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PROGRESSIVE IOT PLATFORM BASED ON EDGE COMPUTING TECHNOLOGY

The article introduces a cutting-edge IoT platform that capitalizes on edge computing technology, revolutionizing data processing and analysis in the Internet of Things (IoT) landscape. By relocating data collection, processing, and analysis functions to the local level of the IoT network, the platform effectively mitigates delays and reduces excessive data transmission costs associated with the global network. The core architectural concept revolves around an autonomous multifunctional processing center, responsible for executing crucial tasks, including data collection, real-time processing, and comprehensive analysis from IoT devices. Additionally, it facilitates system visualization, monitoring based on diverse indicators, and offers a wide array of user services. The platform's functional model caters to various domains, fostering innovation and efficiency. A prototype IoT platform has been developed to conduct experimental analysis, assessing the hardware and technical capabilities of the proposed tools, thus paving the way for further advancements and refinements. The architecture comprises three primary components: IoT devices, the edge processing center, and a user-friendly interface. IoT devices equipped with sensors collect data, transmitted to the edge processing center for real-time analysis, considerably reducing global network data transmission requirements. As a result, the platform significantly enhances cost-effectiveness and responsiveness. In conclusion, this article showcases a transformative IoT platform, empowered by edge computing, streamlining data processing, and analysis. The multifunctional processing center serves as the linchpin, surmounting data-related challenges in the IoT ecosystem. The prototype serves as a valuable testing ground, providing insights for future improvements. Embracing this state-of-the-art platform, businesses and industries can unlock IoT's full potential, ushering in a new era of efficiency and innovation.

Keywords: IoT ecosystem, IoT platform, Internet of Things, edge computing, Flask, fog computing, cloud computing.

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ПРОГРЕСИВНА IOT-ПЛАТФОРМА НА ОСНОВІ ТЕХНОЛОГІЇ ПЕРИФЕРІЙНИХ ОБЧИСЛЕНЬ

У статті представлено передову платформу IoT, яка використовує технологію периферійних обчислень, революціонізуючи обробку та аналіз даних у середовищі Інтернету речей (IoT). Завдяки перенесенню функцій збору, обробки та аналізу даних на локальний рівень мережі IoT, платформа ефективно зменшує затримки і знижує надмірні витрати на передачу даних, пов'язані з глобальною мережею. Основна архітектурна концепція базується на автономному багатофункціональному обчислювальному центрі, який відповідає за виконання найважливіших завдань, включаючи збір, обробку та всебічний аналіз даних, отриманих від пристроїв Інтернету речей. Крім того, вона полегшує візуалізацію системи, моніторинг на основі різноманітних показників і пропонує широкий спектр користувацьких сервісів. Функціональна модель платформи охоплює різні сфери, сприяючи інноваціям та ефективності. Прототип платформи Інтернету речей був розроблений для проведення експериментального аналізу, оцінки апаратних і технічних можливостей запропонованих інструментів, що відкриває шлях для подальшого розвитку і вдосконалення. Архітектура складається з трьох основних компонентів: Пристрої Інтернету речей, периферійний обчислювальний центр і зручний інтерфейс. Пристрої Інтернету речей, оснащені датчиками, збирають дані, які передаються до периферійного обчислювального центру для аналізу в режимі реального часу, що значно зменшує вимоги до передачі даних через глобальну мережу. В результаті, платформа значно підвищує економічну ефективність і швидкість реагування. На закінчення, ця стаття демонструє трансформаційну платформу Інтернету речей, яка розширює можливості периферійних обчислень, оптимізуючи обробку та аналіз даних. Багатофункціональний обчислювальний центр служить стрижнем, долаючи проблеми, пов'язані з даними в екосистемі IoT. Прототип слугує цінним випробувальним майданчиком, що дає змогу отримати інформацію для майбутніх удосконалень. Використовуючи цю найсучаснішу платформу, підприємства та галузі можуть розкрити весь потенціал Інтернету речей, відкриваючи нову еру ефективності та інновацій.

