IoT-based agriculture monitoring platform architecture

A Zorkin\(^1\), N Ivanova\(^2\)

\(^1\) National Research Tomsk State University, Higher IT-school, 634050, Tomsk, Russia
\(^2\) Botanical Garden of the Ural Branch of the Russian Academy of Sciences, 620144, Yekaterinburg, Russia

E-mail: i.n.s@bk.ru

Abstract. The research is aimed at solving one of the most urgent tasks of our time: the development of reliable and scalable software for monitoring the climate of agricultural fields. The goal is to create an architecture of simple and universal systems for collecting and storing data from various measuring devices located on agricultural land. The methodological basis for the monitoring system is the "Internet of Things" (IoT) approach. The agro-industrial complex of the Tomsk region (Russia) was chosen as a model object. About a hundred measuring devices have been installed in agricultural fields, which provide continuous delivery of data series in real time. Our developed platform includes both the server part of the application that processes and stores these weather data, and a convenient user interface for visualizing data to agronomists. The results of the research can be used in designing the architecture of similar IoT-based monitoring systems.

1. Introduction
The frequency of extreme weather events is increasing due to global climate changes [1]. This will inevitably lead to a decrease in the efficiency of agriculture, which affects the economic well-being of not only individual countries, but also of the entire mankind [2-5]. Therefore, the problem of timely obtaining data on the agro-climatic situation in sown areas is acutely relevant all over the world. A fairly large number of huge agricultural industrial enterprises located in Russia use classical methods for calculating the most important indicators, such as the sum of useful temperatures, productive soil moisture, the duration of the growing season, and many others. This requires a lot of work: from the relocation of an agronomist to his planting field with a measuring device to the manual calculation of these indicators.

Of course, in the modern world there are many suppliers of automated measuring devices: from small and simple Arduino-based microcontrollers to multi-functional and expensive weather stations or even drones [6]. The approach to collecting climate data also differs greatly: older models of meters store data locally on a flash card, and the most modern models use cloud storage and are created in the technological approach of "big data" [7, 8]. Despite the technological differences, all these models are created with one major goal to simplify the work of agronomists by automating many business processes for collecting and calculating the necessary metrics, saving planting field statistics for many years, and sometimes even predicting some phenomena and interesting events based on machine learning technology [9].
The main purpose of our research is to consider various approaches to creating an architecture of a simple, reliable and universal system for collecting, monitoring and storing agrometeorological data from various measuring IoT-devices.

2. Materials and methods
The agro-industrial complex of the Tomsk region (Russia) was selected as a model object. On 12 agricultural fields were installed 92 IoT-devices of the "meteorological probe" type and 10 devices of the "meteorological post" type (Figures 1, 2). The first is the most primitive device that collects the profile of soil temperature and humidity at several depths, air temperature and humidity, as well as atmospheric pressure, while the second is a more advanced model, additionally equipped with wind force and direction sensors, a precipitation meter and a photosynthetically active radiation (PAR) sensor. According to our assessment, three meteorological probes located at the upper, middle and lower points of the territory are sufficient for a medium-sized planting field, and one meteorological post and about a dozen probes are sufficient for large farms (Figure 3). Both device types were made and established on planting fields by the Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of the Russian Academy of Sciences (IMCES SB RAS).

Measuring IoT-device itself is a simple microcontroller equipped with some sensors. Technically, a lot of motherboards can be used as a device base. Often, the structure of the device (from the motherboard to the sensors) and the architecture of the platform used for it are chosen based on the specifics of use and, typically, IoT-devices are assembled based on Arduino/ESP32 microcontrollers or Raspberry Pi microcomputer [10-14]. In our case, a low-cost and low-power ESP32 board was chosen.

Communication of devices with the server is organized via the HTTP(S) protocol. Devices with equal time intervals (usually 1 or 3 hours) collect a packet of weather data, assign it a timestamp and send it to the server. If it is not possible to send the packet due to a bad connection or unavailability of the server, the device saves the packet locally and tries to send it again at the next moment of collection. A human-readable JSON object is used for sending these packets over the network (Figure 4). In the server response, the devices receive the result of the operation, information about their actual configuration, the current time on the server so that it can be adjusted locally, and a link to the latest firmware binary file. Often, more advanced binary protocols are used for the Internet of Things, such as MQTT, ZigBee or similar [15], which reduce the load on the network or operate in the absence of Internet coverage, but...
these problems are not significant for the system, then HTTP(S)-based communication is a fairly stable, secure and easy-to-develop tool [16].

