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Smart control system for optimal energy use in the oil and gas sector

Abstract: This paper delves into the development of a smart control system for air conditioning and heating within the oil, gas, and energy sectors. It explores techniques for creating an automated sensor monitoring framework and adjusting sensor settings for temperature and air conditioning management. The proposed intelligent HVAC (Heating, Ventilation, and Air Conditioning) system acquires live data from temperature and leak sensors, along with air conditioning units and switches. The paper introduces the system's structure, its operational principles, schematic representations of the control module, and the monitoring and management setup. The core component of the real-time monitoring and management system is realized through the utilization of the SCADA software for the control and supervision of sensor parameters.

Keywords: Industrial Internet of Things, intelligent Control System, sensor network, real-time monitoring system, energy efficiency.

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Introduction

Thermal comfort, productivity, energy consumption, and overall well-being are significantly influenced by the thermal conditions within buildings, industrial facilities, and various other environments. The primary method of regulating indoor temperatures is through the Heating, Ventilation, and Air Conditioning (HVAC) system. Nevertheless, there is a prevalent issue of localized discomfort within these spaces. To meet the demand for intelligent, on-demand control of indoor thermal conditions, there is a pressing need for innovative strategies to enhance HVAC systems. These intelligent HVAC systems find utility not only in buildings and rooms but also in the Industrial Internet of Things (IIoT), particularly in the oil and gas industry.

Presently, the oil and gas sectors rely on conventional HVAC methods, making intelligent systems an opportunity to provide comfortable working conditions for laborers and equipment, irrespective of extreme climate conditions prevalent in certain oil and gas regions, such as droughts, hot summers, or severe winter temperatures. Moreover, the industry often deals with spaces prone to hazardous gas accumulation, making proper ventilation, an integral HVAC component, crucial for worker safety and explosion prevention. Furthermore, equipment and storage facilities in this sector may require specific temperature maintenance for optimal functioning, a task that HVAC systems can effectively accomplish.

The indoor environment holds paramount importance in people's lives, as approximately 90% of their time is spent indoors (Cheng et al., 2019). Beyond impacting the occupants' thermal comfort and physical health, the thermal conditions inside buildings have a direct bearing on energy consumption (Zhao et al., 2014). HVAC systems are responsible for a significant portion, ranging from 30% to 55%, of a building's total energy usage (Wang et al., 2016). The traditional thermostat-based approach, though straightforward, often falls short in catering to the real-time thermal experiences of occupants, given the thermostat's placement far from where people work.

In essence, there exists a gap between the automatic air conditioning control system and the actual thermal sensations of the occupants. This gap not only complicates efforts to enhance thermal comfort through air conditioning but also impedes energy savings and emissions reduction in buildings. To effectively manage HVAC systems, it is imperative to consider various parameters, including heat and mass transfer processes that can influence air and fluid properties within the system. To optimize HVAC system operation, solving algebraic equations using the Newton-GMRES (Generalized Minimal Residual) method proves essential and is the preferred approach (Imankulov et al., 2021). This method is employed for solving linear and nonlinear algebraic equations that may arise during HVAC system optimization and management.

Numerous research endeavors have aimed to address these challenges (Sheriyev et al., 2016; Retnawati, 2017; Zhapbasbayev et al., 2021; Rohde et al., 2023; Zhapbasbayev et al., 2024). The utilization of human-machine interfaces (HMIs) (Chen et al., 2016), mobile applications (Santosh et al., 2016), and online feedback tools on computers (Samuel et al., 2014) has shown promise in improving thermal comfort, energy efficiency, and environmental well-being by gathering user thermal comfort data. Model-free control techniques, relying on user thermal sensations feedback, have demonstrated significant energy savings (Jazizadeh et al., 2014). Some researchers have integrated user thermal preferences into HVAC system control methods for personalized intelligent control (Ghahramani et al., 2014). Control methods incorporating a thermal comfort model and infrared thermography have enhanced comfort without disrupting daily routines (Zhao et al., 2016). However, infrared thermography may lose accuracy in low-light conditions or when users are distant. To assess subjective thermal sensations, wristbands monitoring skin temperature on the wrist and fingertip have been utilized (Ghahramani et al., 2018). Additionally, wearable devices of laboratory quality have been employed to create personal thermal comfort models for everyday activities (Liu et al., 2019). In our previous research (Tasmurzayev et al., 2022; Tasmurzayev et al., 2021), a software package based on the well-known Internet of Things platform Genesis64 played a pivotal role. This software package represents the 'upper' level of the Smart City system, facilitating process visualization, management, indicator analysis, and predictive process modeling.