Ключові слова: екосистема IoT, платформа IoT, Інтернет речей, периферійні обчислення, Flask, туманні обчислення, хмарні обчислення.

INTRODUCTION

The IoT paradigm is conceptually linked to remote servers, services, and clouds, which leads to a well-known problem of transporting large volumes of data, delays in their transmission and processing, scalability of remote resources, and an uncertain level of data transmission security over the global computer network. General-purpose cloud processing and analytics services pose the problem of inefficiency and rigid monolithic binding of IoT platforms to universal solutions. To address complex transportation issues, the concept of decentralizing IoT computing is considered. Fog computing aims to create decentralized IoT architectures based on the integration of cloud and fog services. However, experience has shown that the fog of things does not solve all the existing problems in IoT systems. While reducing delays and relieving network congestion, fog computing does not take into account the specific nature of IoT systems, related to their monolithic nature and hardware and functional specificity in terms of the tasks being solved, implementation principles, and application areas. The concept of edge computing aims to bring analytics and decision-making tools as close as possible to the data source and localize hardware and software specialized solutions at the IoT's peripheral level. The greatest effect is achieved through the integration of cloud and edge technologies.

Research into the effectiveness of edge computing and the developments of scientists in this field characterize the current stage of IoT concept development. This work is dedicated to exploring the issues of IoT edge computing and the development of an IoT platform that provides services at the IoT edge.

Review of Existing Solutions for Enhancing IoT Technology Efficiency:

Existing solutions for enhancing the efficiency of IoT technologies have been developed to address various constraints associated with the IoT paradigm, such as performance, delays, security, confidentiality, and reliability. The integration of IoT with cloud computing is known as Cloud of Things (CoT) technology. In [1], the positive aspects of applying cloud computing to IoT are summarized, including remote computational power, reduced dependence on local IoT infrastructure, centralized data security and confidentiality, efficient authentication and encryption protocols, no entry barrier for hosting providers, and support for powerful API interfaces. These features are beneficial for companies implementing IoT systems as they provide control and the ability to offer subscriber support to users.

However, traditional cloud technologies are characterized by a centralized architecture, which introduces technical and economic challenges for the effective implementation of IoT. These challenges include delays, limited data transmission channels, intermittent network failures, increased security risks, and the need to consider the limited resources and specifications of IoT devices. Factors such as high waiting time, delays, remote servers, distance between clients and servers, uncertain security levels, lack of notifications, distributed server processing, and partial technical maintenance associated with cloud computing are assessed as having a negative impact on the efficiency of IoT paradigm implementation in [2, 3]. In [3], a widespread five-level architecture for IoT is described, where all data is collected and analyzed in the cloud. It can be summarized that large-scale IoT systems with numerous sensors and significant data volume are characterized by excessive network traffic and a decrease in the level of service. Communication convergence leads to management delays in the system, which is critical for time-sensitive IoT applications. For example, a centralized cloud architecture [3] is not efficient for medical applications or for vehicle control and collision avoidance. The authors of [2-4] also note the high standardization of cloud solutions, which creates challenges for the application of IoT devices with heterogeneous platforms and specific approaches to analytics and decision-making.

Overall, these existing solutions highlight the need for alternative approaches to enhance the efficiency of IoT technologies and overcome the limitations associated with traditional cloud-based architecture

In the literature, decentralized IoT architectures based on fog and edge computing technologies are described as advanced concepts for organizing IoT systems [4-6]. The term "fog computing" was introduced by Cisco and described in the work [7]. Similar to the cloud, this technology provides services to IoT users as Fog as a Service (FaaS). These services are provided at the level of fog devices located at the edge of the cloud, where data from sensors are sent to fog devices for processing and storage instead of being sent to the cloud. This reduces network traffic and latency, and provides better solutions for latency-sensitive IoT applications.

In studies [2, 3], fog computing factors are evaluated in comparison to cloud computing, and they are found to have low waiting time, very low latency, local server placement with minimal distance between the client and server, defined security level, distributed topology, processing on distributed servers, technical maintenance, and real-time interaction. Fog computing, as defined in literary sources [6, 8], extends the cloud to its periphery. Thus, fog computing is located at the boundary of the cloud closer to the source of IoT data. Fog computing offers many advantages for IoT, but there are limitations associated with the fact that fog is essentially a cloud with limited resources, and offloading cloud tasks to fog computing inherits the disadvantages of cloud technologies.

