Investment Feasibility of Building the Architecture of Greenhouse Automated Control System Based on the IoT and Cloud Technologies

Viktor Khavalko[1[0000-0002-9585-3078]], Sofiia Baranovska[1[0000-0003-3264-9210]] and Galyna Geliznyak[2[0000-0002-3624-0255]]

[1] Lviv Polytechnic National University, S. Bandery Str., 12, Lviv 79013, Ukraine
[2] Separated structural unit - College of telecommunications and computer technologies of Lviv Polytechnic National University, Volodymyra Velykogo Str., 12, Lviv, 79000, Ukraine
viktor.m.khavalko@lpnu.ua, sofiia.p.baranovska@lpnu.ua, galyna.geliznyak@gmail.com

Abstract. The paper deals with the process of building the architecture of an automated control system for the greenhouse operation. The advantages and disadvantages of the traditional greenhouse ACS architecture, which consists of three major components - the greenhouse, the IoT platform and the ML model - are analyzed. In order to avoid the disadvantages of such ACS, it is proposed to use cloud technologies. The greenhouse ACS architecture has been developed based on cloud technology and an IoT platform that is flexible, reliable, mobile and versatile. The results of the operation of the greenhouse, the microclimate of which is controlled and maintained with the help of automatic control system, which is built on the basis of the developed architecture, are presented.

Keywords: Iot Platform, Cloud Technologies, Greenhouse Agent, ML Model, Automated Control System Architecture, Microclimate Parameters.

1 Introduction

A large number of greenhouses are used in Ukraine and abroad to grow a wide variety of crops. A significant difference between greenhouses and other types of protected soil structures is the ability to create favorable conditions not only for cultivated plants, but also for maintenance personnel and process equipment. As a result, greenhouses increase productivity and culture of production, and the seasonal nature of agricultural work disappears. In a greenhouse, unlike small shelters, all agrotechnical measures can be performed without compromising the integrity of the fence, and various mechanisms for plant care can be widely used.

Ensuring the operation of a greenhouse requires optimal investment support by attracting financial resources from different economic entities. At the same time, the role of public-private as the most effective way of modern investment is important.

Forms of investment can be: corporatization; issue of bonds; direct capital investments; sponsorship contributions; state financial support, etc.

It should be noted that industrial greenhouses can occupy an area of more than 50 thousand m2 (Fig. 1). In the middle of each such greenhouse is created its own climate, which depends on the type of crops grown and sensitive to that climate. In order to effectively control the work of such complex systems [1,2], it is necessary to use powerful automated control systems that control the work of a variety of modern equipment, the latest technologies, methods and algorithms and generate control decisions accordingly.

Fig. 1. Industrial greenhouse

The greenhouse and control system are affected by the unsteady behavior of a large number of internal and external factors: equipment failures, sensor failures, unstable software operation, dramatic changes in climatic conditions, etc. Many of the static and dynamic characteristics of a number of greenhouse elements and units make the task of quality process control difficult, but to effectively control the climate of the greenhouse, all these impacts must be taken into account, which is quite a challenge. Therefore, projecting and implementing an ACS architecture with the operation of a greenhouse based on artificial intelligence, the IoT and cloud technologies in such a way that ensure the functioning of all equipment and sensors within the required limits is an important and actual problem.

2 Analysis of existing solutions

Among the technological processes that take place in greenhouses, the processes of automatic control, determination and maintenance of microclimate parameters of greenhouses are of particular importance. All these parameters are closely linked and affect each other [3,4], but together they determine the growth and development of greenhouse plants. Recently, adaptive automated control systems [5-7] using neural networks have become more widespread and used [8-10]. The use ACS of in greenhouses of mathematical apparatus of fuzzy logic makes it possible to formalize and process large amounts of information in real time [11].However, most of such systems do not have real-time research object information because they process databases from previously obtained information [8-10], which is of no importance.

In the last decade, methods and systems of fuzzy analysis and control [4, 10], which operating with incomplete information about control object, are high-performance and interference resistant, have been rapidly evolving. In addition, the development of approaches and tools for artificial intelligence also significantly increase the efficiency of such systems. The work [5, 6, 9, 11] offers methods and ways of using intelligent technologies that can significantly reduce the complexity of control systems and simplify their design and development.

