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OPTIMISATION OF COMMERCIAL BUILDING MANAGEMENT PROCESSES USING USER BEHAVIOUR ANALYSIS SYSTEMS SUPPORTED BY COMPUTATIONAL INTELLIGENCE AND RTI

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Abstract. *The aim of the presented project was to create a comprehensive building management system equipped with a network of wireless and energy-efficient sensors that collect data about users and on their basis control final devices such as lighting, ventilation, air conditioning and heating. In the presented system, end devices can be both products offered by the market (commercial) and proprietary solutions (own). This is to allow the adaptation of commercial radio communication protocols with high integration capabilities and common occurrence. In addition, the system has been enriched with an innovative system of tracking and building navigation and access control, which are supported by a network of radio beacons and radio-tomographic imaging technology (RTI). The whole system is to be supervised by computational intelligence learned from scratch.*

Keywords: building automation, building management systems, computational intelligence, indoor radio communication, radio navigation, tomography

OPTYMALIZACJA PROCESÓW ZARZĄDZANIA BUDYNKAMI KOMERCYJNYMI Z WYKORZYSTANIEM SYSTEMÓW ANALIZY ZACHOWAŃ UŻYTKOWNIKÓW WSPOMAGANYCH INTELIGENCJĄ OBLICZENIOWĄ I RTI

Streszczenie. *Celem prezentowanego projektu było stworzenie kompleksowego systemu zarządzania budynkiem wyposażonego w sieć bezprzewodowych i energooszczędnych czujników, które zbierają dane o użytkownikach i na ich podstawie sterują urządzeniami końcowymi, takimi jak oświetlenie, wentylacja, klimatyzacja i ogrzewanie. W prezentowanym systemie urządzeniami końcowymi mogą być zarówno produkty oferowane przez rynek (komercyjne), jak i rozwiązania autorskie (własne). Ma to na celu umożliwienie adaptacji komercyjnych protokołów komunikacji radiowej o dużych możliwościach integracyjnych i powszechnym występowaniu. Dodatkowo system został wzbogacony o innowacyjny system śledzenia i nawigacji po budynkach oraz kontroli dostępu, które są wspomagane przez sieć radiolatarni oraz technologię obrazowania radiowo-tomograficznego (RTI). Nad całością systemu ma czuwać inteligencja obliczeniowa wyuczona od podstaw.*

Słowa kluczowe: automatyka budynkowa, inteligencja obliczeniowa, systemy radiowe do użytku wewnętrznego, systemy zarządzania budynkiem, nawigacja radiowa, tomografia

Introduction

The development of the field of automation in recent years has resulted in high market demands for the degree of integration of individual subsystems in commercial and residential buildings. These activities are not only aimed at in-creasing the comfort of use, but also at seeking savings and ecology. This is the reason for the increasing emphasis on the degree of integrity of individual building components. Although manufacturers of such components are trying to unify products under one established communication protocol (wired or wireless), this still does not allow for free mixing of devices and locks them into groups with a specific supplier.

The idea of the system, realised on a real building and then described in this article, is to integrate all the comfort modules of a typical office building: light, heating, ventilation and air conditioning in such a way as to simultaneously meet the requirements and then independently adjust the environmental parameters of individual rooms according to the habits of users detected and located by the building. This also involves linking the previously mentioned actuators to a network of sensors, and then collecting the results in a storage medium that can be accessed by a service and computational intelligence. Combined with security aspects such as access control or time recording for people and devices, the number of devices working on a centralized control system will increase exponentially.

1. Structure of building subsystems

The system developed consists of many subsystems of different types. To help understand the complexity of the resulting network, Figure 1 has been used.

The core of the system is the Home Assistant service and the Apache Kafka data bus located on the main server. The main server in turn is connected to the clients. The Home Assistant service is supported by a number of additional programmes and plug-ins, such as a module for data collection and archiving or a statistical module, which presents building parameters in a user-friendly graphic form [9].

Behind the client platforms, there are PAN (Personal Area Networks) designed to maintain communication with individual building subsystems. These networks consist of such wireless communication technologies as Bluetooth, Wi-Fi, ZigBee or Z-Wave. The use of all of them is obviously not obligatory and depends on the solutions selected for installation and those found in the building. All subsystems that have been used in the building can be traced in figure 1. Their presence depends on the needs and does not have to include all items, however, it should be remembered that some cannot function without the others, e.g. the use of comfort module control without the installation of sensor networks will prevent learning and effective operation of computational intelligence [5].

The computational intelligence (algorithms) are located together with the Home Assistant service on the customer's server. For the computational intelligence being created, the learning system uses three algorithms: linear regression, logistic regression and support vector machine (SVC). Based on the tests carried out (during normal working days, which are the source of data for learning), the following links were selected: linear regression with air conditioning, logistic regression with ventilation and heating, and light with SVC [8, 13, 15].