To improve application performance, reduce costs, and lower energy consumption, the transition to decentralized systemic IoT architectures that fulfill data processing requirements at the edge of the IoT network has become relevant in recent times. This concept is known as Edge IoT Computing (EC) [8, 9]. In the work [10], a characteristic example of implementing edge computing in IoT is described – a smart programmable automatic controller. The software collects data, analyzes it, processes it, and immediately sends a response to the user-sender device. The controller determines which data needs to be sent to the cloud and which can be analyzed locally.

In the work [8], the application of edge computing is defined as an advanced approach to enhancing IoT efficiency. The main factors of edge computing are defined here in comparison to cloud and fog technologies. Edge computing exhibits low waiting time and almost negligible latency, local server placement and proximity between the client and server, a defined and controlled level of security, reorganized and scalable topology, real-time interaction capabilities, low implementation cost, solution specialization, and the need for specific software and hardware development.

Edge computing is efficient in addressing performance and scalability issues in intelligent systems and local applications that are latency-sensitive. It achieves this by offloading data collection, processing, and analysis functions to the local level, avoiding delays and reducing traffic transmission costs in the global network. Increasing the resilience and robustness of intelligent systems is possible by distributing computational functions across the network and eliminating single points of failure. It is relevant to utilize less complex and expensive IoT devices, with the processor and memory capacity shifted to edge gateways and servers. Edge computing enables the decentralized processing of data from IoT devices, sensors, and applications at the local level before they are transmitted to the corporate data processing center or the cloud. Services in edge technologies are implemented at the periphery of the IoT network, even closer to the data sources being processed compared to fog computing. A characteristic example of an IoT architecture with edge computing system (IoT-EC) is described in the work [11], where data collection, filtering, and feedback control functions are implemented on peripheral servers of base stations.

However, IoT-EC is not without certain challenges [8], which necessitate further research and development in the field of edge computing. This article is dedicated to addressing these issues and exploring the relevance and feasibility of edge computing.

Task statement

An IoT platform is a component of the IoT ecosystem that provides IoT services and connects IoT devices with the information stored on servers. The main functions of an IoT platform include data storage, IoT device communication, data detailing, data analytics, decision-making mechanisms, data visualization, security provision, and protocol translation.

The article focuses on the processes of data transportation, processing, and analysis in an IoT system. The research examines the means and approaches to addressing hardware and transportation problems related to the efficiency of tasks and reducing cloud traffic in the IoT system using edge computing technology.

The goal of the article is to develop tools for transferring data collection, processing, and analysis functions to the local level of the IoT network to address issues of delays and traffic transmission costs. The complex of these tools for implementing services at the edge of the local network represents an advanced IoT platform based on edge computing technologies. To achieve this goal, we propose an architectural concept of an IoT platform based on an autonomous and multifunctional processing center at the local level of the IoT network. The processing center's tasks include data collection from IoT devices, data processing, data structuring, analysis and visualization of results, and system monitoring based on various indicators. The article presents a prototype of an IoT platform based on the proposed solutions.

The architectural concept of implementing an IoT platform

The development of SoC technology leads to increased performance of processors and microprocessor devices, allowing them to handle complex tasks with high computational complexity. This further stimulates decentralized computing at the edge of IoT networks. Microcontrollers, microcomputers, and even smartphones can now compete in performance with cloud servers, as their functional capabilities enable a wide range of complex tasks to be performed.

From this perspective, we consider a high-performance multifunctional processing center that can be used for building scalable EC-IoT systems. Therefore, as the hardware platform, we choose a high-performance processor [8] optimized for the use of general-purpose operating systems, particularly Linux. Market research on processors and their characteristics justified the choice of the Raspberry Pi platform for implementing the processing center. The Raspberry Pi platform offers a wide range of diverse interfaces for connecting peripheral devices, has capabilities for connecting external memory modules and other additional modules, supports Wi-Fi and Bluetooth connectivity, and includes a built-in graphics module [12].