Therefore, the development of automated control systems for the operation of greenhouses, which in the current conditions of development of industry in Ukraine and abroad make demands of high-tech, reliability, energy efficiency, is an urgent and important task.

3 Problem statement

To describe the process of developing a system of automatic control of the greenhouse operation, which will be able to determine and maintain the optimal modes of the required parameters throughout the period of plant growth, because most of them, namely temperature, light, heat, humidity and fertilizers are the main factors that maximize yield. Functional requirements for such a system are: to maximize the volume of harvested crops, to reduce the impact of the human factor on the process of analysis and decision-making, to make the greenhouse more energy efficient, and therefore reduce its operating costs. In the end, it will result in a significant increase in profits. The architecture of such a system is proposed to be developed on the basis of artificial intelligence, IoT platform and cloud technologies.

4 The structure of the ACS of greenhouse

Before going to the description of the system structure, we would focus on the equipment that affects the creation of the greenhouse microclimate. Such equipment will include: heaters- to regulate the thermal mode; watering pipelines; air-conditioning system; sun screens; lighting system; etc. In addition, it should be noted that the microclimate in the greenhouse is significantly influenced by the macroclimate, and therefore all the smallest changes in the macroclimate should be monitored and the control effects on the greenhouse should be made in accordance with the current changes in the macroclimate.

Such ACS can be both standalone devices and fully integrated systems that provide complete control over the process of growth and ripening of the crop and for the automated control of parameters and climate control in the greenhouse.

The use of the system provides high accuracy of maintaining the set climate modes separately for each greenhouse by influencing the mechanisms and equipment of the following major technological systems and processes:

- lower air heating system;
- upper air heating system;

- soil heating system;
- substrate heating system;
- ventilation system;
- shading system;
- evaporation, cooling and humidification control system;
- drip irrigation system;
- air recirculation system.

The structure of such a complex ACS can be depicted as follows (Fig. 2):

- one or more greenhouses;
- a machine learning model that will intellectually process data in real time and control the operation of the entire system;
- a platform that integrates the two previous components and provides effective interaction between the greenhouse and the machine learning mode

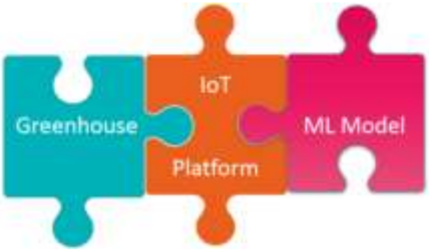

Fig. 2. System structure

The general approach to the process of controlling all components of a projected greenhouse ACS can be summarized as follows (Fig. 3). The first thing to do is to get from the sensors installed in the greenhouse all the necessary current data, i.e. parameters of temperature, humidity, lighting, etc., as well as weather forecast data for the near term. Submit them to the ML model input together with the desired microclimate in the greenhouse (for example, temperature and humidity for the next 24 hours). The output of the ML model will give you the control steps that must be applied to all the greenhouse equipment in order to get the desired result.

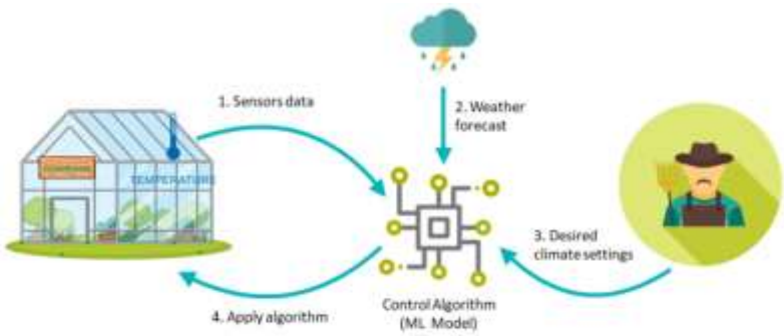

Fig. 3. The structure of the proposed greenhouse climate control approach

The most important in this structure is the use of an IoT (Internet of Things) platform that will enable the integration of human factors, technologies and processes to maximize human interaction with all kinds of sensors and equipment. That is, it will allow the person who oversees the operation of the greenhouse to avoid most errors and maximize the automation of manual adjustment or control of all equipment that is responsible for maintaining the microclimate of the greenhouse, and thus reduce the role of humans only to monitor the current parameters.