Computational intelligence algorithms are designed to retrieve the settings of individual devices belonging to the actuator group and data from devices recording environmental parameters. This concerns not only the conditions inside the building but also the weather outside. Taking such data into account is possible by means of a network plug-in downloading data from a local meteorological station.

The presented mechanism of machine learning as a whole is supposed to lead to elimination of cases of wasting electrical energy and life of operating elements by carelessness of a human factor, while maintaining operating parameters of individual parts of the building in accordance with the requirements of users. In the long run, it also has a positive effect on the rate of wear and tear and service costs of building equipment.

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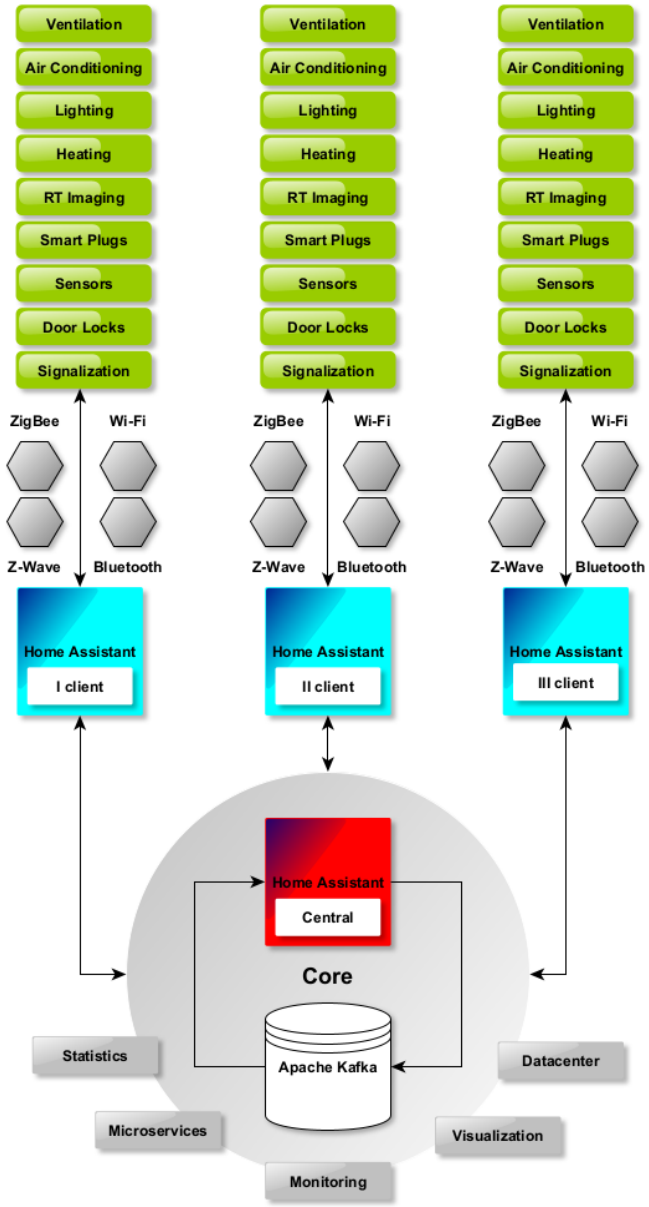

Fig. 1. General structure of created building system management

2. Comfort management systems

The comfort modules cover all the energy consumers that provide the user with the right level of light intensity, air temperature and air circulation. Each of these characteristics is reciprocated in a separate device adapted to its operation.

2.1. Comfort management – hardware

The comfort modules designed for the project fall into two categories: devices with actuator and controller in one housing, and devices with actuator and controller mounted in separate housings.

An example of an actuator and controller in one is the air conditioning controller. It is shown in figure 2 and consists of a PCB (Printed Circuit Board) equipped with a microcontroller for Bluetooth version 5 and ZigBee wireless communication, as well as necessary peripheral elements such as quartz resonators, antenna path, signal filters, communication ports and other minor RLC elements. Due to the fact that it is common to control air conditioning using an infrared beam, one of the PWM ports of the microcontroller was equipped with a high-power IR emitter. Based on the code table of the air conditioner, a sequence of instructions was created to enable automatic and manual control from the Home Assistant console. In order to make it possible to connect the widest possible range of devices to the service, the PCB was designed in such a way that emitters of different wavelengths and different powers could be used (even several at the same time). A schematic of the IrDA port-controlled actuator and controller is shown in figure 3.

The remaining hardware layer serving ventilation, heating and light was divided into two parts. First, the parts whose design is the same, i.e. the controllers, will be presented. These are PCB boards without IrDA port and equipped instead with other circuits useful for controlling a given comfort module. The appearance of the controllers separated from the actuator is shown in figure 4.