The processing center has a branching architecture (fig. 1). The basic modules include a memory module with expandability, a communication module for network connectivity, and a graphics module for system monitoring and visualization. An important functional component of the software is the web server, which is responsible for implementing all specialized platform services.

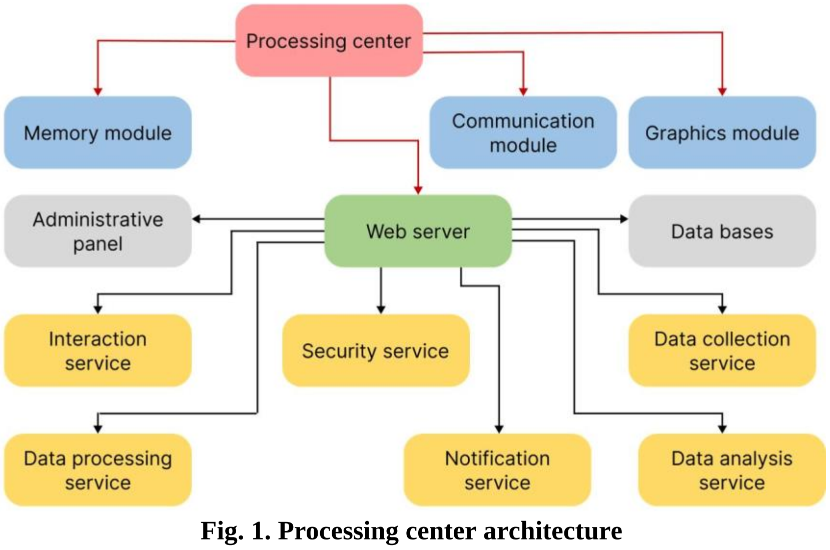

Fig. 1. Processing center architecture

To implement the web server and develop the software, the Flask framework [13] and the Python programming language [14] were used. Python is supported by all advanced technologies and tools, including the Raspberry PI platform. The Flask framework provides communication capabilities with a wide range of modern databases and technologies, making it simple and flexible for creating developing systems.

On the IoT platform, several databases have been implemented. The main database is implemented using the SQL-like DBMS PostgresQL and is intended for storing IoT data from sensors and the results of their processing. PostgresQL allows us to ensure optimized data storage and accelerated query processing through parallel read-write operations. We also utilized the advanced interaction capabilities of PostgresQL within the Flask framework [13].

A message queue database is implemented to support message exchange within the application. It is designed to store messages in the system, especially for cases when there is no internet connection. To implement this mechanism, we used the RabbitMQ service in the Python programming language [14], which is based on the MQTT protocol [15] and provides convenient interaction with the web server [16].

The functional concept of an IoT platform

According to the proposed architectural approach, the IoT platform consists of a complex of IoT devices and a processing center that belong to the same local IoT network domain. The functional model represents a complex software application that implements all functional processes within the IoT platform. The main components of the functional model are also depicted in fig. 1. The functional model of the IoT platform is shown in fig. 2. The processing center controls all components of the IoT platform, performs data transmission and processing, and makes decisions. Sensors are devices that collect and transmit data, actuators are devices that implement control actions from the processing center, and smart devices are devices that perform the functions of both sensors and actuators. All artifacts at the data collection level are collectively referred to as IoT devices.

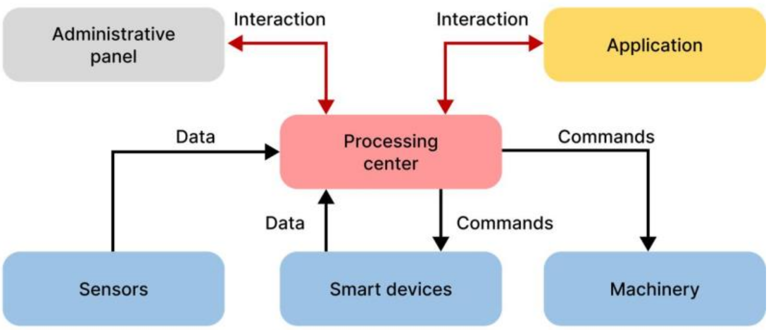

Fig. 2. Functional Diagram of the IoT Platform

The processing center implements the following complex of IoT platform services.