To address the challenges, this article endeavors to develop a data management system for room temperature control and a corresponding software and hardware complex. The article is organized as follows: Section 2 covers the development and design process, along with application, server, and database implementation. Section 3 encompasses framework testing and result presentation, with the conclusion drawn in the final section.

Architecture of the System

The intelligent HVAC system is an advanced ventilation solution equipped with 11 different sensors, enabling users to have precise control over each room's temperature at any given moment. This system not only monitors temperature variations in each room throughout the day but also automatically adjusts airflow to maintain the preferred temperature settings of occupants. What sets the intelligent HVAC apart is its ability to track these changes, thanks to its connection to cloud-based technology.

Moreover, beyond temperature control, these intelligent HVAC systems also actively oversee and manage carbon dioxide levels and indoor air quality. By employing real-time energy management and a sophisticated algorithm, these smart HVAC units can adapt and sustain desired room temperatures in response to fluctuations in the external environment.

Figure 1 illustrates the operational space, responsible for monitoring and controlling room temperature and air conditioning. It also houses essential components such as the control box, local server, and monitoring panel, featuring the following functionalities:

- Real-time room condition monitoring.
- Utilization of microcontrollers to regulate the air conditioner and heating system, leveraging devices like Siemens SIMATIC S7-1200, Siemens SIMATIC IoT 2040, and Raspberry PI 4.
- Reduced power consumption, contributing to energy efficiency.

Figure 1. Control Room Configuration

The test setup for the intelligent temperature and air conditioning control system, as depicted in Figure 1, comprises the following key components:

- A control and command cabinet equipped with I/O modules and a programmable controller.
- An array of sensors and actuators.
- The VEGA Absolute wireless data acquisition system, leveraging LoRaWAN technology for communication.
- A video surveillance system.
- The SCADA Genesis64 software installed in an automated workplace referred to as APM.

The monitoring system showcased in Figure 1 serves as an automated system directly linked to the control unit. This system is comprised of a controller and input/output modules, responsible for receiving data from various sources, including temperature sensors, leak detectors, air conditioning units, and switches. Consequently, the control unit can receive this data and issue specific commands to regulate the parameters of executive devices such as LED strips and control valves, with the aid of an intelligent decision-making platform. Furthermore, the core component is integrated with the SCADA monitoring system.

On the testing platform, sensors and executive devices execute control commands generated by the control system and produce primary signals required for further processing. Utilizing cutting-edge LoRaWAN technology, the wireless data collection system VEGA collects information from primary sensors and transmits it to the server via a base station, subsequently forwarding it to SCADA.

Our next step involves the integration of the selected devices into a monitoring program designed to oversee the building's status. We have opted for the use of the ModBus TCP protocol over an Ethernet network, where each device's IP address corresponds to its ModBus address.

To achieve more precise results in this system, we have chosen to employ two software programs that were utilized in our prior research (Tasmurzayev et al., 2021):

1. Open Platform Communication Unified Architecture (OPC UA).
2. Supervisory Control and Data Acquisition System (SCADA).

Furthermore, we have implemented a cloud platform for data collection, allowing us to retrieve data from the structure and manage controllers and programs. To address the need for adaptable data interfacing with the OPC server, explicit object typing has been implemented within the OPC UA server's address space. This involves the use of templates or classes to categorize similar groups of technological parameters. This approach enables automatic responses to changes in volume on the server side and offers control over the completeness of received information. By linking class descriptions to their instances and providing semantic information within the OPC UA server, a template for the list of objects can be created. This eliminates the need for manual entry of a list of class instance names when setting up the interface. Additionally, the OPC UA client can subscribe to the server's notifications regarding address space changes (Nolan et al., 2016).