Based on the above, the main role was focused on the development of such an IoT platform. Its structure (Fig. 4) consists of:

- Greenhouse agent, responsible for reading sensor data and operating greenhouse hardware and for controlling greenhouse equipment;
- A set of APIs that would allow other system components to communicate with the kernel to transmit or receive data. For example, a Greenhouse agent at certain intervals (such as once a minute) would transfer all sensors' data of the Greenhouse to the Sensor API, which would normalize the data received and store it in a database for later use;
- Web Application (Web APP), which is intended for the person who manages the operation of the greenhouse, can enter the necessary parameters of the greenhouse microclimate and set the system settings. This web application is linked to the Climate Settings API, which will allow it to interact with the system kernel and the corresponding database;

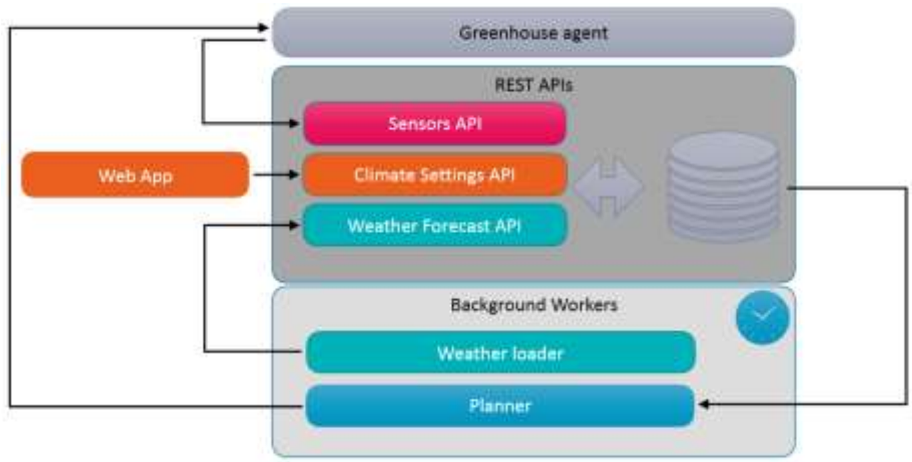

Fig. 4. IoT platform structure

- Service for downloading weather forecasts from different sources, normalizing these data and bringing them to a specific form, suitable for further processing by the system. The received data will be transferred to the system using the Weather Forecast API;
- A software service (Planner) that will run the ML model, which inputs' are all necessary data (weather forecast, climate settings, current sensor data, etc.) from the database. The output from the ML model will be submitted to a Greenhouse agent who will apply the resulting control actions.

Since the planning and retrieval of weather forecast data must occur periodically, these two processes must be started on a specific timer.
There may be a problem with server deployment when deploying the system, that is, where the entire system and therefore the database will be stored. Among the main difficulties are:

- availability of high-speed Internet, which is necessary for timely transmission of data between all components of the system;
- logging, monitoring and alerting - how under these unstable conditions to carry out these three processes;
- data backup - since most data have a critical impact on the functioning of the greenhouse and maintain a proper microclimate, the issue of data backup is extremely acute;
- increasing the number of greenhouses - under the traditional approach, is reduced to the installation in each greenhouse of a separate server, which again does not remove the previously considered difficulties.

5 Choosing a cloud environment

Avoid all of these difficulties and problems allows the use of cloud technologies [12, 13]. Among the most popular public cloud repositories are: Google Cloud Platform, Azure, AWS.
Considering these three cloud repositories with the perspective of using IoT, they all offer specific IoT solutions that are 90% similar in functionality. As for the selection criterion, here are some requirements that are related to the functional requirements of the projected greenhouse ACS and the following wishes:

- Python support, since the ML model was created in Python, like all software development when creating an IoT platform (Google Cloud Platform had better capabilities in this regard);
- the cost of using cloud services (the Google Cloud Platform was cheaper, though not insignificant);
- experience in cloud services.

