System of Prediction, Optimization and Detection of Users with the Use of Radio Tomography and Computational Intelligence Methods

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Abstract:

Purpose: The objective of the article is to present a comprehensive building management system using radio tomography methods and computational intelligence methods.

Design/Methodology/Approach: The system under development integrates a number of proprietary solutions with solution existing on the market, the best and most recent communication standards for IoT (Internet of Things) devices have been used, the software used allows for high scalability of the platform in the future, easy adaptation to various types of supported facilities, while remaining open to new integration with more and more popular solutions for servicing the Smart Home / Building market. Great emphasis was placed on the visualization on both tomographic solutions and presentation of the current state of the building equipped with a number of software and hardware solutions.

Findings: The results of the research work indicate that created building system will optimize energy consumption through direct management of energy receivers as well as indirectly through appropriately adapted control algorithms taking into account many internal and external factors. Detection of people by means of radio tomography, automation adjusting the operation of devices to the environmental conditions of the building and individual rooms, prediction of behavior, appropriate visualizations and the ability to check the energy condition of the building.

Practical Implications: The system can be used to analyze and predict the behavior of consumers in any larger facility equipped with standard comfort systems like lighting, heating, ventilation and air conditioning.

Originality/Value: The created innovative system, thanks to the ability to accurately determine the position (RTI) and identification of a person (individual tags), will allow to manage building systems in an individual way.

Keywords: Building management, radio tomography imaging, energy saving, computational intelligence, autonomous building.

JEL codes: C61, C88, O32.

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1. Introduction

In the era of constant increase in demand for electricity, its proper rationing becomes equally important. The presented system is designed to reduce the electricity consumption in the building to a level that allows the building management costs to be reduced by 15-18%. Decisions made by the system relate to the aspects of proper management of the entire building, not just individual devices, take into account a greater number of input parameters than typical building automation solutions, and based on historical data, decisions are made regarding the future behavior of both devices and people. Automatic adjustment of working conditions (lighting, sunlight, air conditioning or heating), checking the presence of people in rooms using modern techniques based on Bluetooth 5, automatic shutdown of energy consuming devices when they are not needed, monitoring systems and algorithms that take appropriate actions correlated with the current and the anticipated situation significant affect the functioning of the serviced facility, thus creating a friendly and pro-ecological ecosystem of an intelligent building (Tian *et al.*, 2018; Shao *et al.*, 2018; Barendse, 2014).

As part of the project, key elements of the system will be designed and developed, the implementation of methods and algorithms (statistical computer intelligence of deep learning) will be carried out, the design of the communication module will be developed, as well as the analysis of individual technologies and their classification. Then, a demo version of the system will be developed research platform will have all the functionalities of the designed system and will allow for energy management in terms of controlling existing systems (in this case it is exactly about lighting, heating, ventilation and air conditioning), as well as for access control (Styła *et al.,* 2019; Lehtimäki, 2019; Wei *et al.*, 2014; Park, Noh, and Cho, 2016).

One of the main assumptions is also that the system is possible to install (compatible) with as many existing solutions as possible, and that it is susceptible to extension and modification. This applies to both the comfort subsystems, scaling the radio tomography system and the possibility of influencing the created PAN (Personal Area Network) networks like Bluetooth, Zigbee or Wi-Fi that can be used to create connections between the service server, data intermediaries, and target actuators (Zeng, Pathak, and Mohapatra, 2016; Zhang *et al.*, 2016; Yiğitler *et al.*, 2016). The control system in conjunction with a network of sensors selected for specific environmental parameters essential for maintaining the well being of people inside the facility will enable full-fledged, two-way data exchange (Azhari and Whitty, 2016; Alippi *et al.*, 2016; Pu *et al.*, 2013).