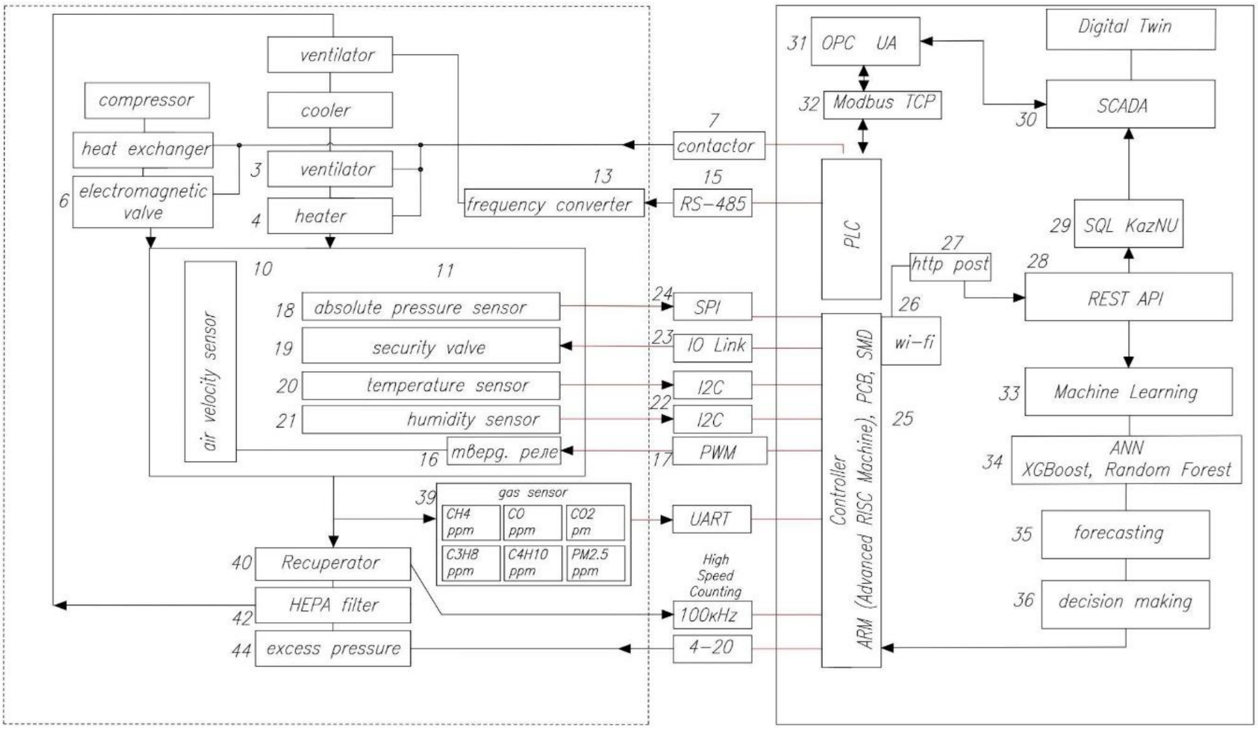

Figure 2. Architecture of the System

In Figure 2, we present a comprehensive architecture of our system, which has been previously discussed in detail. Now, let's delve into how the operation of the oil and gas industry is intricately connected to the intelligent temperature and air control platform, considering that we are optimizing a conventional HVAC system, or more precisely, transforming it into an intelligent HVAC system.