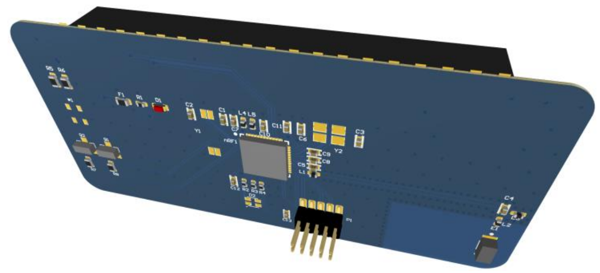

Fig. 2. Appearance of the actuator and controller of an IrDA-enabled air conditioner

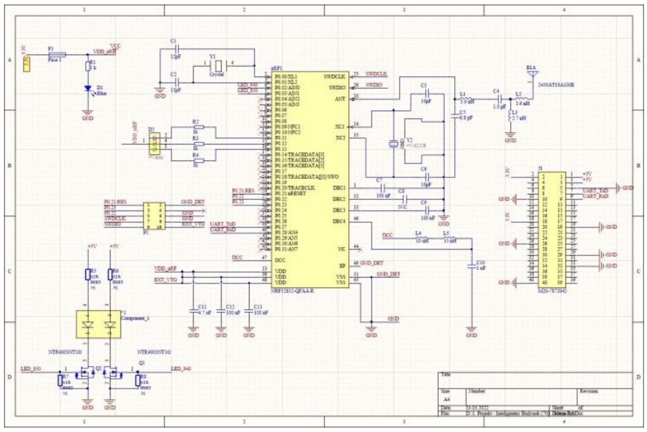

Fig. 3. Schematic diagram of an actuator and controller of an air conditioner equipped with an IrDA port

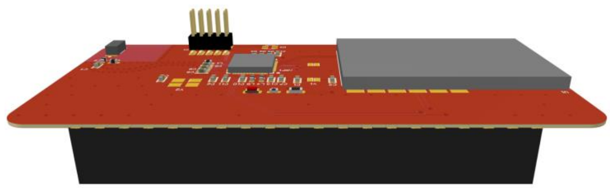

Fig. 4. Appearance of the heating controller

The common feature of this group is the appearance of a wireless communication module using the Z-Wave protocol. This treatment was intended to give the platform versatility in terms of actuator selection.

Due to the presence of two radio transmitters (Bluetooth/Zigbee and Z-Wave), the transmitting and receiving parts were moved away from each other by the maximum possible distance. Therefore, on each of the boards they are located at two opposite ends of the PCB. This is all the more important due to the fact that these protocols (including Wi-Fi) operate on the same band (ISM 2.4 GHz) only with a different band distribution. Additionally, the same type of modulation should be taken into account here (modulation with phase-shift keying and approximation with Gaussian curve) [16].

The electronics part using Wi-Fi technology is not directly on the boards shown, but on the Raspberry Pi Zero W single-board computers, which are connected to the designed PCBs via a 40-pin connector. This makes the complete controller, when placed in the enclosure, take the form shown in figure 5.

Fig. 5. The prototype of the comfort controller: the parts of the controller responsible for communication with the actuators and the single board computer managing the network communication enclosed in a single housing

The primary tasks of the Raspberry Pi Zero W single board computers are to maintain a network connection to the server service, support the Apache Kafka data bus, parse and process the data and then interpret it correctly and pass it on to the part responsible for communicating directly with the actuator. It is worth noting that the controller does not have to support just one actuator. Just bear in mind that too many slaves may cause minor delays in communication.

2.2. Comfort management – software

Programmatically, the upper layer of the controller in figure 5 represents (in the realised case) a simple operating system designed for embedded systems with radio stack support. All the code managing this hardware part was realised using C language (embedded). In addition to processing incoming and outgoing data from the controller, the BLE stack was used to cyclically transmit radio signals with a range of up to 30 metres. These signals are compatible with the Bluetooth version 5 radio transmission standard and advertising mode. This means that the devices do not force each other to connect permanently, i.e. "pairing", but work on the principle of miniature radio stations, where each message can be received by any device of interest in the system [1].

A single board computer running the Linux OS family is responsible for delivering instructions from the Home Assistant service to the WSoC (Wireless System on a Chip). It is connected to the local area network of the building and using a script that runs automatically at system start-up, it initiates the Apache Kafka producer and consumer module written in Qt Creator with the help of C++ language. Thanks to this the device has obligatory two-way communication up to the Linux system level. The connection between the computer and the wireless microcontroller is realised using a serial port. Although it provides two-way communication, it is used or not depending on building subsystem. In the case of comfort controllers, two-way communication is used.

In the case of the GUI (Graphical User Interface), the creation of a control panel that allows the user to remotely manipulate each of the settings offered by the selected actuators should be emphasised. Its appearance is presented in figure 6.

Fig. 6. View of the Home Assistant control panel for controlling the designed comfort modules

3. Environmental data acquisition system

Environmental data acquisition inside the building is provided by proprietary electronic modules equipped with sensors for temperature, humidity, light and carbon dioxide content in the air.