Google Cloud Platform is a global cloud provider that supports IoT solutions. Its Google Cloud IoT suite allows you to create and manage IoT systems of any size and complexity. The Google Cloud IoT solution includes a number of services that can help to build IoT networks. Google Cloud for IoT offers the following solutions (Fig. 5).

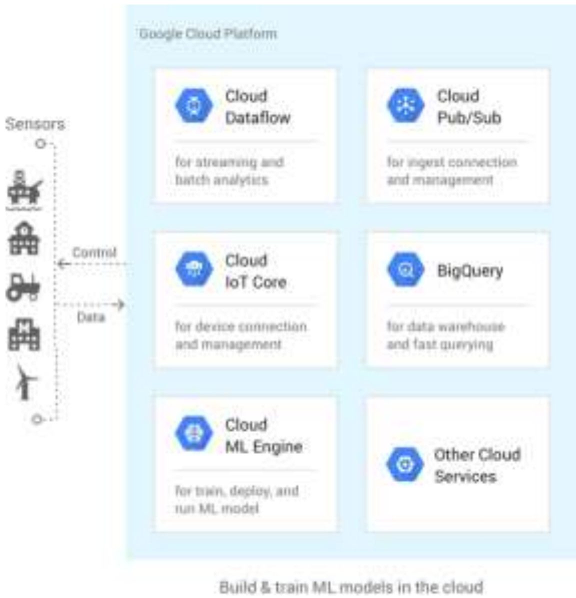

Fig. 5. Reference diagram of Google Cloud Solutions for IoT

The central and most important element of this system is Cloud IoT Core - a fully managed service for easy and secure two-way connection between devices and the

Cloud IoT platform, as well as managing and receiving data from different devices. Cloud Pub / Sub is a service that processes event data and provides real-time flow analytics. Cloud ML Engine is a service that allows to create ML models and use data obtained from IoT devices. Goole Dataflow is a data conversion service (can work both in real-time and in batch mode). Google's IoT solution includes a number of other services that may be useful for building complex connected networks.

So, after analyzing all the possibilities, it was decided to implement a greenhouse ACS on the base of a cloud architecture that would allow the implementation of the IoT platform.

6 Architecture of the greenhouse ACS based on cloud technologies and solutions

The architecture of the projected greenhouse ACS considering that the system platform is transferred to the cloud will take the following form (Fig. 6). The Greenhouse agent remains a core element that must operate on the same network as the greenhouse in order to have access to all the greenhouse hardware and equipment. All other system elements are moved to Google Cloud. The platform's entry point will be Cloud IoT Core service, and the Greenhouse agent will communicate with it using one of the two protocols it supports HTTP / MQTT.