The Data Processing Service enables communication with IoT devices, administrative panels, and applications. It provides fast interaction with the IoT platform, such as viewing messages and analytical data, as well as diagrams, tables, and graphs. The administrative panel utilizes the service's capabilities but also implements additional features, including user notifications, customization, and personalization of the processing center's operations.

The Security Service ensures data security by storing information about devices and their communication methods on the web server. The following security options are implemented: each device is assigned a unique identifier used for all requests, only directed unicast transmission is used within the local network, and during the initialization process, Raspberry Pi configures its own access point. Device connections occur during a special controlled connection mode through the administrative panel. During this process, the security service scans the network and suggests to the processing center which devices need to be interacted with, followed by sending welcome messages to the devices.

The Information Collection Service verifies the network during the establishment of a connection. It allocates a window or socket for each device, with the socket server responsible for the connections, utilizing a special Python library for implementation. Upon receiving a device connection message, the information collection service stores it in a special message table and sends an acknowledgment to the processing center. The stored information includes the connection time, device identification number, and additional data.

The Information Analysis Service processes the latest unprocessed messages from the message table based on the data analysis schemas and device types configured in the administrative panel. The processed data is stored in administrative panel tables. Status data, such as current status, charge level, and additional parameters, are recorded in the device table. An example of the message table is shown in fig. 3, while additional data is stored in the log table for each device (fig. 4). The processing center utilizes the information stored in these tables for further analysis and decision-making.

Event type	Event value	Event timestamp ▲	Processing time (sec)	Count	Error...	Created on
DeviceStateUpdated	{'_eventType': 'DeviceStateUpdated', '_id': 'bc33acfffe636e59', '_userId': 'NoN', '_correlationId': 'ce005b36-72c9-430c-9777-c50bbbdf7972', 'hubId': 'omo-sl-prod-ua-dnipro-festyvalnyi-20', 'deviceType': 'Intercom_timed', 'reported': {'dead': False, 'signalLevel': 3, 'isLeft': False}, 'providerId': None, '_version': 16, '_timestamp': 1653943997555}	05/30/2022 23:53:17	0.01	1		05/30/2022 23:53:17
DeviceStateUpdated	{'_eventType': 'DeviceStateUpdated', '_id': 'bc33acfffe5dd6e6', '_userId': 'NoN', '_correlationId': 'db6657ae-7f62-417d-aebd-5db6ece9525a', 'hubId': 'omo-sl-prod-ua-kharkiv-zalivnaya-8a', 'deviceType': 'NfcTransmitter', 'reported': {'dead': False, 'signalLevel': 2, 'isLeft': False}, 'providerId': 'bc1763c5-47d4-4256-997a-9aa4c2e07b7c', '_version': 16, '_timestamp': 1653943988708}	05/30/2022 23:53:08	0.01	1		05/30/2022 23:53:08

Fig. 3. Table of messages in the administrative panel

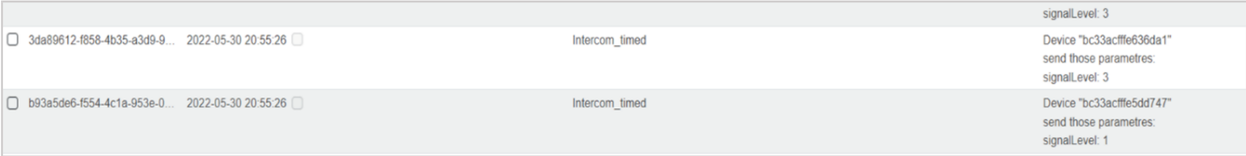

Fig. 4. Table of "logs" of the administrative panel

The Interaction Service involves establishing a connection with a device based on the stored data in the device table. The service utilizes the device type and predefined message templates, which can be customized in the administrative panel, to send commands to the devices. The IoT platform services create records of commands in special command tables. The Interaction Service reads a record from the command table, forms the command, establishes a connection with the device, and sends the command in JSON format. An example of a device table entry is shown in fig. 5, and each device has the ability to check its availability using the "Ping" function.