2. Research Methodology

The entire platform consists of many integrated solutions. The platform works in the client-server structure, which enables the integration of many sources of data about the condition of the building at one point (headquarters) (broken down into clients

located in different zones of the building) or clients representing different buildings in different locations. Such a structure does not limit us to monitoring one facility, and can be used to support many buildings in different locations with data collected centrally in one place (headquarters). One of the most popular data exchange platforms in the form of the Apache Kafka message broker was used to exchange data both between individual sensors and the entire managed areas. This allows for almost instant data transfer even between locations that are many kilometers apart. An example of the structure of the platform prototype is shown in the Figure 1.

Figure 1. *Structure of the created system*

Source: Own creation.

2.1 System Data

The presented solution has a clear web (and mobile) interface in the form of a visualization platform with many dashboards informing about the current state of the building. It contains min. view of the environmental condition of the building surroundings. An example is shown in the Figure 2.

Figure 2. *A dashboard that stores the weather data used by the system*

Source: Own creation.

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Dashboards monitoring the status of devices supporting the platform itself (self-monitoring) have also been added. An example is shown in the Figure 3.

**Figure 3.** *A dashboard that stores data on the state of service hardware resources*
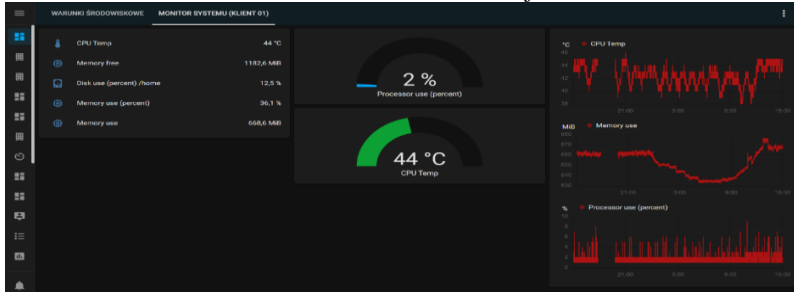
Source: Own creation.

2.2 Detection and Tracking of Users with Radio Tomography

Presence detection was implemented on the basis of proprietary algorithms (computer intelligence, deep learning) and a dedicated device based on Bluetooth® 5 tags working as radio tomography. Tags are used for the ongoing detection of the presence of users in the building's premises. Appropriate visualization (2D, 3D) allows you to clearly detect and monitor the number of people in a given space. The platform allows you to view the monitored rooms at any time with full 3D visualization of the movement of detected people. The presented functionality is directly related to the use of radio tomography. The effects of work can be discussed in Figure 4.

Figure 4. *Methods of 3D visualization of the registered presence of the user / s for various cases: (a) – four objects (view from the top), (b) – four objects (view from the side)*

| (a) | (b) |
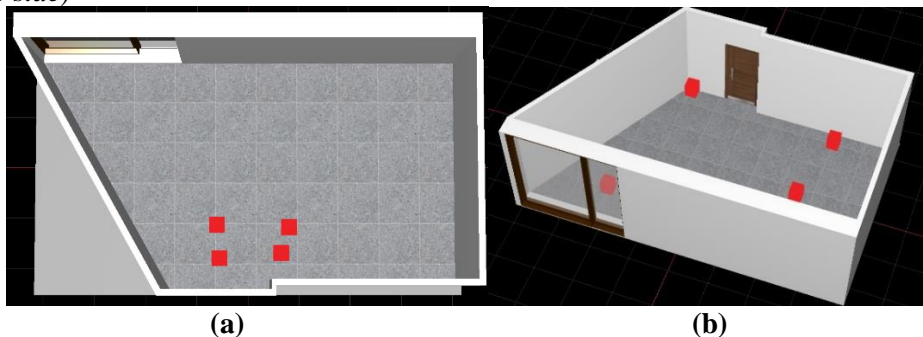
Source: Own creation.