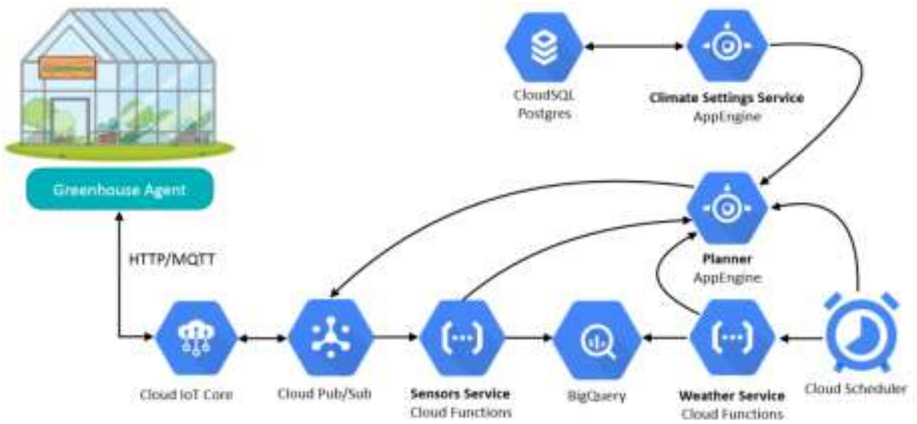

Fig. 6. Cloud Architecture of the proposed system

All data received from a Greenhouse agent with a certain frequency by a Cloud IoT Core is sent to Cloud Pub / Sub. From there, all the data goes to the Sensor Service, where the datas are normalized and brought to look necessary for further processing, and then the entry in BigQuerry (this is a serverless data warehouse for interactive large-scale analysis of large datasets. It can be used via the web interface, the command line interface and API. Payment is for the number of terabytes of data processed when querying), where both people and our other applications can access it. The next element of our system's cloud architecture that uses cloud functions and transmits data to BigQuerry is the Weather Service. This service periodically (using Cloud Scheduler for this purpose) receives weather data from providers, processes it and normalizes it to store in the required form in BigQuerry. The Climate Settings Service is the next item used, and it is responsible for transmitting the desired greenhouse climate settings. This data is stored in CloudSQL Postgres. The core of the system is Planner, which was developed using Cloud ML Engine and ML Flow. Planner inputs are the desired greenhouse climate settings, the latest greenhouse sensor data, the most up-to-date weather forecasts, and the result is submitted to Cloud Pub / Sub. From where they get to Cloud IoT Core and are transmitted to the Greenhouse agent, who interprets the resulting numeric data into control influences. This model plans a microclimate for the next 24 hours, but redevelopment is possible due to refinement of the data every 10 minutes. This is due to the update of the weather forecast data.

Let's analyze how the situation with the problems described in the previous paragraph has changed. So, the system deployment. Docker, a software used to automate deployment and application management in container-enabled environments, has been used to eliminate all deployment-related issues except cloud-based features. Allows you to "place" an application with all its environment and dependencies in a container that can be migrated to any system, and also provides a container management environment. In addition, a Google Cloud component, namely Cloud Deployment Manager, has been deployed that has the ability to form an image of the system and deploy it to a specific location.

Another Google Cloud component, StackDriver, which is a necessary and free service for managing cloud computing, has been used to resolve logging, monitoring, and alerting. It provides performance and diagnostics data (in the form of monitoring, logging, tracking, error messages and alerts) for public cloud users. Stackdriver is a hybrid cloud solution that supports both Google and AWS cloud environments. It collects all metrics and logins centrally from all cloud components of the system, and you can also specify user parameters to collect the required metrics and logs or alerting.

System backup is organized using BigQuerry and CloudSQL, where puts a checkbox that enables backup at certain intervals. In addition, the BigQuerry component enables you to stream data to Google Cloud Storage and then restore it if necessary.

If we consider the extension of the proposed system to several greenhouses, its structure will have the following form (Fig. 7). That is, in the case of one greenhouse, we will have one Greenhouse agent - one platform, and in the case of several greenhouses - several Greenhouse agent - one platform. The new Greenhouse agent is connected in console mode via Cloud IoT Core. That is, we see that the use of cloud technology has allowed us to develop an architecture, the advantages of which are: system flexibility; ease of installation; ease of setup and operation.

As can be seen from the analysis of the shortcomings of the previous architecture (Fig. 4) the use of cloud technologies and accordingly developed on this technology system architecture (Fig. 6) allows to avoid all the above disadvantages and has several advantages.