3.1. Environmental data acquisition – hardware

The sensors can be connected to the microcontroller using the communication interfaces it offers, such as UART, I2C or SPI. The WSoC nRF52832 microcontroller offers them in sufficient numbers to connect all the necessary sensors and to leave a reserve in case the design evolves. For analogue sensors, the platform offers A/D converters with 12-bit resolution, which are quite sufficient for the application presented. The appearance of the sensor assembly design is presented in figure 7, while the schematic diagram is presented in figure 8.

Fig. 7. Appearance of the actual environmental measuring module for indoor mounting (in the upper left corner of the drawing a 3D visualization of the PCB reverse side has been added, showing a cage for mounting a CR2032 battery with ~320 mA capacity)

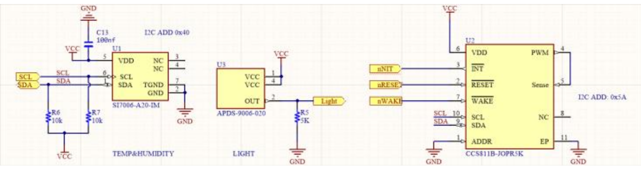

Fig. 8. Schematic diagram of the sensors and their electronic circuits used in the design of the module for testing environmental parameters

The environmental monitoring module includes temperature and relative humidity sensor SI7006-A20-IM (for use with heating and air-conditioning control modules), light intensity sensor APDS-9006-020 (for use with luminaire control modules) and carbon dioxide sensor CCS811B-JOPR5K (for use with ventilation control module), which is also capable of recording the content of organic particles in the air (VOC – Volatile Organic Compounds) expressed in ppm (particles per million) or ppb (particles per billion). Taking into account the completed set, it can be concluded that the sensor is suitable for basic tests of air quality in a building [4, 11].

The data obtained from this device is pre-formatted by it and then transmitted to the service and displayed on the control panel. Properly archived, they also provide material for machine learning algorithms.

3.2. Environmental data acquisition – software

As with the comfort modules, communication between the sensors and the system was implemented using Bluetooth 5. A 31 byte user data container was used for data transport. It is nested in a frame compatible with BLE advertising packet data transmission. Data from individual communication interfaces and analogue-to-digital converters are collected and then formatted to fit into the specified container size. The way the data is formatted is not the same for all sensors, because in the case of temperature the result is stored on two bytes, while for the light sensor four are reserved. They also differ in the way of coding or in the byte stacking weight (LSB/MSB). As an example, we can give a temperature sensor, which, despite the nature of its application (eliminating the need to work in negative temperatures) takes into account the sign of the returned value in the results. All these discrepancies had to be taken into account both in the comfort controllers and their scripts handling communication for the Home Assistant, and in the service located on the server (Node-RED).

The participation of the comfort modules in the communication is dictated by the fact that the sensors do not have their own unit providing connections to the local network, so they use neighbouring computers belonging to the light, ventilation, etc. controllers. This makes the controllers a kind of hub. This surplus of computing power means that this has been achieved without compromising the working conditions of the other components of the system. In addition, even if the sensors were equipped with a Wi-Fi module (a wired connection was rejected due to installation constraints), it would not guarantee a long operation time per single cell due to battery power.

The data collected by the comfort controller is reformatted to transmission standards using the JSON standard and sent to the service and then presented in a clear form in the operator panel. Its appearance is presented in figure 9.

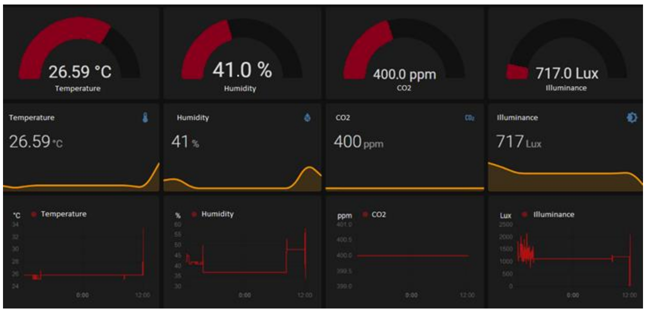

Fig. 9. View of the Home Assistant control panel for monitoring the environmental parameters of a building at a selected point

4. Indoor navigation and RTI system

The indoor navigation system is divided into two parts: classical by means of beacons and RTI (Radio Tomographic Imaging) supported. The beacon part uses location techniques based on the user's device and triangulation or related methods. It is characterised by good scalability, relatively low production costs, and low failure rates, but it should not be expected to have a high tracking accuracy (it achieves an accuracy of 1-2 metres) [6].

RTI, on the other hand, does not require any direct electronic device to track the user and is characterised by an increased level of positioning accuracy (up to several tens of centimetres). However, it is characterised by a higher degree of system complexity.

The purpose of the beacon navigation system is to guide the user from point A to point B through large, open spaces and main communication routes. After reaching a specific room and leaving the corridor, the RTI system takes the initiative, which is able to identify the presence of the user in the room, and then put his signature on the heat map.