Detecting the presence and identifying the number of people staying in the rooms has a decisive impact on the solutions used in the building service system. On the one hand, it can be used to monitor traffic, the number of people, the formation of queues in public buildings, and also affects the entire building control. The decisions

of intelligent algorithms largely depend on whether the presence of people in the rooms (and in what number) is detected, which allows us to e.g. automatically turn off energy-consuming devices, or we can influence the traffic in rooms by blocking / opening individual passages. In this way, it is possible to maintain an appropriately determined number of people staying at one time in communication routes or rooms.

2.3 Access Control and Record of Working Time of Devices and Employees

Prepared software and hardware solutions allow the user to be identified without any action, such as holding the card close to the reader. Thanks to this, it has become possible to control access to rooms and automatic opening of locks to rooms to which the employee has been granted access. The prepared mobile version of the system also enables remote identification of devices marked with appropriate bluetooth tags, which is used, for example, in periodic inventories.

User identification solutions also allow for the automatic adaptation of the infrastructure of intelligent devices to the user's preferences using appropriate computational methods of predicting behavior. For example, the detection of an employee entering the room in which he works can automatically turn on lighting, ventilation, heating / air conditioning based on the history of settings stored in the analytical database. Each activation / deactivation and change of parameters of monitored devices is saved in the database, thanks to which the appropriate algorithms, based on many internal and external factors, taking into account individual preferences, are able to predict user behavior. The platform enables visual presentation of the current access status, open / closed rooms with remote control of the locks from one place. An example is shown in the Figure 5.

**Figure 5.** *Door access control subsystem*
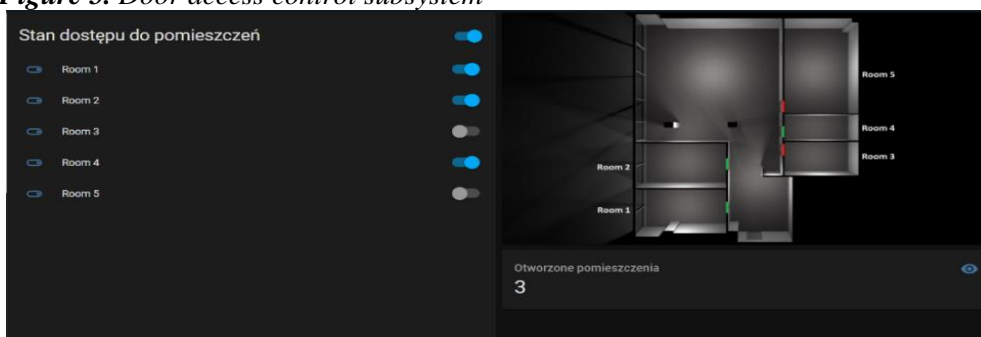
Source: *Own creation.*

2.4 Management of Devices Found in the Building

Due to the intended use of the presented solution for building service, the possibilities of visualizing the operating parameters of both the building as a whole and the division into individual floors / zones or individual rooms were prepared.

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Visualizations are interactive, depending on the permissions, you can gain access from the level of individual dashboards to control the devices placed on them. Of course, the available control depends on the type of device. It is about lighting, heating, ventilation and air conditioning. An example is shown in the Figure 6.

Figure 6. *Management of hardware resources in one of the rooms of the building*
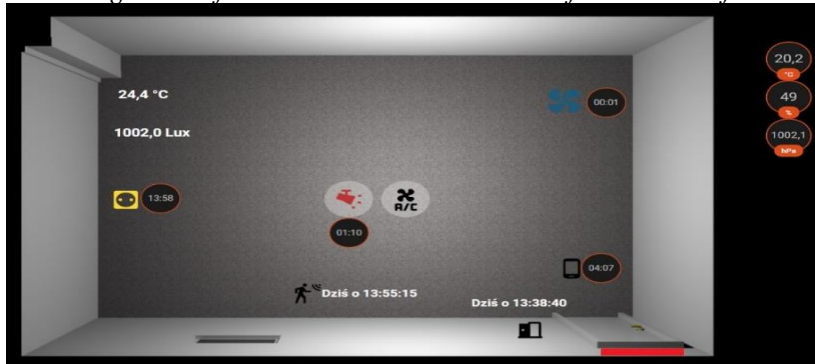
Source: *Own creation.*

2.5 Monitoring Energy Consumption in the Building

The platform allows you to monitor the consumption of total electricity as well as the current control of the power consumption parameters in individual rooms. This is extremely useful in diagnosing and identifying devices that contribute to increased energy consumption. An example is shown in Figure 7.