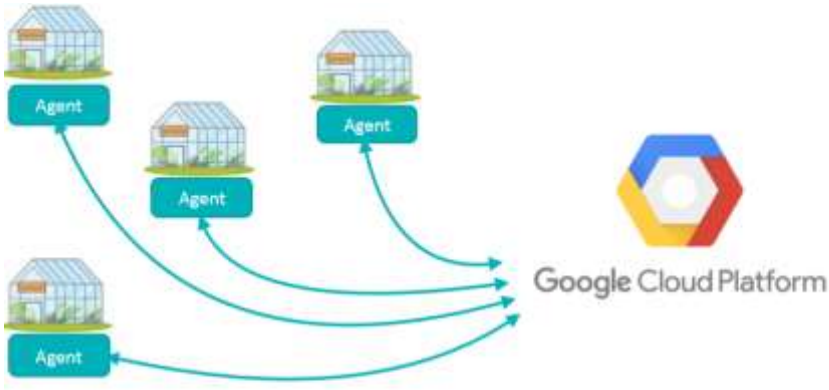

Fig. 7. One platform – multiple agents

7 Results of modelling of greenhouse ACS

As a result of the system functioning, all operating parameters and indicators are displayed as graphs. As already mentioned, the functioning of the greenhouse is set at 24 hours, but in the event of severe changes in climatic conditions or equipment parameters, greenhouses can be adjusted every 10-15 minutes. That is why each graph shows the behavior of the parameters in 24 hours. In Fig. 8 shows a screenshot of a web application seen by a person monitoring the operation of a greenhouse, namely a schedule for temperature control. The thick red line is the microclimate of the greenhouse installed by the farmer. The blue dotted line is the current temperature in the greenhouse that the ACS could set and support. The yellow line is the temperature outside, according to the weather forecast.

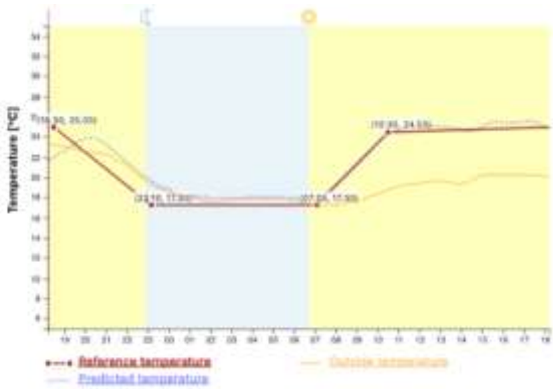

Fig. 8. Temperature control

In Fig. 9 shows a graph of humidity control. In this graph, similar to the previous figure, the red line is the humidity parameters set by the person, who controls the operation of the greenhouse. The blue dotted line is the current humidity in the greenhouse, which is measured by sensors and which the ACS could support, and the yellow line is the humidity curve outside, according to the weather forecast.

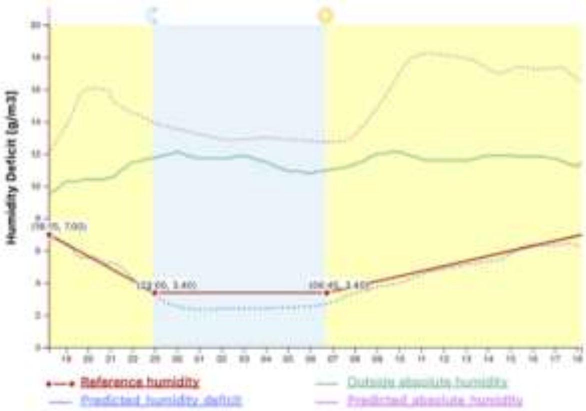

Fig. 9. Humidity control

Finally, the most interesting result of the operation of the greenhouse ACS is the results of the proposed control effects from the ML model (Fig. 10). The functionality of the application is constructed in such a way that if you click on one of the graphs (highlight it), this graph will become more bold. In Fig. 10 shows the temperature curve of the pipe responsible for heating the soil of the greenhouse. Each of the graphs in Fig. The 10 curves correspond to a specific device in the greenhouse, which can be controlled and responsible for the establishment and maintenance of the necessary greenhouse microclimate.

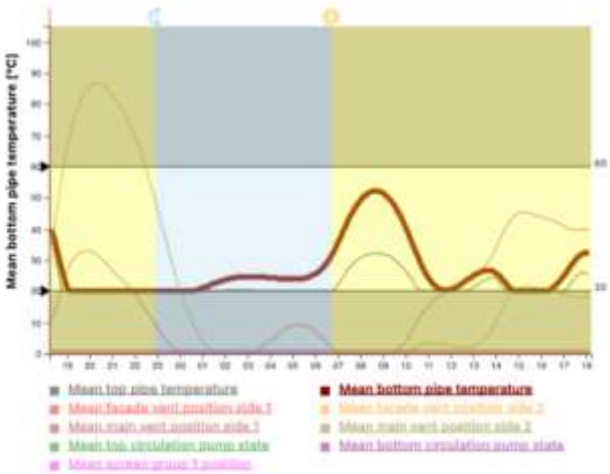

Fig. 10. Planned control impacts obtained from the ML model output

Because the system is complex and control many parameters, it is clear that it requires testing and setup. The approach is quite simple - it makes assumptions how to control the system, what parameters are important and what is not, and based on these assumptions the current version of the model is created. We take a test set of data based on some historical data and run it on our model to investigate how well it can meet the desired greenhouse climate. The obtained results are analyzed and accordingly make changes to the created model of the system. And the process of testing the model continues again until we reach the desired results.