The principle of RTI operation is based on the area of the room surrounded by networks of radio probes, which receive from other transmitters, apart from themselves, information about the received signal strength. Then, after conversion and conversion, this signal takes the form of the RSSI (Received Singal Strength Indicator). Each connection of the transmitter and receiver can be treated as a projection angle, i.e. one thread of the mesh, the examination of which (and more precisely, examination of the signal fluctuations occurring in them) gives information about the presence or movement of users. The mathematical representation of this grid is the matrix, which is divided into two categories: the background matrix (i.e. the representation of the room at rest) and the measurement matrix (i.e. the representation of the room with recorded disturbances). In order to extract disturbances from the measurement matrix, it is necessary to perform a differential analysis with the background matrix. Then, on the basis of appropriate algorithms from the matrix, the heat map is reconstructed.

4.1. Indoor navigation and RTI – hardware

The hardware layer of the beacon system is represented by the so-called beacon, i.e. a miniature, energy-saving (most often battery-powered) and cheap to produce radio signal transmitter [2]. In the system offered, a proprietary structure of this type was created, the dimensions of which do not exceed 30 mm in diameter (wheel shape) and are powered by a single CR2477 lithium cell with a capacity of 960 mAh. The appearance of the beacons is presented in figure 10.

A cell with the indicated capacity and voltage of 3 V in combination with energy saving techniques implemented in beacons (standby, put to sleep) led to a working time counted in months. The maximally simplified structure in relation to other devices makes this structure perfect for production in large quantities. After the implementation of the microcontroller from the nRF family, only the source of the clock signal and a correctly designed antenna path were necessary to start the WSoC, but to ensure the correct start-up at each start-up and stable operation, it was necessary to use additional RLC elements.

Fig. 10. The appearance of the designed beacons

The hardware layer responsible for the RTI system includes two devices: a radio probe and a central unit. The radio probe is a BLE radio transmitter enriched with a wireless communication module compatible with the IEEE 802.15.4 standard. It is used alternatively for BLE due to the increased stability of the sent signals. The central unit (CU), in turn, is a Raspberry Pi 4 or Jetson Nano single-board computer equipped with a proprietary Bluetooth expander (it was replaced with a factory network card due to instability in the presented solution), a 7-inch TFT touch screen and an omnidirectional 30 cm long antenna. The appearance of the devices is presented in figures 11 and 12.

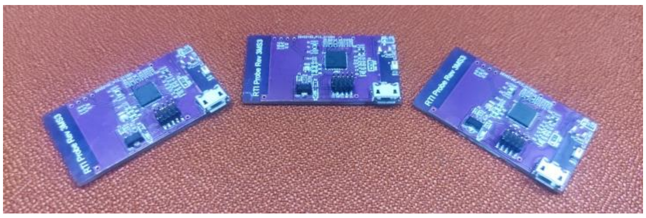

Fig. 11. Appearance of the designed radio probes

For both beacons and RTIs, a sufficient number of units are required for operation. The number of beacons depends on the floor area of the building and its arrangement plan. In RTI, an average system cell spanning one room contains sixteen radio probes. This value is sufficient to cover medium-sized office spaces. Otherwise the number can be increased or decreased (usually times / by 2). The central unit consists of one device per RTI cell, i.e. it covers one room. It is possible to cover a larger number, but the location should be considered in such a way that it receives a set of signals from each room [14].

Fig. 12. The appearance of the prototype of the central unit during operation (visible outline of the measurement matrix)

4.2. Indoor navigation and RTI – software

In terms of software, the beacons were implemented in accordance with the iBeacon standard. Using the advertising designed for this purpose, they periodically inform all interested devices about their RSSI, minor and major (these are a kind of identifiers of belonging to specific groups of devices serving a common area), Tx Power and a unique UUID identifier [2]. All data in the beacon frame are constant (as macro-definitions), therefore their cyclical update is not needed. This makes communication one-way by definition. If necessary, a subprogram for remote software update has been implemented in all transmitters so that the operator with the help of a smartphone with an application and a data package containing a complicated program can (without having to search for, get in or remove the device) introduce changes to the system without any problems [3]. A similar system has been used in the case of radio probes, but the device, unlike a beacon, often changes the content of its data packet. Often, these changes cannot even be captured with the unaided eye due to the limited refresh times of scanners, and their effects are only visible in the image reconstruction. The application (apart from handling the Bluetooth layer) has three tasks. Get information on the strength of signals from other probes, preformat the measurement results and activate subsequent devices to work. The entire code of the beacons and radio probes was implemented using the C (embedded) language [7]. The central unit software is a system from the Linux OS family. The software supporting the RTI system was realized with the help of the C ++ language in the Qt Creator environment. The generated script is run at the system start-up and can automatically start the measurement or wait for the user's command. Figure 13 shows a typical heat map realized by the built RTI system.

