1. Michał STYŁA[1], 2. Przemysław ADAMKIEWICZ1[1,2]

Centrum Badawczo Rozwojowe Technologii Informatycznych Sp. z o.o., Rzeszów, Poland (1),
University of Economics and Innovation in Lublin, Poland (2)
ORCID. 1. 0000-0002-1141-0887, 2. 0000-0003-3425-9566

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Optimization of building control systems with use of alternative tracking methods using the RSSI index and artificial intelligence mechanisms

***Abstract**. The article presents the results of work carried out on the design of an intelligent building equipped with a centralized resource management system, an internal device-free detection and navigation system and machine intelligence increasing the capabilities of all other subsystems. The main functionalities of the project included presence detection, facility energy optimization, user identification and resource management, as well as access control and work time recording.*

***Streszczenie.** W artykule przedstawiono wyniki prac prowadzonych nad projektem inteligentnego budynku wyposażonego w scentralizowany system zarządzania zasobami, wewnętrzny system detekcji i nawigacji bez użycia urządzenia oraz inteligencję maszynową zwiększającą możliwości wszystkich pozostałych podsystemów. Główne funkcjonalności projektu obejmowały detekcję obecności, optymalizację energetyczną obiektu, identyfikację użytkowników i zarządzanie zasobami, a także kontrolę dostępu i rejestrację czasu pracy. (**Optymalizacja systemów sterowania budynkiem za pomocą alternatywnych metod śledzenia wykorzystujących wskaźnik RSSI oraz mechanizmów sztucznej inteligencji**).*

Keywords: smart building, energy optimization, device-free localization, computational intelligence
Słowa kluczowe: inteligentny budynek, optymalizacja energetyczna, lokalizacja bez urządzenia, inteligencja obliczeniowa

Introduction

The progressive automation of buildings, and hence the constant growth of electronic systems for various purposes, entails the need for their proper management to maintain the facility's proper functioning, personnel, and energy savings.

The presented system integrates all the basic subsystems used in modern commercial buildings into one coherent structure supported by selected mechanisms of artificial intelligence [6,9.10]. Artificial intelligence is designed to learn the habits of users on the basis of a proprietary network of sensors, tracking systems using beacons and radio tomography [3,5], as well as information about the current power consumption and operating time of devices. Then, it must regulate the building's operating parameters in such a way as to reconcile the comfort of use with the greatest possible energy profit. Additional criteria influencing its decisions may include data on the opening hours of the building, the working time of individual employees (which has an impact on the activity of individual rooms) and weather data collected from the network using an external weather station. Due to the communication protocols and types of networks used, the created network has the ability to support both proprietary solutions and existing solutions [11]. Proprietary solutions include hardware and software resources and a control panel supported by visualizations and statistical methods. All elements are connected with each other short-range Bluetooth 5 [12,13,14]. Apache Kafka data bus and the Node-RED tool used for interfering interfaces. The general structure of the system is shown in Figure 6.

Proprietary control system for comfort modules

Hardware solutions designed to control the climatic parameters boil down to controllers and associated actuators for light, heating, ventilation and air conditioning. The controller and actuator are interconnected via Bluetooth 5. The only exception is the air conditioner controller, which is both parts within the same electronic system. Depending on the variant, lighting and heating control actuators are a light dimmer or a speed controller for a single-phase motor. Its appearance is shown in figure 1. The heating controller actuator has the form of a stepper motor driver or H-bridge (DC motor), which opens or closes the thermal valve via a pushing pin. The air conditioner controller communicates with the actuators via a high-power infrared diode, and the control codes (depending on the manufacturer) are stored in the microcontroller's memory. The appearance of one of the drivers is shown in Figure 2.

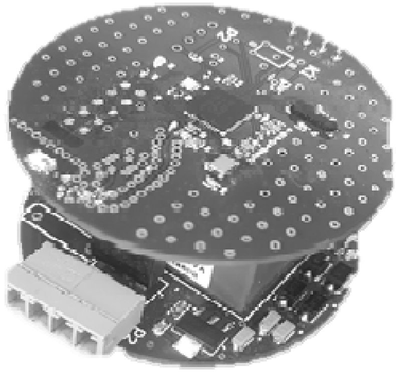

Fig.1. The appearance of the light dimmer actuator and the ventilation rotor speed controller