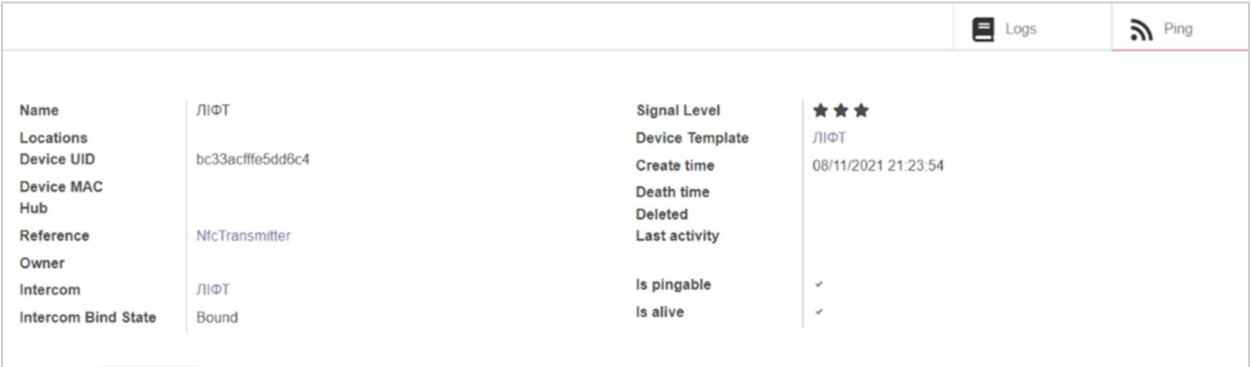

Fig. 5. An example of an entry from the device table

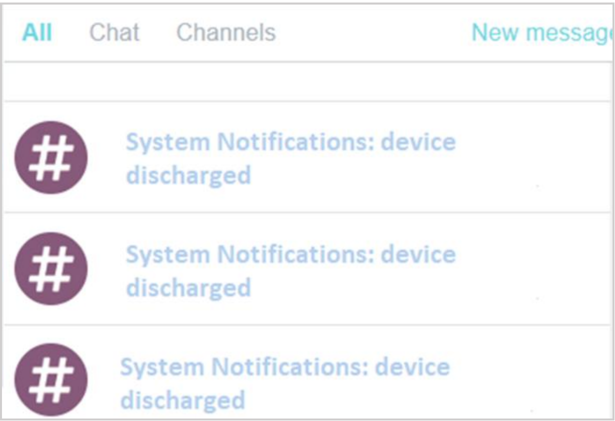

Fig. 6. Messages in the admin panel

The Notification Service operates when there is a need to send information to the user. The service sends a new message to the RabbitMQ service and also sends a message to the user in the administrative panel. An example of the administrative panel for the user is shown in fig. 6.

The admin panel is part of the web server. It allows for the configuration of the operation process of all services in the system. Additionally, the administrative panel visualizes analytical data, which can lead to certain conclusions. An example of data visualization regarding system malfunctions is shown in fig. 7. All current device information is stored in the device table. If necessary, it is possible to open and view the event history related to the operation of a specific device.