Figure 3. Example of the location of devices on the map (25x25 km).

```json
{
    "t": 22.299999,
    "hm": 74,
    "pr": 99053,
    "far": 1013,
    "u_pow": 13.354,
    "wd": 310,
    "ww": 8.15821,
    "w_max": 11.25815,
    "t_box": 28,
    "rssi_sim": 7,
    "time": 1628199680,
    "device_id": "bab073511db3",
    "device_type": "P",
    "firmware_version": "7.0.0"
}
```

Figure 4. The structure of the weather post data in JSON format.

The main requirements for the server part of the system were simplicity, reliability and the ability to scale. For this reason, a virtual machine with a white IP address was selected for the initial hosting of the service. It is worth noting that cloud solutions (AWS, Azure) are often used for large and distributed systems [7-9]. They are rational to use in case of a large computational load on the server or if it is necessary to save a larger amount of data, but this will be applicable for us in the long term only. Quite a lot of requirements were put forward for the user interface: an agronomist should be able to see the collected data in several formats, and some processes should be automated for him, for example, calculation of certain agro-climatic indicators or warning about the occurrence of a dangerous meteorological situation, such as drought or frost.

3. Results and discussion

IoT-system architecture can be designed in a lot of different ways and it really depends on plenty of different factors [10, 13-14, 17-18]. For our use we have chosen a service-oriented approach in building the platform architecture. This allowed us to present the server part of the system as a group of loosely-coupled modules (services), each of which solves its specific task, encapsulates the logic of its work and provides a unique interface for internal and external interactions (Figure 5):

1. Controller API is responsible for direct communication with devices.
2. Backend carries all the business logic, such as devices schemes and relation between users, companies (farms) and devices related to them.
3. Monitor, Report and Forecast APIs are second-level components. They perform tasks related to data visualization, building reports and predictions based on the machine learning module.
4. Frontend and Admin Panel are only two nodes representing a web interface for the user and the administrator respectively.

The system has two different relational databases that store user data and raw data of weather devices independently and separately. The UserDB, as mentioned earlier, is represented as several related tables with enterprise data and device schemes. The DeviceDB is a global meteorological data storage, where a separate table corresponds to each individual device. This is quite convenient: queries most often occur for one individual device, and if you want to collect all the data for one company, you can apply for device-company relationships stored in the first database. Both databases are managed by the MySQL
database management system (DBMS). The use of relational storage is advantageous because it is very reliable, productive and, moreover, familiar to developers [19].

Figure 5. Services deployment diagram in UML notation.

Each component of this system is an isolated container managed by the Docker platform [8]. This allows you to quickly and safely deploy parts of the system with the necessary environment for them and makes the system completely platform-independent. The current version of the platform is deployed on a Linux-based virtual machine with minimal system characteristics (1 CPU, 2 Gb RAM), but it can potentially be deployed in the cloud if necessary. As stress testing has shown, the current configuration can safely process about 300 parallel write requests from devices per second.

Our developed platform provides the agronomist with the most up-to-date data in real time in several visualization formats. At first, it is a map of its devices with the ability to view the latest data packet. In addition, the map displays weather phenomena at the posts, such as the presence of precipitation and the degree of cloud cover, which is especially convenient if the agronomist’s usual location is far from his fields.

Secondly, we have developed dashboards with graphs that logically group related measurements, for example, the entire range of soil temperatures. The user can set the desired period for displaying data: from 6 hours to several years. The entire weather history for the planting field is perfectly visible on dashboards: the dynamics of soil temperature can show the dates of snowfall/precipitation, the precipitation meter displays in detail the amount of precipitation by day, the PAR sensor shows the accumulated solar radiation. An example of a dashboard developed by us is presented on Figure 6.

But information panels alone are sometimes not enough to provide information effectively. Sometimes an agronomist needs to process the received data with his own computing tools. To do this, thirdly, we have developed a tab with detailed reports. For the required period, the minimum, maximum,
sum or average value for the necessary metrics can be obtained. In addition, the system prepares and sends users a daily summary of the meteorological situation: whether precipitation/frost was observed, whether there were strong wind gusts, what is the dynamics of atmospheric pressure. Also export to CSV format is supported.

Figure 6. Visualization of soil temperature on the platform’s website.

4. Conclusion
Agriculture in many countries and regions is not developing as dynamically as other sectors of the economy, so digitalization and automation of its main business processes are important. A network of measuring IoT-devices placed on planting fields allows agronomists to get the most up-to-date information about any weather events. And a digital platform built on this network is able to extract useful information from gigabytes of meteorological data and provide both an analysis of the current weather situation and its long-term dynamics. The result of the work was a productive and reliable agricultural monitoring system, which is currently actively developing on the territory of the Tomsk region, providing agronomists with up-to-date information about weather events on their territory.

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