Conclusions

As a result of these developments, two greenhouse ACS architectures were designed. The advantages and disadvantages of these architectures are analyzed, and it is argued that the most appropriate option is an architecture created on the basis of artificial intelligence, IoT platform and cloud technologies. The machine learning model is used to analyze current greenhouse microclimate parameters obtained from greenhouse sensors and equipment, weather data, and desired climate settings. As a result of the machine learning model, there are control effects that are recommended to apply to the greenhouse equipment to achieve the desired parameter settings.

The application of the IoT platform and cloud technologies enables the creation of an architecture that offers flexibility, ease of deployment, ease of setup and operation, as well as monitoring, alerting and drastic changes in greenhouse operation parameters.

The IoT platform-based greenhouse architecture and cloud-based architecture allows for the rapid and efficient implementation of the process of extending the proposed system to multiple greenhouses, as well as performing regular backup of data, which is important for a large data system.

References

1. Sethi V.P., Sumathy K., Chiwon Lee, Pal D.S.: Thermal modeling aspects of solar greenhouse microclimate control: A review on heating technologies. In: Solar Energy, vol. 96, pp. 56-82 (2013).
2. Santosh, D.T., Tiwari K.N., Vikas Kumar Singh and Raja Gopala Reddy A.: Micro Climate Control in Greenhouse. In: Int.J.Curr.Microbiol.App.Sci. vol. 6(3), pp. 1730-1742 (2017).
3. Nicolosi G., Volpe R., Messineo A.: An Innovative Adaptive Control System to Regulate Microclimatic Conditions in a Greenhouse. In: Energies. vol. 10, issue 5, 722 (2017).
4. Hahn, F.: Fuzzy controller decreases tomato cracking in greenhouses. In: Comput. Electron. Agric. vol. 77, pp.21–27 (2011).
5. Kryvenchuk, Y., Shakhovska, N., Shvorob, I., Montenegro, S., Nechepurenko, M.: The smart house based system for the collection and analysis of medical data. In: CEUR, vol. 2255, pp. 215–228 (2018)
6. Melnykova, N., Marikutsa, U., Kryvenchuk, U.: The new approaches of heterogeneous data consolidation. In: 2018 IEEE 13th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT), Lviv, pp. 408–411 (2018).

7. Bennis, N., Duplaix, J., Enéa, G., Haloua, M,, Youlal, H.: Greenhouse climate modelling and robust control. In: Comput. Electron. Agric. vol. 61, pp.96–107 (2008).
8. Fourati, F. Multiple neural control of a greenhouse. In: Neurocomputing. vol. 139, pp.138–144 (2014).
9. Maher, A.; Kamel, E.; Enrico, F.; Atif, I.; Abdelkader, M.: An intelligent system for the climate control and energy savings in agricultural greenhouses. In: Energy Effic. vol.9, pp.1241–1255 (2016).
10. Zhang, D.; Wu, X.; Zhang, C.: The application of fuzzy control in greenhouse environment control. In: Appl. Mech. Mater. 543–547, pp.1432–1435 (2014).
11. Tsmots I., Skorokhoda O., Tsymbal Yu., Tesliuk T., Khavalko V.: Neural-Like Means for Data Streams Encryption and Decryption in Real Time. In: IEEE Second International Conference on Data Stream Mining & Processing. pp.438-443 (2018).
12. Joon Yong Kim, Chun Gu Lee, Dong-Hyeok Park, Heun Dong Park, Joong-Yong Rhee: Building a Private Cloud-Computing System for Greenhouse Control. In: Journal of Biosystems Engineering. vol. 43(4), pp. 440-444 (2018).
13. Vatari S., Bakshi A., Thakur T.: Green house by using IOT and cloud computing. In: 2016 IEEE International Conference on Recent Trends in Electronics Information & Communication Technology (RTEICT), pp. 246-250 (2016).