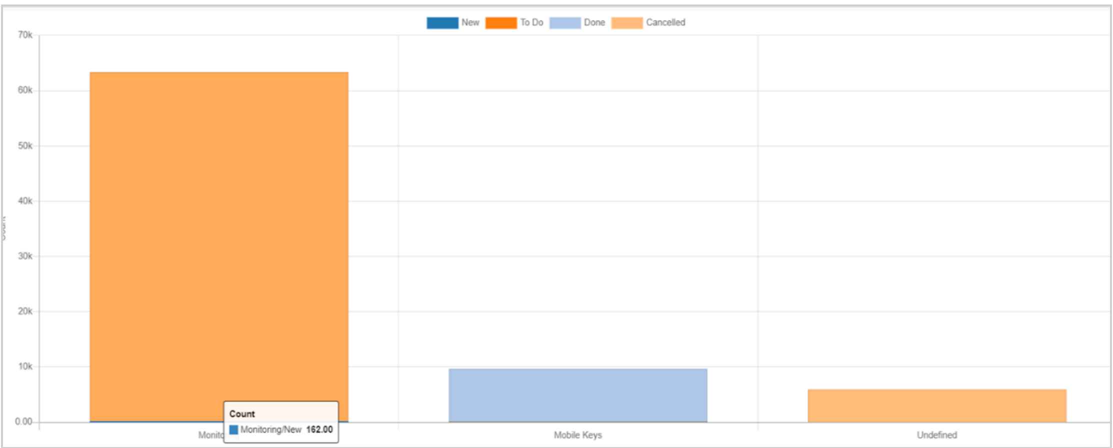

Fig. 7. Analytical data on system malfunctions

A user with administrator rights in the administrative panel can configure user permissions (fig. 8) and add new users to the system.

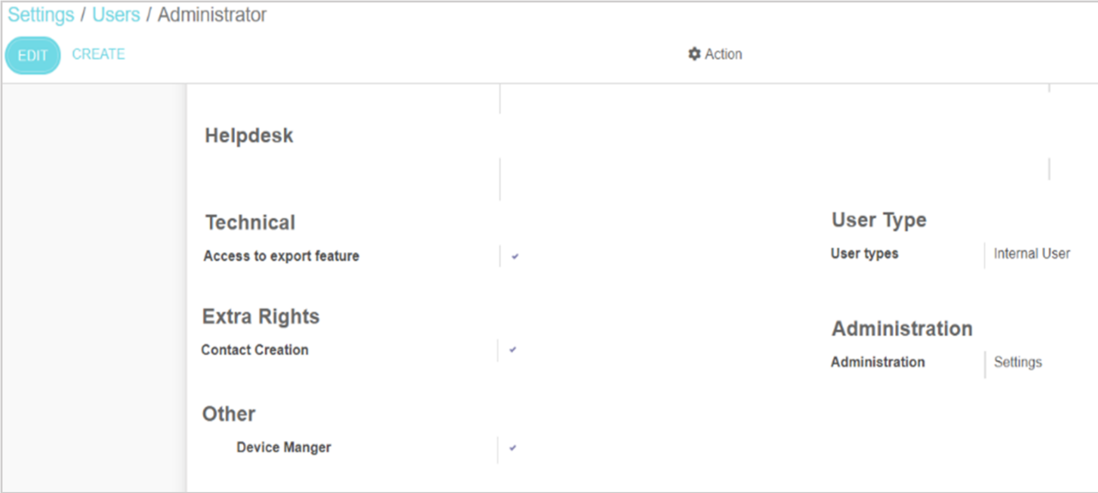

Fig. 8. User settings in the admin panel

Developers and users of the IoT platform can extend the functionalities of the administrative panel using the modular application system (fig. 9.)

The modular application system allows for the expansion of the admin panel's features and the addition of other functions beyond just managing the IoT platform. The admin panel serves as a powerful and convenient tool for managing the IoT platform in conjunction with the processing center. The modular application system ensures the multifunctionality of the IoT platform.