The control and regulation process in the HVAC system within the oil industry involves a series of components and systems working in concert to uphold specific air and climate conditions within oil and gas industry facilities. Here is an overview of the control and regulation process:

- Data Collection: The process commences with the collection of data regarding the prevailing conditions both inside and in the vicinity of the oil and gas industry. This data encompasses various parameters such as temperature, humidity, gas levels, air movement, and more. Sensors (18), (20), and (21) on the left side of the architecture handle the collection of these parameters, with the data being stored in an SQL database (29).
- Data Analysis: The collected data undergoes rigorous analysis to ascertain whether it adheres to predefined standards and requirements. For instance, if the temperature within a well deviates from the specified range, the system identifies it as a deviation. To enable the system to autonomously regulate these parameters and make informed decisions, an intelligent component has been seamlessly integrated. The right side of the architecture illustrates the operational diagram of this intelligent platform, implemented using methods such as Artificial Neural Networks (ANN), XGBoost, and Random Forest (34).
- Decision-Making (36): Based on the outcomes of data analysis, the system formulates decisions concerning necessary adjustments. These adjustments primarily involve modulating the operation of various HVAC devices, including heaters, air conditioners, and fans.
- Execution of Commands: The HVAC system translates these decisions into executable commands aimed at regulating the identified parameters. For example, if the temperature inside a well surpasses the specified threshold, the system may activate the air conditioner to cool the environment.
- Monitoring and Feedback: Concurrently with the execution of commands, the system continuously monitors changes in parameters and the status of equipment. Feedback from this monitoring phase empowers the system to dynamically adapt to evolving conditions and make further adjustments as required. The monitoring system aligns with what is depicted in Figure 1.

- Safety: Ensuring safety stands as a pivotal facet of control and regulation. HVAC systems may encompass emergency ventilation and automatic protection systems, which spring into action in response to hazardous situations such as gas leaks. Security measures are underpinned by a dedicated controller (25), which communicates with data using OPC Server (31) and ModBus (32) protocols. Furthermore, this controller interfaces with additional amplitude-frequency sensors and a safety valve.

This meticulous control and regulation process collectively enable the HVAC system to uphold optimal conditions for both the equipment and personnel operating within the oil and gas industry. The intelligent HVAC management system contributes significantly to safety, operational efficiency, and energy conservation within oil and gas industry operations.

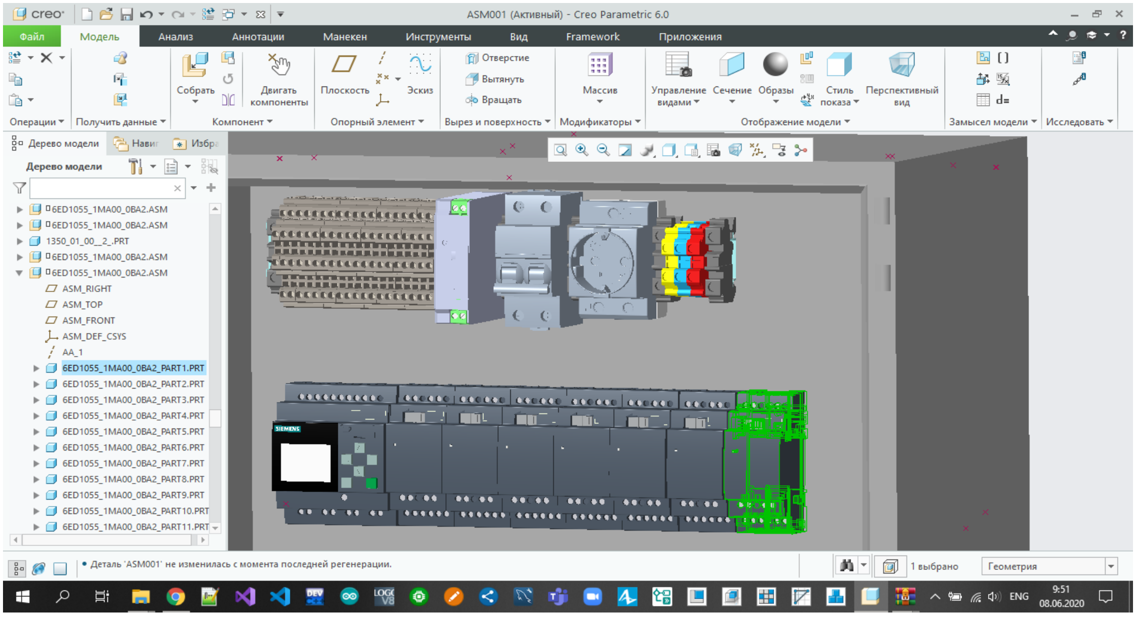

Figure 3. CAD of the control box

The detailed structural diagram of the control unit is provided in Figure 4.

