Real-time tree physiology monitoring system

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Abstract. Electronic devices have been developed to operate in real time with an alarm on the streets of Diptychs. The devices are IoT-platforms based on the ESP-32 microprocessor, equipped with a LoRa transceiver to transmit data to a module that collects tree data and sends it to the cloud using GSM/GPRS. Pilot implementation will take place in 2023 on the territory of the Botanical Garden of Petrozavodsk State University (Republic of Karelia, Russia). The work was carried out with the aim of studying the seasonal dynamics of Malus domestica under growing conditions in the extreme territories of Northern Russia. The research results show that on May 16-18, during the characteristic phenological phase «The beginning of reddening of leaves» (BBCH 11) at an average daily air temperature of +5.7°C, a sum of temperatures of 487°C and an average daily temperature of 325°C. The phenophase «Beginning of flowering» (BBCH 61) was noted on May 28 at an air temperature of +13.3 °C. The phenophase «Beginning of fruit ripening» (BBCH 81-86) was noted on August 16. The beginning of the increase in trunk diameter, according to the distant number, was noted on June 15-20, the growth lasted until July 20-25 and amounted to about 3 mm. The research results showed that the species Malus Domestica may be preferable for introduction into the culture of northern fruit growing.

1 Introduction

The study of the processes of seasonal growth and development of trees within the natural range and during introduction makes it possible to establish the degree of adaptation of species to new growing conditions. In the last 10 years, observations of the seasonal development of trees have also become relevant for establishing the response of plants to ongoing climate change, which may lead to changes in introduction practices due to shifts in the boundaries of winter isotherms [1].

Methods for studying the physiology of trees in the field are based on field measurements. It is known [2] about a pilot study using Internet of Things (IoT) technology and a network of wireless, low-cost and multi-parameter TreeTalker+ (TT+) devices to monitor in real time the physiological state of trees in the form of meaningful indicators.

The study of plant development is an area of scientific and practical interest for fruit trees, among which one of the dominant places is occupied by the domestic apple tree

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(Malus domestica Borkh.). The purpose of the study is to study the seasonal dynamics of Malus domestica under growing conditions in the North of Russia.

2 Materials and methods

The experimental study took place in 2023 on the territory of the Botanical Garden of Petrozavodsk State University (Republic of Karelia, Russia). For the study, 5 domestic apple trees (Malus domestica) aged 21-22 years were selected. This type of tree is imported for this area, but annually produces a very abundant harvest of apples and is considered as a very promising crop for northern fruit growing. Geographic coordinates of the trees: 61.843223 N, 34.381783 E.

The study area is located in the northwestern part of the temperate climate zone. Characterized by a long (4–5 months), but not severe winter, late spring (April) with frequent returns of cold weather, cool and short summers (2 months), high relative humidity, significant amounts of precipitation and unstable weather conditions during all seasons [3]. The average annual air temperature in 2019–2022. (before the research) according to the Davis Vantage Pro 2 PRO in the Botanical Garden, it was 4.45 °C, 6.14 °C, 3.93 °C and 5.27 °C, respectively.

To monitor the physiological parameters of trees, innovative devices have been developed in the form of the "Plants" module. "Plant" modules are IoT platforms based on a low-power microprocessor ESP-32, which is a system-on-chip with integrated radio controllers, equipped with a LoRa transceiver for radio transmission to the Base Station module, which collects individual data about the state of the tree and sends them to the cloud using GSM/GPRS.

The "Plants" module is capable of measuring (1) light transmission spectra through the canopy in 12 spectral ranges using two spectrometers (visible and near-IR), (2) trunk diameter growth with an optical IR pulse sensor, (3) crown surface temperature through a thermal imaging sensor, (4) trunk temperature and humidity, (5) air temperature and humidity, (6) takes digital photographs inside the crown to further describe the phenological phase of development.

Renewal of device energy occurs through the use of solar panels. All sensors are measured once every 60 minutes. Data from devices enters the cloud of the digital platform "Monitoring 4.0" [4] in packaged form in a hexadecimal string (HEX format). Each parameter is encrypted using a certain number of bytes. At the beginning of each line there is a device identifier (id) equal to 6 bytes, then the date/time, sensor readings in hexadecimal (HEX) format, the last two bytes are a checksum to check data integrity.

The struct library is used to decrypt the string. To decrypt a string, an enumeration of matches with a given number of bytes is constructed (for example, 'b' is unsigned data in the amount of 1 byte, 'H' is unsigned data in the amount of two bytes, etc.). Then, using the unpack function, this enumeration is converted into an array of data; Ultimately, the following string is sent to the digital platform cloud:

- pl10010208350f0029cf08421dba19270840090f0b0d1db42d4528cd267202a703e803e803e803e803e803e803e803e

The digital platform "Monitoring 4.0" is a web application logically divided into two components: the server part, which is responsible for storing information, the logic of data processing and analysis, interaction with devices, and the interface part, which is responsible for presenting information to the user.

To develop the server part, we used the python3 programming language and the flask library, which allows you to create applications for interaction via the HTTP protocol (REST-full API). This protocol was used both by the interface part to obtain the necessary...
information, and by devices to save data about their indicators. To store data, a postgres DBMS with distributed storage on several disks and a system for creating data archives was used.

The interface part is implemented in the typescript programming language using the React library and the Mui component library. The ECharts library was used to construct charts, and the Leaflet library was used to display cartographic information.

The digital platform has the following functionality: storage and analysis of large volumes of data (big data), access to data in real time (IoT) via a web browser, construction of graphs and charts using current and archived data, calculation of the NDVI vegetation index using multispectral data sensor, automatically configured mode of notifications and user alerts, import of data into Excel or Jpeg (PNG), administration and separation of user rights.