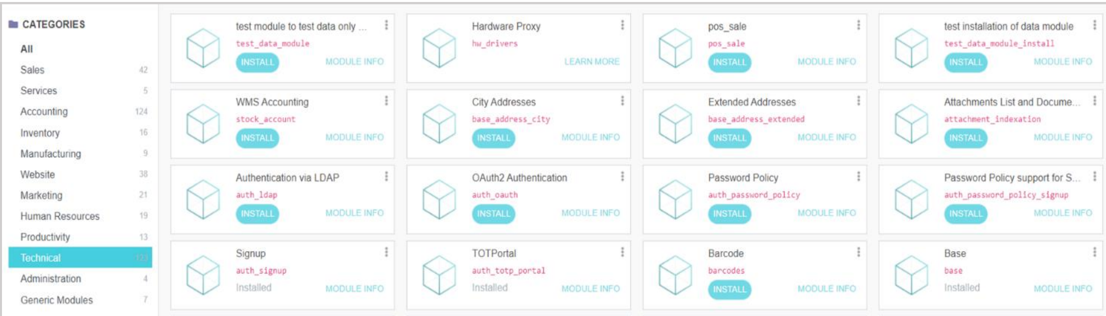

Fig. 9. Modular system of machining center applications

Review and Discussion of Results

The data processing center has extensive capabilities for collecting data from IoT devices. This can involve scenarios such as continuous streaming and processing of data, storing all data, or only data that differs based on certain criteria. It can also include polling IoT devices at specific time intervals or listening to the network for incoming data from devices.

The ability to expand the functions of the data processing center allows for the implementation of complex analytical processes and the integration of neural networks. By utilizing neural networks, the IoT platform can provide recommendations for adjusting control inputs and improving the platform itself based on monitoring results. The IoT platform is capable of sending notifications to users through a dedicated mobile application, generating diagrams, tables, and charts for the visual representation of information, and sending emergency alerts.

Here are a few relevant application areas. The IoT platform can be deployed in enterprises for equipment monitoring and management. By integrating into the enterprise's local network, the data processing center can be used to monitor sensor performance, devices, loads, generate control inputs, and notify about hazardous situations. The data processing center can also be configured as a logistics center for managing targeted equipment.

The use of the IoT platform in stores and shopping centers enables efficient management. By utilizing a neural network and sensor complex, it becomes possible to detect expired products, empty shelves, and analyze product demand. Hospitals and public institutions equipped with the IoT platform can significantly improve the living conditions of individuals.

As an enhancement to smart homes, the IoT platform can analyze temperature, air quality, residents' activities, provide recommendations for improving living conditions, and generate control inputs to create a comfortable environment. It can respond to stimuli such as flooding or critical substance levels in the air, acting as a protective system, notifying the homeowner, or making decisions according to protocols and informing relevant services.

Conclusions

The article proposes and investigates means of improving IoT platforms based on edge computing technology, which enables the transfer of data collection, processing, and analysis functions to the local level of the IoT network. This approach addresses issues of latency and excessive data transmission costs over the global network.

The implementation of a prototype IoT platform based on the proposed solutions demonstrates that enhancement through edge computing technology allows for autonomy, flexibility, personalization, and multifunctionality of the IoT platform. The proposed tools are versatile and multifunctional, making them applicable in various industries and sectors.

Based on the analysis of existing technical solutions, it was found that the main cause of delays and transportation issues in IoT technology is the cloud-centric architecture of IoT. Companies implementing IoT systems are interested in using the cloud to control and provide subscriber support to users. The proposed IoT platform provides specific services to ensure the system's functioning and necessary user services, similar to cloud services, with the ability to customize, expand, and adapt to the specific needs of IoT applications in the local domain. Decentralization from the cloud also eliminates data processing delays and reduces the load on the global network.

The functional concept implemented in software focuses on offloading tasks from cloud and fog systems to the IoT platform at the edge of the local IoT network. The security of the developed concept follows advanced ideas and technologies for securing the local network domain, thereby isolating all data within the local domain.

To address hardware requirements, the Raspberry Pi microcomputer was used, providing a cost-effective and versatile solution that allows for the connection of inexpensive and diverse sensors and devices, reducing the cost and increasing the accessibility of the IoT platform.

The adoption of the proposed architectural and functional concept of the IoT platform enables system configuration and personalization according to individual needs, resulting in significant operational flexibility of the network. As a result, the system not only becomes user-friendly but also significantly improves the quality of life. The underlying concept of analysis and suggestions allows for environmental quality monitoring, utilization of the system as a research station, and even the application of advanced neural technologies to obtain prepared analytical data with suggestions for improving environmental parameters.

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