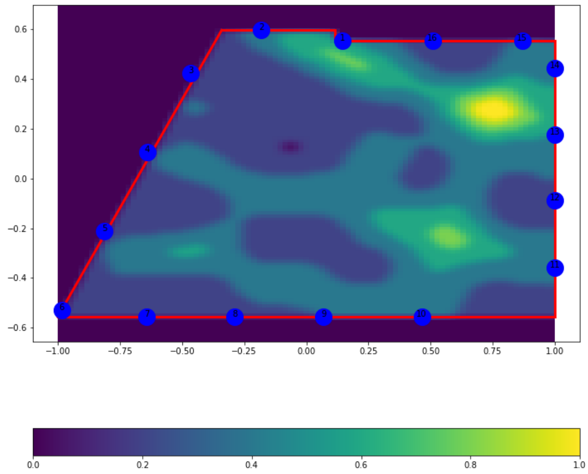

Fig. 13. Heatmap of the test room with one person inside (visible in the upper right corner of the room)

5. Access control

Access control is a derivative of navigation with beacons and differs from it mainly in the way of placing this type of transmitters and the software. In terms of hardware, there are no significant differences to be specified. At least as far as the radio signal transmitter is concerned. To the sum of devices, you need to add a wirelessly controlled door lock module and hardware compatible with it. The control is carried out using the user's telephone. The signal received from the directional antenna mounted on the door frame, after exceeding a certain threshold, sends reports to the system and releases the lock. After the user enters the room, in order to avoid the cyclical opening and closing of the door, the RTI module will not lock the lock back when detecting an animal, however, it can be done by manual change by the user. The view of the door management panel of one of the sections of the building is shown in figure 14.

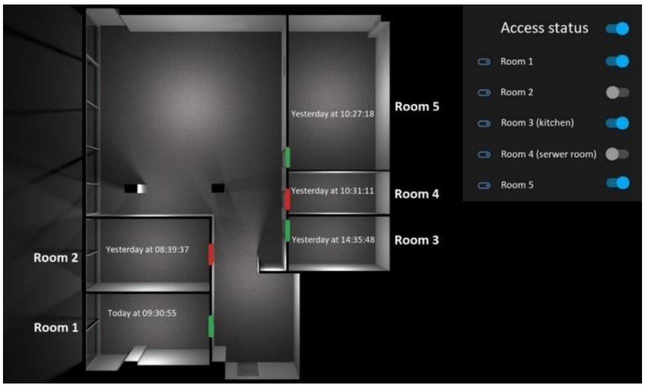

Fig. 14. View of the control panel for door access control in the Home Assistant service

6. Other subsystems

The remaining subsystem includes minor building functionalities, such as a panel with 3D visualizations of the building and active marking of users' positions, recording the working time of people and devices, and a panel for monitoring weather conditions outside the building. The method of implementation of the panels for monitoring the working time of devices and people is presented in figures 15 and 16.

In order to enable the observation of the operating time of the devices, the so-called smart plug with a built-in electricity meter and the possibility of wireless connection to the network via Wi-Fi. Thanks to them, it is also possible to estimate the expenses related to powering the building.

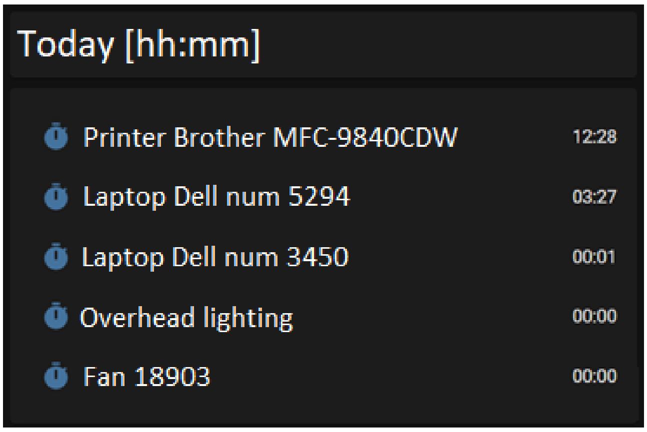

Fig. 15. Method of implementation of the panel for assembling employee working time

Fig. 16. The method of implementation of the panel for assembling the working time of devices

The method of recording the working time of employees was carried out with the help of the same application that is used for building navigation. After the system is registered on a given day, a device with a unique UUID assigned to the employee confirms his presence in the system until the time provided for in the supervision timeout has elapsed. This time can be modified in a very wide range.

The 3D visualization system is designed to present the building in a three-dimensional form, and then the coordinates obtained through the operation of beacon navigation and RTI are applied to the building map.

A plug that allows you to download data from weather services allows computational intelligence to better adjust the operating parameters inside the building. The energy input for summer / winter operation can vary considerably and must be taken into account in machine learning.

7. Computational intelligence

Most of today's devices dedicated to building automation are controlled with simple dependencies using information provided by sensors. The rules created usually refer to continuous control of a set parameter and starting or stopping a device depending on the current deviation [10].