**Figure 7.** *Observation and control of energy consumption*
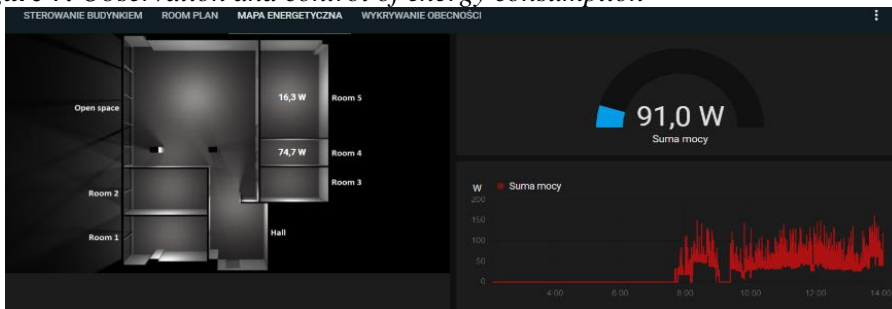
Source: *Own creation.*

2.6 Integration of Sensors and IoT Devices

Due to the assumptions of the project, which relate to the operation of new buildings (the possibility of creating the necessary infrastructure from the very beginning) and existing buildings (using the existing infrastructure without the possibility of full modification to meet the needs).

Figure 8. *System integration with IoT sensors for local observation of environmental parameters (within a single room)*
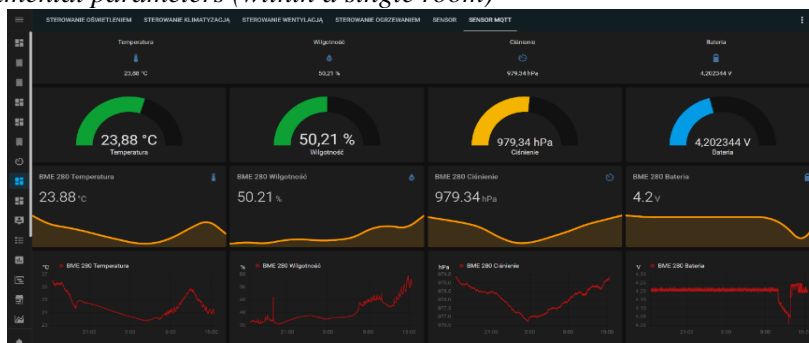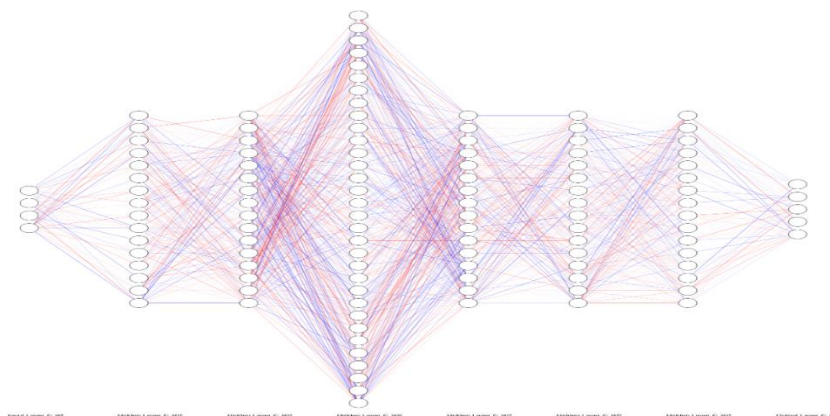

Source: *Own creation.*

The project assumes the use of equipment existing on the market. The hardware analysis of the available solutions has shown the existence of many device manufacturers, which indicates the increasing popularity of this type of systems. These are mainly devices aimed at the so-called intelligent houses, but they can be successfully used in larger facilities where control of circuits not exceeding the maximum loads of devices is used. An example is shown in Figure 8.

