.

Collected results are used to perform comparative analyzes with results of numerical simulations of heat transfer phenomenon in ground material (Fig. 7). The application of back analysis makes possible to determine the thermal diffusivity coefficient of soil that will allow effective predictions of ground freezing depth depending on weather conditions. Till now, the analysis of collected results showed, among other things, the proximity of the groundwater table, which, as a powerful heat storage, effectively prevented the penetration of frost into the ground. Detailed analysis of the data that are still being transmitted by the IoT system is subject to separate publications.

FINAL REMARKS AND CONCLUSIONS

The paradigm of Internet of Things is still evolving and developing. One of the branches of this development is Internet of Underwater Things (IoUT), defined as a world-wide network of smart interconnected underwater objects that enables to monitor vast unexplored water areas (see [8]). We should hope that this kind of paradigm will evolve and become also a standard component of geotechnical engineering.

Fig. 5. View of the research field; a) masked research site; b) clipboard with IoT module; c) installed IoT module.

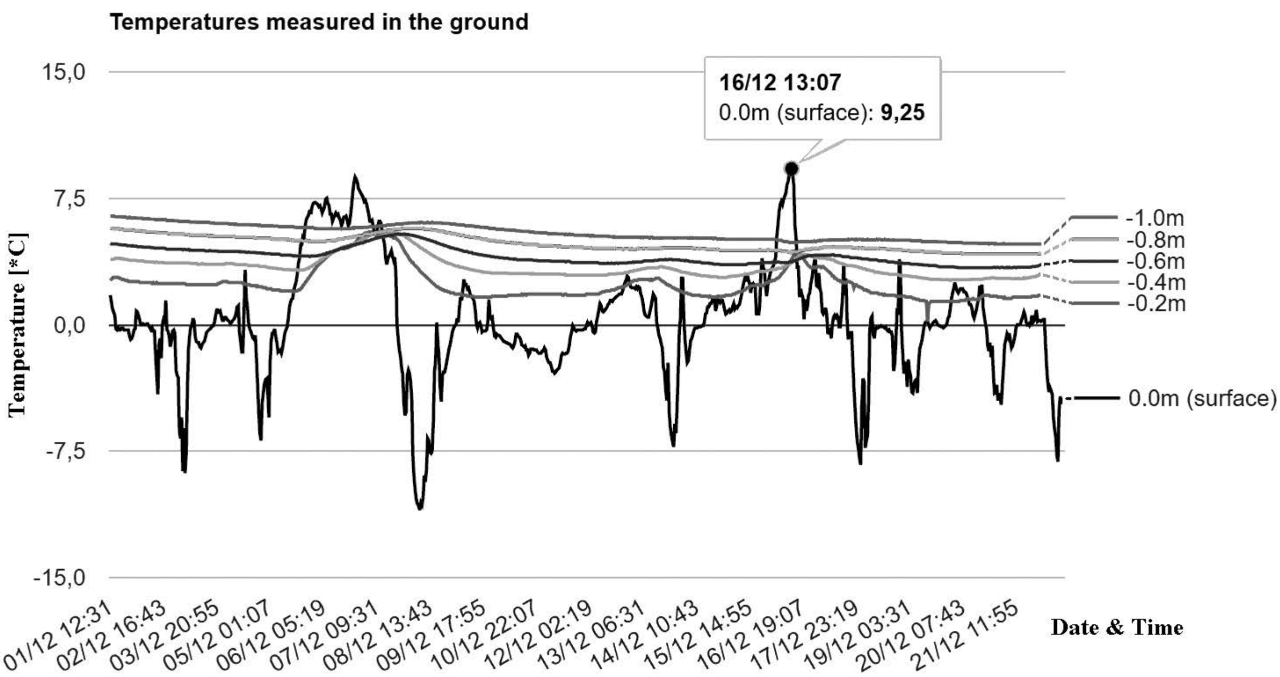

Fig. 6. Example of measurements updated by the IoT on webpage

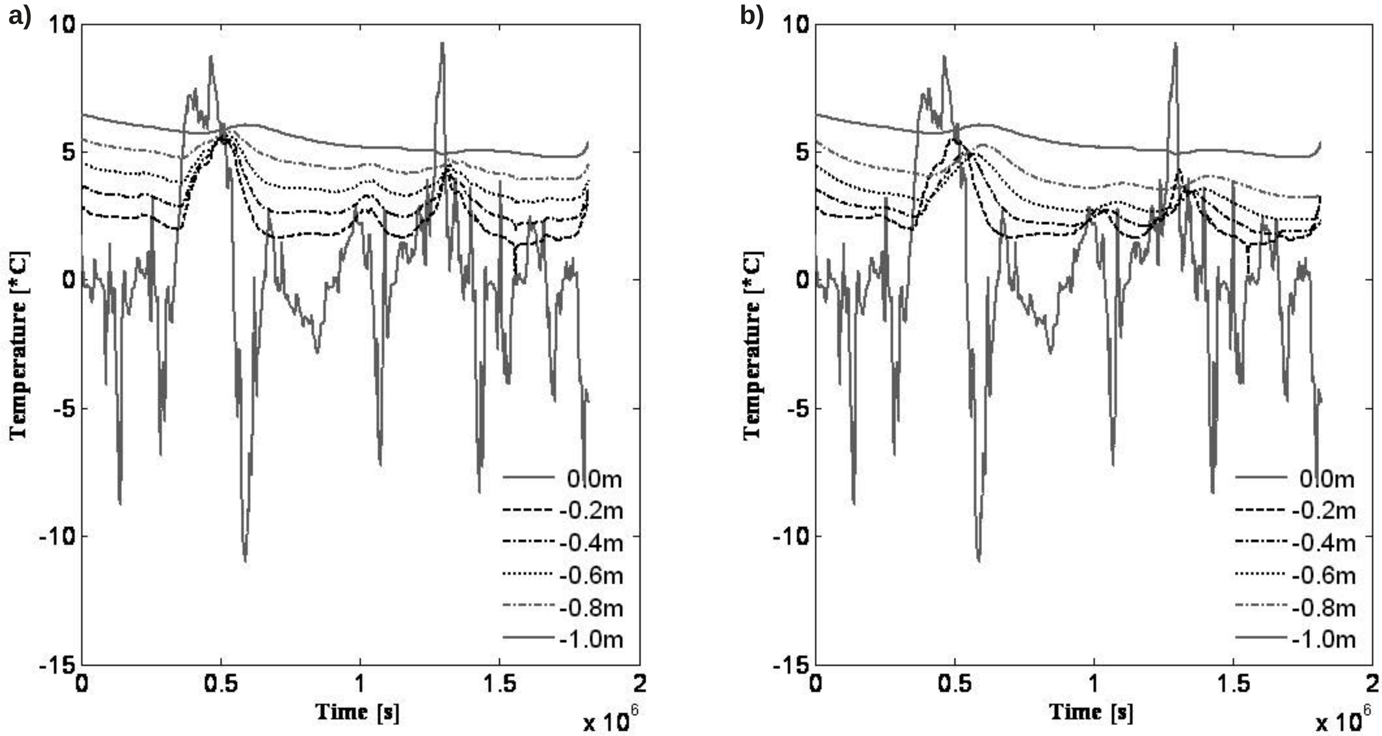

Fig. 7. Example of heat transfer analysis for thermal diffusivity coefficient (m^2/s): a) $7.395 \cdot 10^{-6}$; b) $6.723 \cdot 10^{-7}$

The results which are being collected from described IoT temperature measurement system are used to determine basic parameters describing the phenomenon of heat transfer. The derived information will be used in the design of the set for soil freezing (frost heaving) study. Taking into account the undoubted advantages of IoT systems and the numerous geo-environment monitoring needs, the plans for further actions include the construction of slope monitoring IoT system including soil moisture sensors and inclinometers. The system will be installed in Ruś near Olsztyn probably until 2018. The work lasts.

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