In the project presented here, an attempt has been made not to rely solely on current data but also to archive historical data and use it in machine learning to act in a more personalised way towards users. This requires adapting the sensory infrastructure and actuators in such a way that any changes in them are registered by the system. The result is increased overall energy efficiency and a longer lifespan for individual building components without compromising working conditions [12]. The designed system integrates several original solutions with those already available on the market. In addition, the most up-to-date communications occurring in IoT (Internet of Things) can be included. The adopted structure of the system allows easy scalability and simple adaptation to different types of existing and future solutions on the market.

To achieve the assumed effect, proprietary algorithms supporting effective building management and machine learning mechanisms were used. The model is trained using previously collected data. This data relates primarily to the way individual rooms are used by the personnel assigned to them. Data acquisition and transport is carried out on the basis of mechanisms described in the previous subsections.

Building machine learning is carried out with the use of a strictly defined algorithm. Three different computational methods were used to solve the estimation problems, such as linear regression, statistical regression and the support vector machine. However, before any calculations can be made, each data must follow the path presented in figure 16. Based on the algorithm from Figure 16, the system's response to the user's presence is adjusted, and then the comfort modules are properly controlled.

In addition, figure 17 shows the control of the comfort modules taking into account selected elements of computational intelligence and their relationship to inputs and outputs.

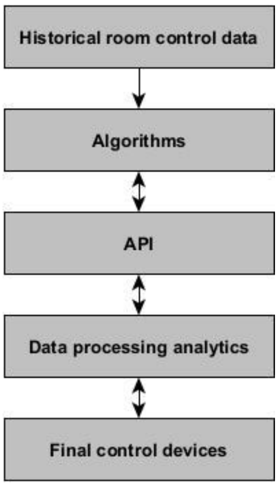

Fig. 17. Prediction and control of end devices

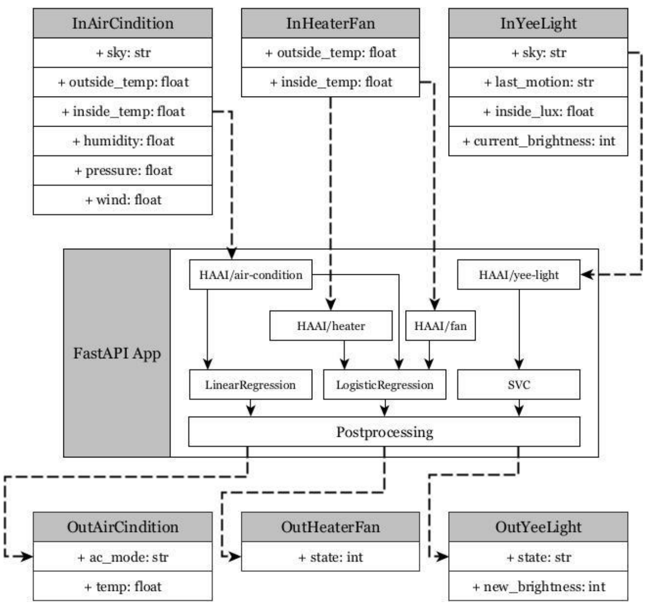

Fig. 18. Diagram of machine learning activities of the test building

As shown in figure 18 the simplest computational intelligence element used is linear regression. This makes it affordable to implement and relatively user-friendly. This mechanism is based on the assumption that a certain set of characteristics $N\ (x_1, \dots, x_N)$, is known by which a continuous value of y is predicted. Then if a proportional relationship is found between the elements of the set N and the predicted values of y then the whole relationship can be approximated by the equation [8]:

$$\tilde{y} = c_0 + c_1 x_1 + \cdots + c_N x_N \tag{1}$$

or otherwise:

$$\tilde{y} = c_0 + \sum_{i=1}^{N} c_i\, x_i \tag{2}$$

where $\tilde{y}$ is assumed to be a linear combination of the characteristics denoted by x_i and c_i are the coefficients of the assumed model. The next requirement is to find the objective function, which can be calculated for n data points. The case described leads to the calculation of the mean square error using equation:

$$L = \frac{1}{n} \sum_{i=1}^{n} (\tilde{y} - y)^2 \tag{3}$$

In this way, the defined objective function is minimised. This makes it possible to determine the optimal value for the $\boldsymbol{c_i}$ variables while maintaining their minimum fitting error.