3. Computational Intelligence Algorithms for Control and Optimization

The end result of the work is to teach machine intelligence that can successfully manage the building in the most economical way, as well as integrate the possibilities of artificial intelligence with the navigational potential of radio-tomographic imaging. Based on the described functionalities and subsystems collecting data on user behavior and habits, the creation of machine intelligence was started.

Figure 9. *Structure of the developed deep neural network*

Source: *Own creation.*

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The project uses proprietary algorithms to support building management, including neural networks to forecast user behavior based on historical data. As it's known, predictive analytics combines techniques such as predictive modeling with machine learning to analyze past data to predict future trends. However, neural networks are different from the usual predictive tools. The most widely used model - linear regression - is in fact a very simple procedure compared to neural networks.

Neural networks perform better in predictive analytics because of hidden layers. Linear regression models use only the input and output nodes to create predictions. The neural network also uses a hidden layer to make predictions more accurate. This is because it "learns" the way a human does. An example of the developed structure of a deep neural network is presented in Figure 9.

The neural network can be compared to a game of chess with a computer. It has algorithms by which it sets tactics depending on movements and actions of its opponents. The programmer enters into the computer database data about the movement of individual pieces, determines the boundaries of the chessboard, introduces a huge number of strategies, according to which chess players play. At the same time, the computer can, for example, learn from any human, it can become a deep neural network. After some time, this results in the selection of the best possible operating conditions, for example, an energy building by taking decisions and control from typical building automation to intelligent methods of device management.

To verify that the network predicts correctly for the user, for this purpose, we examine predictions for a user with id = 0 for the entire year. An example is shown in Figure 10.

Figure 10. *System integration*
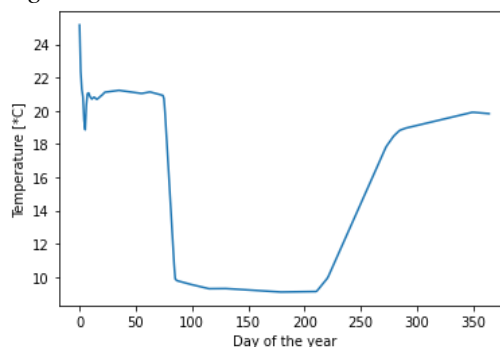
Source: *Own creation.*

The chart above shows the thermostat temperature settings predictions depending on the day of the year. The diagram shows the dependence where, during summer days, the temperature set on the thermostat is about 10 degrees C. This may be due to the

fact that the user has set continuous cooling in the room in the training data. During the fall, you can see the prediction of a gradual increase in temperature set by the user. In winter, the prediction predicts that the user in a given room will set a comfortable temperature of about 22 degrees C.

4. Conclusions

The article presents a designed system for building management using the methods of radio tomography and computational intelligence. The system integrates a number of proprietary solutions. The best and latest communication standards for Internet of Things devices were applied. The system allows for high scalability and easy adaptation to various types of supported facilities, while maintaining openness to new integrations with more and more popular solutions for managing smart buildings.

The results of research work indicate that the created system will optimize energy consumption through direct management of energy receivers, as well as indirectly through appropriately selected control algorithms taking into account many internal and external factors. The created innovative system, thanks to the possibility of precise position determination by means of radio tomography imaging, enables the identification of persons and allows for intelligent management and adaptation to the personal preferences of users.

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