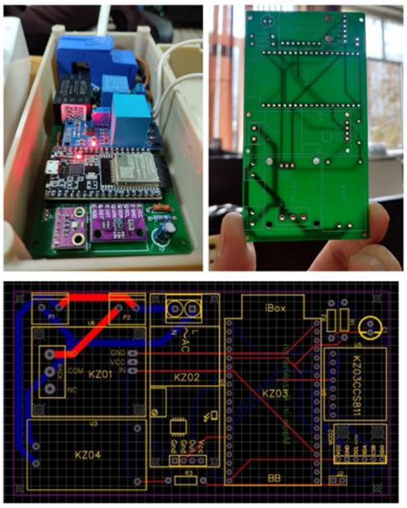

Figure 4. Control and data acquisition module

Research Results

The developed HVAC system comprises three primary components: physical components, an intelligent system, and a control and monitoring system. The control system is driven by SCADA Genesis64.

The provided SCADA system, as depicted in Figure 5, offers a range of valuable capabilities:

- Monitoring and Control: Operators have the ability to closely monitor the current parameters of the HVAC system through the SCADA interface. This includes parameters like temperature, humidity, ventilation speed, and more. Moreover, operators can make real-time adjustments and take control of the system based on the data at hand.

- Data Collection: The SCADA system serves as an efficient data collector, gathering information from various sensors and HVAC system devices. It also archives this data for subsequent analysis and reporting purposes.
- Real-time Optimization: SCADA plays a crucial role in optimizing the HVAC system's operation in real-time. For example, it can dynamically adjust room temperatures in response to prevailing conditions and specific requirements, thereby enhancing efficiency and comfort.
- Emergency Management: The SCADA system is equipped to respond automatically to emergency situations or deviations in the HVAC system's operation. It not only alerts operators to these issues but also initiates preventive measures to avert potentially serious problems.
- Remote Control: SCADA empowers remote control of the HVAC system, a particularly valuable feature for systems situated in remote or challenging-to-access locations. This remote-control capability facilitates efficient management and maintenance of the system, even when it is not physically proximate to the operators.

The SCADA system consists of several key components, including a tag database, a graphical display module, and a script processor. The graphical display module, as depicted in Figure 5, provides buttons for turning on and off dampers, as well as a window for adjusting variables like pressure, temperature, humidity, and gas levels. It also features buttons for parameter control, an emergency stop button, and windows for configuring pressure and temperature settings. This module allows for monitoring and setting specific parameters for maintenance, with the intelligent platform maintaining these values during operation.