Another element used is logistic regression. To some extent, it can be thought of as a derivative of linear regression. The main difference here was treating the variable y not as a continuous element, but as a variable with a two-point distribution. This makes this mechanism work better in cases where we are dealing with two states, or in other words, a binary response. This causes the mechanism to operate on the values in the range [0,1]. This is called the conditional probability for the value $y = 1$ given the value of x [13].

$$P(y = 1|x) = p = \frac{1}{1 + e^{-f(x)}} \tag{4}$$

where $f(x)$ should be treated as linear combination of independent variables (in other words, features). It can be expressed in the same way as the value $\tilde{y}$ in linear regression, that is:

$$f(x) = c_0 + \sum_{i=1}^{N} c_i x_i \tag{5}$$

It should be added that in such a case the occurrence of the opposite event will be complementary and expressed by the equation:

$$P(y = 0|x) = 1 - p \tag{6}$$

Determination of the objective function that will enable the determination of c_i coefficients is possible after defining the model. The c_i coefficients should be treated as parameters of the chosen model. Thus, in the case of a two-point distribution, the square of the error should not be used this time, but the likelihood function given by the formula:

$$L(C|y;x) = \prod_i p(x_i)^{y_i} \left(1 - p(x_i)\right)^{(1 - y_i)} \tag{7}$$

Ultimately, the objective function is the logarithm of formula 7, which is then maximized to find optimal parameter sets. Simple gradients are used for this process.

The last of the three elements is SVC that is support vector classifier. It is especially useful when working with data broken down into binary classes. Belongs to support vector machines (SVM). Compared to the two previous methods, it can be used to make accurate indications even when the classes do not show a tendency in proportion to the changes in features (in other words, when there is a non-linearity) [15].

The method aims to find a hypersurface that does not belong to either of the two binary classes, separates them from each other, and at the same time is as far away from both of them as possible. Moving on, any of the outputs marked with X can be represented as a point in a multidimensional space. Each of these points can be described as follows:

$$Y = \{0,1\} \tag{8}$$

In the process, the SVC mechanism tries to find an area in space that separates the two sets. Typically, hyperplanes are used to split data apart.

If, however, the separation process becomes ineffective, then the SVC can extend the model with additional dimensions until the effect is achieved, i.e. until the place where the classification is more optimal is found. In some cases, it is possible to use nonlinear nuclei incapable of generating hyperplanes but surfaces with a greater degree of shape complexity.

The selection of optimal parameters for the SVC method can be performed by minimizing the expression:

$$\left[\frac{1}{n}\sum_{i=1}^{n} max\left(0,1-y_i(W^T x_i - b)\right)\right] + \lambda||W||^2 \qquad (9)$$

where the number of points in the data set should be taken as n, and the matrix of coefficients in W. The λ parameter should be treated as a regularization factor, the lack of which will make it impossible to determine the objective function. In this case, an initial regularization parameter of 0.0001 was used. It should only be added that the base radial function was used as the nucleus. Finally, the presented transformations lead to the receipt of a model that needs to be checked in terms of the accuracy of its predictions. If so, you can start its implementation in the developed solutions.

8. Research and summary

During the research, a huge amount of data related to the functioning of the building was recorded, such as environmental parameters, both internal and external (weather station), through user location data, record of employees and equipment working time, non-contact access control (ten-meter standard of Bluetooth range), detection of equipment idleness and neglect resulting from not exclusive of receivers.

In the case of the comfort modules and their actuators, manipulating the parameters in the service panel revealed a delay response of less than 1 second. What is taken into account here is the full path that the signal takes from the server through the network to the controller module and then through the PAN to the actuator. The only exception here was the actuator for the heating system, which was a DC motor for the valve control head. Its response time varied within 5 seconds. Given that the heating system has the highest inertia this delay was imperceptible in practice. The sensor network acquiring environmental data was similarly efficient.

Research conducted on combined detection and prediction systems has eliminated instances of wasted resources due to staff negligence. Together with other aspects of work optimization resulting from the use of machine learning, energy savings of 20% were achieved. Confirmation was provided by a series of test scenarios consisting of two parts. The first involved user behavior recorded during learning, the second was a decision automatically made by the system when a request was made. As an example, the cooling in a conference room was started as soon as work began when the room was scheduled to be used after 12:00 p.m. Allowing the computational intelligence to automatically select the start time and air conditioner settings saved approximately 350 Wh of energy. The management mechanism has done this on the basis of data on the structure of the building, the weather forecast and the technical parameters of the equipment it controls. In another case, the service carried out an automatic shutdown of the air conditioner due to the absence of detected identifiers (radio beacons) and human signatures (RTI) in the room left behind. The cooperation between the radio beacon system and the RTI has proved to be important, as in the absence of one of them the certainty of the choice is reduced. During the observation, for example, cases were registered in which the room remained empty for a long time, but had an identification signal from the telephone locked in it. The absence of an employee in such a case can only be confirmed by the absence of a signature on the heat map. Based on the observations of users in the room, the optimum height of the radio probe belt of 120 cm was worked out (analysis of heat maps and the reaction of the system to the introduced disturbances). This was due to the fact that there is the greatest amount of matter at this height. For an average height European, this is the range of the abdomen and waist.

Future plans include increasing the level of integration of individual building elements (adding new actuators) and extending the areas covered by the RTI system, i.e. expansion from 16 to 32 and more radio transmitters to cover not only offices but also warehouses.

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