3 Results

The life activity of plants is influenced not only by the current, but also by the previous state of the environment. One of the parameters that allows us to characterize the thermal regime of the environment for the period from the moment the air temperature passes through 0°C until the beginning of a particular phenophase is the average daily sum of positive air temperatures.

The transition of the average daily temperature through 0°C in 2023 (the onset of spring) occurred in early April. On the 20th of April, there was an increase in the sum of effective temperatures above +5°C. Analysis of photographs of the crown obtained from the "Plants" module allowed us to establish the dates of the passage of the main phenophases of the development of Malus domestica (presented below). The dependence of phenological development on air temperature is shown in Figure 2.

On May 16-18, the "Onset of leaf flushing" phenophase (BBCH 11) was observed in the trees under study. Hereinafter, the names of phenophases are given in accordance with the methodological recommendations of Meier et al. [5]. At the same time, the BBCH 11 phenophase in trees was noted at an average daily air temperature of +5.7°C and a sum of positive temperatures of 487°C.

The transition of the average daily air temperature through +5°C during the research period occurred on April 22. At the same time, for the leaves of Malus domestica to begin to bloom (May 16-18), an average daily sum of active temperatures of 325°C was required. The peak increase in the maximum average daily temperature occurred in mid-June. During
this period, the trees reached complete leafing (the "Onset of leaf-out" phenophase (BBCH 12–13)).

The phenophase "Onset of the flowering" (BBH 61) in *Malus domestica* was noted on May 28 at an air temperature of +13.3°C. "Full flowering" (Defloration completing, BBCH 69) took place on June 10 at a temperature of +19.7°C. The phenophase "Onset of fruit ripening" (BBH 81-86) was noted on August 16.

Climatic autumn and the phenophase "Onset of autumn coloring of leaves" (BBCH 92) began on September 27, by October 9 a mass change in coloring of leaves ("Mass change in coloration of leaves", BBCH 94) was already noted, the phenophase "The beginning of leaf fall" (Onset of leaf abscission, BBCH 93) was noted on October 19, at which time the average daily temperature transitioned below 0°C (the onset of winter).

![Fig. 2. Dependence of phenological development of Malus domestica on air temperature.](image)

The phenological development of trees was partially recorded using multispectral sensors aimed at the tree crown. The dynamics of the *Malus domestica* NDVI index according to multispectral sensor data for the period May-September is presented in Figure 3.

![Fig. 3. Dynamics of the Malus domestica NDVI index according to multispectral sensor data for the period May-September.](image)

The beginning of the growth diameter of the trunk according to the rangefinder (Figure 4) was marked on June 15-20, the growth lasted until July 20-25 and amounted to about 3 mm. The growth of the barrel took place after passing the phenological phase "Onset of Leaf-out" (BBCH 12–13) in parallel with the formation of fruits on trees (BBCH 81–84).
Fig. 4. Rangefinder readings for studying tree trunk growth for the period June 20 - July 20.

4 Discussion

Methodological approaches to monitoring tree health, even if based on high spatial resolution (e.g., aerial photography from unmanned aerial vehicles or satellite imagery), are limited by temporal resolution, which is often important for detecting the early onset of decline in physiological condition. Our research results show that an IoT network at the individual tree level, using sensors to monitor tree physiology in real time, can be successfully used to monitor the condition of fruit trees in agricultural complexes or trees in urban green infrastructure for early detection of accidents.

It should be noted that at the moment, for the mass implementation of such solutions, there are problems associated with the power consumption of the devices used, since solar panels are located under the canopy of the plant crown.

The study [6] convincingly showed that the developmental characteristics of various plant species are determined by their unequal demands on environmental factors. Therefore, by determining the range of plant tolerance to environmental factors, one can judge the degree of adaptation of the species to new habitat conditions.

Plant heat requirements are expressed by the average daily sums of active and effective temperatures. In plant phenology, the average daily sum of active temperatures is the daily average air temperature above the biological minimum for the beginning of plant development. As a rule, a woody plant begins to develop only at a certain level of heat - if the average daily air temperature exceeds the biological minimum, which is +5°C for woody plants. The conducted research confirms this thesis.

Analysis of the monitoring results of *Malus domestica* showed that the studied species, in most phenological development phases, has very similar development dates to local plant species (*Betula pendula, Sorbus aucuparia, Alnus incana*). No freezing of shoots in winter was observed in the studied tree species; therefore, *Malus domestica* is a highly promising introduced species for this area and can be recommended for introduction into the culture of fruit growing and landscaping in the cities of the North of Russia.

5 Conclusion

Based on the research, methods for remote monitoring in real time of the physiological state of trees have been developed. Analysis of the monitoring results revealed patterns of seasonal development of *Malus domestica* under growing conditions in the North of Russia for the purposes of local fruit growing. The phenophase "Onset of the flowering" (BBH 61) in *Malus domestica* was noted on May 28 at an air temperature of +13.3°C. "Full flowering" (Defloration completing, BBCH 69) took place on June 10 at a temperature of +19.7°C. The phenophase "Onset of fruit ripening" (BBH 81-86) was noted on August 16. Studies have shown that the species *Malus domestica*, in most phenological phases of development, has very similar development dates to local plant species (*Betula pendula, Sorbus aucuparia, Alnus incana*). No freezing of shoots in winter was observed in the
studied tree species; therefore, it can be classified as a highly promising introduced species for this area and recommended for introduction into the culture of fruit growing and landscaping in the cities of the North of Russia.

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References