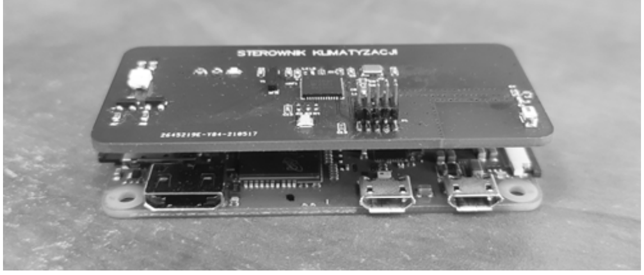

Fig.2. The appearance of the air conditioning controller

Each control part consists of a microcontroller with a converter and a single-board computer with Linux OS. They are connected with a 40-pin strip visible as a black comb in the upper part of figure 2. The microcontroller is an nRF52832 chip compatible with Bluetooth 5 technology. Each computer has a connection to the local network and participates in the transmission of information between the controller and the server. The connection is made using the Apache Kafka data bus. The appearance of the comfort module control panel is presented in Figure 3.

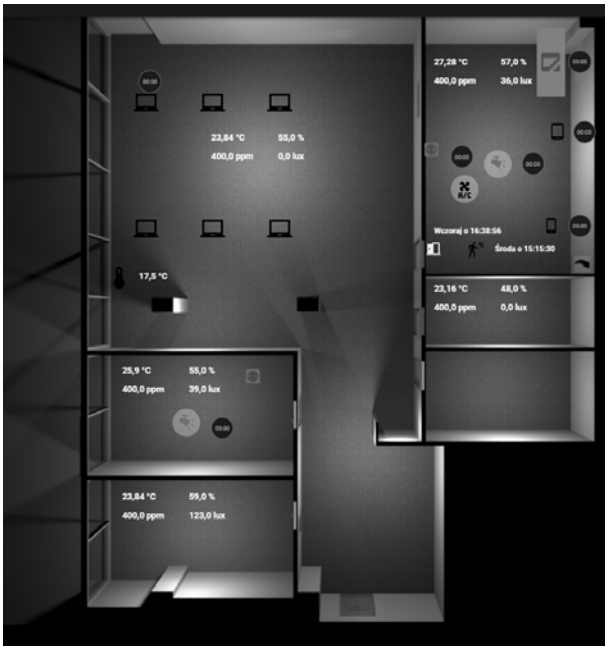

Fig.3. Graphical user panel for managing comfort modules

Wireless sensor network

X The instructions sent to the comfort controllers constitute the output information obtained on the basis of the learned computational intelligence, which treats the indications of environmental sensor units as input information reflecting the preferences of the users. Each unit consists of a temperature sensor, carbon dioxide content in the air, humidity and light. As in the case of controllers, data is obtained wirelessly using the nRF52832 microcontroller located together with sensors on one PCB. Environmental parameters of a given zone are sent to the address associated with one of the access gates to the local network. They are located on the same types of single-chip computers as the drivers. Data reception takes place via the Bluetooth protocol, and then it is entered into the service using a dedicated topic in Apache Kafka. The sensor assemblies are powered by a single galvanic cell made of lithium marked CR2032 .

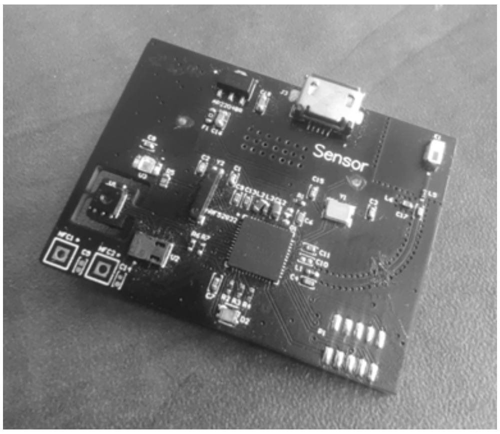

Fig.4. Appearance of the sensor assembly

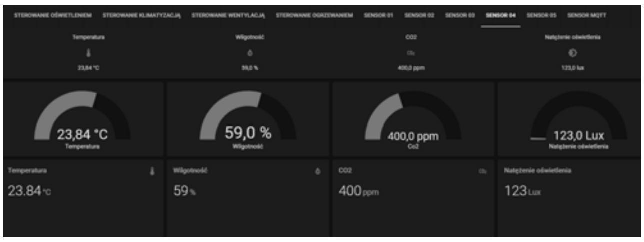

Fig.5. View of the service presenting data from the selected sensor unit

Detection and imaging of people based on the identifier

User detection with identification is closely related to the beacon system located in the presented building. Additionally, they cooperate with the access control subsystem and work time register.

An example of the distribution of proprietary beacons is presented in Figure 7.