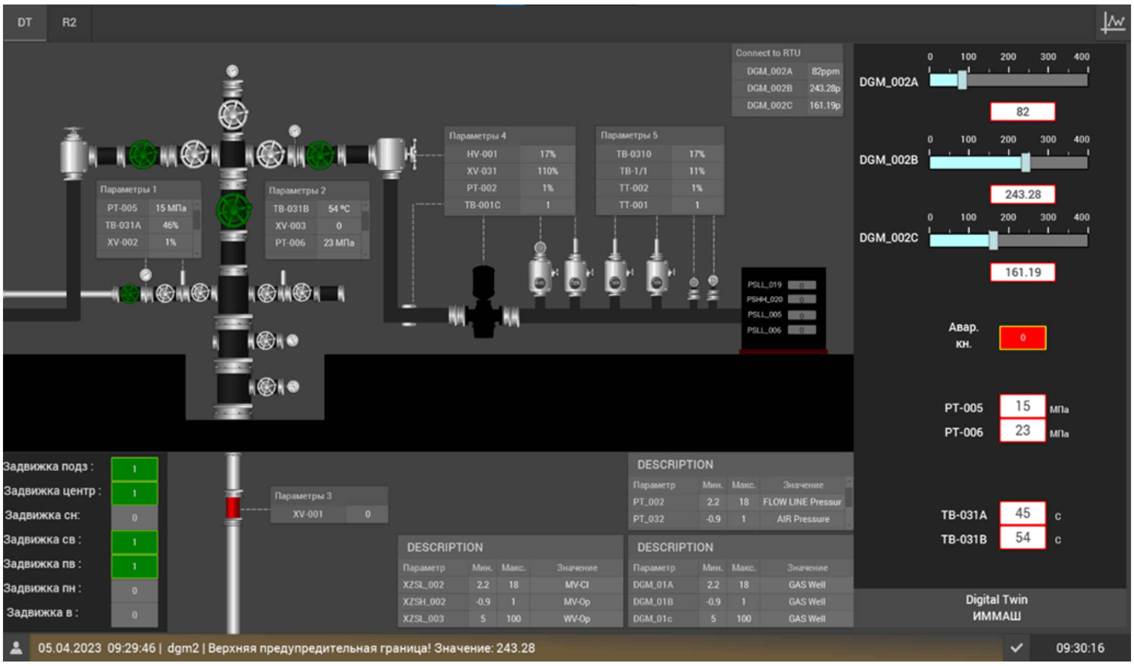

Figure 5. SCADA system

To establish connections among these system components, a communication block, illustrated in Figure 6, is employed. This block plays a vital role in enabling communication and data exchange among controllers, sensors, actuators, and the SCADA monitoring and control system. It collects data from various sensors and devices within the system, including information about indoor environmental conditions and equipment status, such as temperature, humidity, ventilation rates, and pressure. Once collected, the communication block transmits this data to controllers and control devices within the HVAC system, which can include thermostats, ventilation regulators, compressors, and other devices responsible for maintaining comfort and system operation.

The communication block also establishes a connection with the Supervisory Control and Data Acquisition (SCADA) system, allowing operators to monitor the real-time status of the HVAC system and make control decisions based on the data received. Furthermore, it can relay commands from SCADA operators to controllers and actuator devices in the HVAC system. For example, if there is a need to increase room temperature, SCADA can send commands to adjust thermostats and heaters accordingly.

Another crucial function of the communication block is to detect emergency situations. When sensors detect conditions like gas leaks or other hazards, the communication block transmits this information to the SCADA system, which can automatically trigger emergency procedures, such as shutting down equipment or alerting security services. Additionally, the communication block enables remote control of the HVAC system, which can be especially valuable for systems located in remote or inaccessible locations, such as oil wells.

Figure 6. Communication block

Conclusions

Our research efforts have culminated in the creation of an intelligent system designed to optimize the management of heat supply and air conditioning in enclosed spaces while minimizing energy wastage. This system is built upon a robust framework for control and monitoring and incorporates advanced intelligent modeling.

The system's capabilities, empowered by intelligent automation, serve to reduce the need for human intervention, enhance overall system efficiency, and provide both local and remote monitoring and management of all system states. It also enables the analysis of data within specific timeframes, the early detection of deviations and malfunctions in system components and segments, and the optimization of operational procedures.

This intelligent automation system effectively addresses the challenges associated with excessive heat consumption and the associated costs. It operates as a centralized heat distribution system, ensuring the delivery of required heat levels and enabling year-round air conditioning, regardless of the time of day or prevailing weather conditions, especially in the oil and gas industry.

By implementing monitoring and control of predefined parameters, the intelligent system ensures that these parameters are supplied to oil and gas processes only when necessary, thus minimizing unnecessary energy consumption. Moreover, the system is highly scalable, capable of continuous operation over extended periods without interruptions, and it is designed with environmental considerations in mind.

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