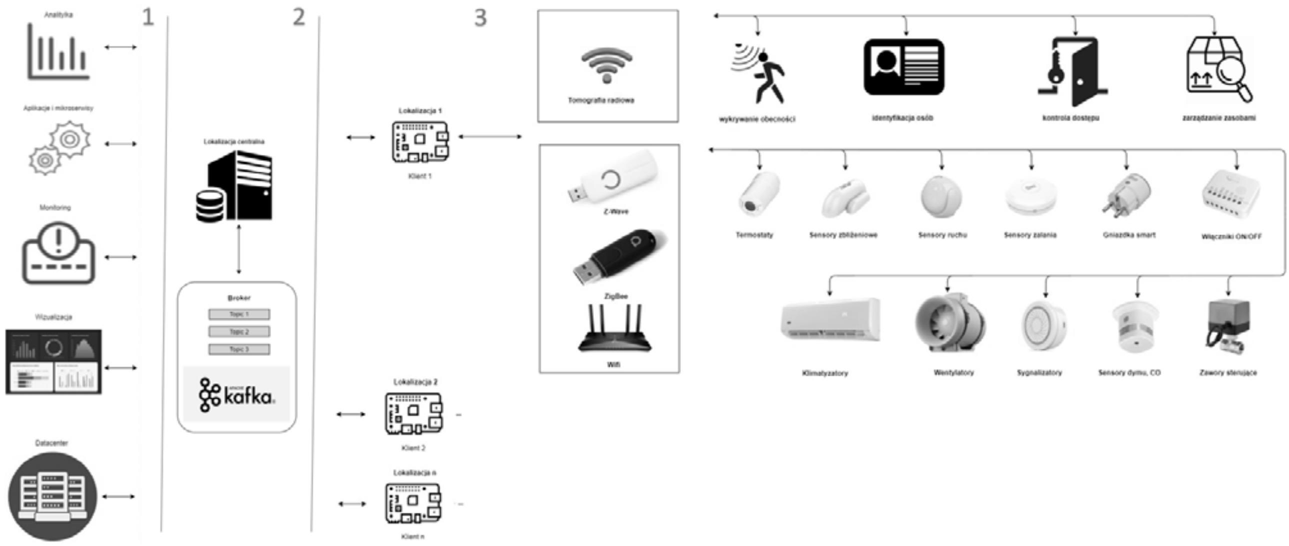

Fig.6. Symbolic cross-section of the created management system

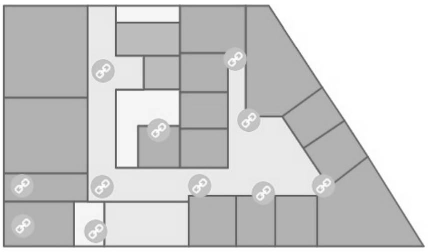

Fig.7. View of the map of the location of beacons registering the presence of users

User detection consists in registering signals from transmitters by a dedicated mobile application. On the basis of the list of employees entered into the system and after assigning a unique ID to each account, it becomes possible to register the user's presence, for example, at his workplace.

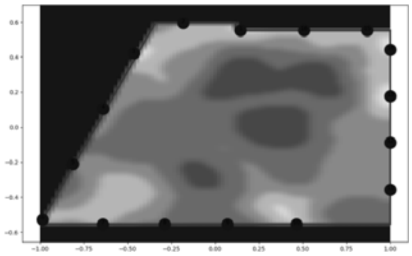

Fig.9. The heat map created by the server for the purpose of detection without the use of the user's electronic device

Fig.10. A relative scale that defines the severity of the registered disorder

Access control and time register of devices and users

The access control system is closely related to the beacon system. Based on the RSSI indicator received by the mobile application from various sources, it became possible to implement the technology that automatically opens the door without removing the identifier. Some of the beacons used are associated with specific rooms. When the signal strength threshold set for a given lock is exceeded, and when the user confirms that the access ID to a given room is sent to the user, the lock is released. The door will not be re-blocked until all authorized personnel have left the room. The door access control system is marked on the graphic panel in Figure 3 in the form of green and red indicators in place of the door.

The access control subsystem and user identification subsystem are sources of input data collected in the work register of employees and devices. Its appearance is presented in Figure 8.

Fig.9. Work time register created with the help of Grafana software

Detection and imaging of people without the device

Detection without the use of a device by means of Bluetooth 5 - supported radio tomography relies on a different use of the RSSI indicator than in the case of beacons. The room to be registered is filled around the perimeter with a specific number of radio probes (in this case, sixteen, which is the optimal number for small and medium-sized utility rooms), which exchange RSSI indicators periodically and with a relatively high frequency (40 milliseconds). The probes were made in the same technology as the beacons, but they consist of two sections, each with one nRF52832 wireless microcontroller, each with its antenna. One section is responsible for transmitting, the other for receiving packets containing RSSI information. Separating the responsibility of the application for transmission and reception allowed the reconstruction speed to be increased to a minimum value of 4 frames per second up to a maximum of 7 frames per second depending on the environmental conditions.

When the zone is not violated, the mean standard deviation of the RSSI index values is within $\mp$ 2 dBm. When the user enters, this balance is disturbed and registered. Then, the standard deviation mentioned above is multiplied. The RSSI indices obtained from the radio probes are arranged in a matrix with a size equal to the maximum number of probes participating in the reconstruction and serialized based on the order numbers of the devices. in the presented case, it is sixteen rows with sixteen indices, which gives a matrix with 256 elements, of which the diagonal remains filled with zeros. Diagonal zeroing occurs due to the lack of its value from the point of view of the image reconstruction algorithm.

Before the data reaches the server, it is collected by the local central unit, whose task is to periodically scan (every 50 milliseconds) the environment for packets compatible with the advertising type (which is the data carrier for the RSSI values collected by the probe). The advertising mode is characteristic of all technology called Bluetooth LE and is classified as one-to-many communication. After collecting all the rows of the matrix, the CU sends the data to the server over the Apache Kafka data bus.

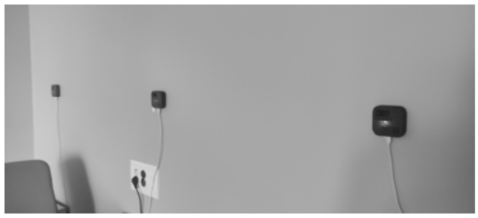

Fig.11. The appearance of the radio tomography system surrounding the tested room

Implementation of artificial intelligence mechanisms

There are many methods for solving optimisation problems and being part of a specific system [16-25]. Machine learning, carried out on the basis of data from the detection and navigation system and a network of sensors supplemented with current weather data, was carried out in accordance with three methods: linear regression, logistic regression and the support vector machine (SVC). The diagram of the created dependencies is shown in Figure 12, while the block diagram of the operation of computational intelligence is shown in Figure 13.

Machine intelligence is based on the history of the room, which is a composition of internal and external environmental parameters, as well as registered presence and intensity of traffic using a specific learning mechanism (selected for the parameter based on the nature of the regulator, expected accuracy and staggered results), controls the comfort modules in order to optimize the condition of the building.

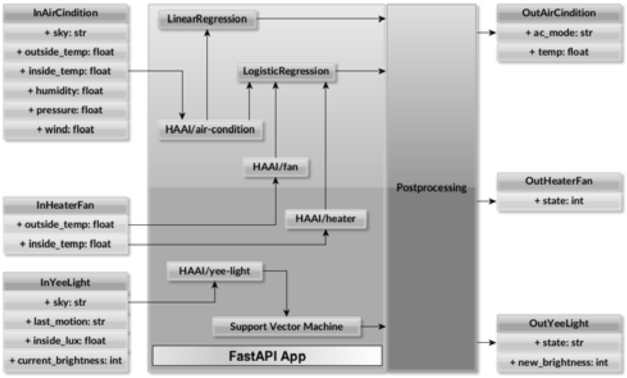

Fig.12. Diagram of dependence of individual algorithms on environmental parameters

Fig.13. Diagram of the created computational intelligence

Summary

Research on the system has shown that commercial radio technology such as Bluetooth LE in version 5 presents the potential in navigation systems inside buildings, both in terms of the cooperation of beacons with other building systems and in radio tomography due to the above-average speed of measurement data acquisition, which translates into a satisfactory refresh rate picture.

In terms of the energy efficiency achieved, calculations were made on the basis of the most demanding comfort module, i.e. air conditioning. A test scenario was carried out, during which the conference room temperature was prepared (cooling the room from 30 ℃ to 23℃) with a total area of 60 m^2 by means of manual regulation and developed by learning algorithms. In the case of manual regulation, an additional expense of 0.35 kWh was incurred for maintaining the temperature for 4 hours, which was 20.3% of the loss compared to the program chosen by the computational intelligence.

Authors:
mgr inż. Michał Styła, E-mail: michal.styla@cbrti.pl,
Centrum Badawczo Rozwojowe Technologii Informatycznych Sp. z o.o., Rzeszów, Poland
dr Przemysław Adamkiewicz, E-mail: przemyslaw.adamkiewicz@cbrti.pl,
Centrum Badawczo Rozwojowe Technologii Informatycznych Sp. z o.o., Rzeszów, Poland
University of Economics and Innovation in Lublin, Poland

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