Using an IoT system for monitoring climatic conditions during flowering in fruit plantations

Hristo I. Hristov[1], Borislav T. Ganev[2] and Lyubomir B. Laskov[3]

1 is a researcher at Trakia University, 6000, Stara Zagora, Bulgaria
2 is with Department of Electronics, Faculty of Electronic Engineering and Technologies, Technical University of Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria
3 is with Department of Radiocommunications and Videotechnologies, Faculty of Telecommunications, Technical University of Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria
h.hristovrd@gmail.com, b_ganev@tu-sofia.bg, llaskov@tu-sofia.bg

2023 XXXII International Scientific Conference Electronics (ET) | 979-8-3503-0200-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/ET59121.2023.10278739

Abstract – **The aim of this research is to use an IoT multi-sensor monitoring system, to track the temperature and relative humidity of the air, as well as the temperature in the active root-inhabiting soil layer during the flowering period of trees in an orchard, as an important stage of spring phenology. With the help of the system, there were detected negative temperatures at night and in early morning combined with high relative air humidity for a long time period, which in the monitored period can affect the coming harvest.**

Keywords – **remote sensing, flowering of fruit trees, IoT, air and soil temperature and moisture measurements.**

I. Introduction

Climate changes and the constantly growing need for increased food production are part of the serious issues that must be resolved by the agrarian sector. Their global character requires the creation of sustainable strategies for food security in the world. Increasing the efficiency of agriculture also includes the creation of varieties resistant to changing climatic conditions and with high productivity. The increasing appearance of peak values of some environmental factors in the moderate climate zone, create the needs to make research on the adaptability and phenological response of cultural plantations. The exclusive importance of these issues has led to the entry of digitization and information technology into the crop growing.

Flowering period is a very important stage in plant phenology and is decisive for the amount of harvest. Phenology is highly dependent on climate, and temperature and moisture are major factors influencing it. [1]. The latent state of buds in winter is interrupted in spring, and soil and air temperatures can have different effects on plants [2]. Low spring temperatures during flowering can cause serious problems and losses in the harvest [3]. Also, winter warming can prolong spring evolution, which can somewhat reduce the risk of late spring frost exposure [4]. Distribution in time and values of winter and spring temperatures affect the spring phenological processes. Different wood species have different climate requirements and, accordingly, different adaptation to extreme temperatures in transitional inter seasons period, as well as to unusually low temperatures late in the spring [5]. The monitoring of the phenology and phenological flexibility of the plants also gives the ability to explore climate change, the cycle of nutrients, and the interspecies connections in ecosystems [6-8]. Every year, spring frosts in the moderate climate zone cause serious losses of orchards. It is crucial to do studies to minimize their influence and to build systems for risk management and prevent damage made by them [9].

The requirements of remote monitoring of various factors and processes leads to the entry of sensory technology into agriculture [10]. They help with the detection of diseases and various types of stress, in localization of infections and areas covered by pests, when measuring soil parameters [11-14]. They are widely used in Resource Management, in the ecology, environmental protection, when the aim is reduction of the used chemicals, in tracking irrigation needs, in complete remote monitoring of plantations, production, etc. [15-17].

II. Motivation and Target

Flowering and the proper flow of spring processes are very important for the quality and amount of harvest in orchard plantations. In addition, if extreme temperatures occur, we could get information on the phenological sensitivity and the resistance of the planted trees to possible deviations from normal temperatures for the season. The importance of these factors for the quantity and quality of the harvest motivates us to do this study. The aim is to trace and evaluate the importance of measured temperatures and humilities of air and soil during the flowering period of fruit trees, to analyze the results, as well as to show the capabilities of the multisensory system for the examination of phenology by constant monitoring of different factors.

III. Methods, Data Collection and System Description

The system is intended for constant monitoring of air and soil temperature and moisture. It was installed in an orchard in southwestern Bulgaria and is made up of numerous sensors located at different heights and depths in accordance with the specific features of grown fruit varieties. In our study, we track the vertical distribution of temperature and relative air humidity, as well as the temperature and humidity in the active root soil layer. To seek a connection between them, we calculated the correlation coefficient between average day air temperatures at a height of 160 cm

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and the average daytime soil temperatures in one of the areas of interest, for a depth of 30 cm, for the whole study period with the help of the formula:

$$r_{XY} = \frac{M[(X-m_X)(Y-m_Y)]}{\sigma(X)\sigma(Y)}, \qquad (1)$$

which gives us a relation between the correlation moment and the product of medium-squared deviations of the two quantities[18]. Then, to trace the dynamics of the measured parameters, we divide the period into three parts and the average daily values for each of these three parts. Finally, to understand the speed at which the average daily air temperature changes as the dates progress for the entire period of study and the speed of change of the average daily soil temperature for the whole period, we calculate the slope function by the formula:

$$B_{slope} = \frac{\sum(x-\dot{x})(y-\dot{y})}{(x-\dot{x})^2}, \qquad (2)$$

Where x and y are the average values of measured quantities.

The sensors submit the measured values of the tracked parameters to a group of controllers who send them wirelessly using Lora Interface to another controller (Gateway), which in turn sends it via Wi-Fi over the Internet to the cloud storage for facilitated quick access, storage and any follow -up processing. Each sensor group with a controller uses autonomous power supply by solar panel and rechargeable battery. The system can be upgraded as needed by adding new different sensors and controllers and software. Figure 1 shows a diagram of the multi-sensor IoT monitoring system.

The first three sensor points, designed to measure temperature and relative humidity for 2.4, 1.6 and 0.8 m, are implemented using BME680 sensors. The communication with these sensors is done through two separate I2C interfaces. Since the length of the connecting wires exceeds the specifications of this interface, the data rate is reduced to ensure reliable communication. A DS18B20 sensor, housed in a hermetic enclosure, is used to measure soil temperature. VMC sensor is resistive type. Each sensor is pre-calibrated for the specific soil type.

A Heltec Wi-Fi LoRa 32 board was used. It consists of an ESP32 microcontroller together with an SX127x LoRa communication module. The LoRa gateway aggregates the data from all sensor nodes and provides a connection to the cloud application. Its structure is like the LoRa gateway, the main difference being the power supply unit. It transmits the measured data via a Wi-Fi interface. It de facto connects the sensor system to the outside world. Its structure is similar to the one shown in Fig. 1, with the difference that there are no sensors, and the power supply is provided by a wall adapter. The use of identical modules allows for easier and faster development of the whole system in the development stage and results in a lower final cost of the system under development[19]. A range extender is also provided for locations where communication over longer distances is required. Its structure is again like the one discussed. Sensors are missing again, but here the requirements for the power supply unit are greater. While the sensor nodes can provide a low-power mode for the system in a few minutes, this is not possible here.

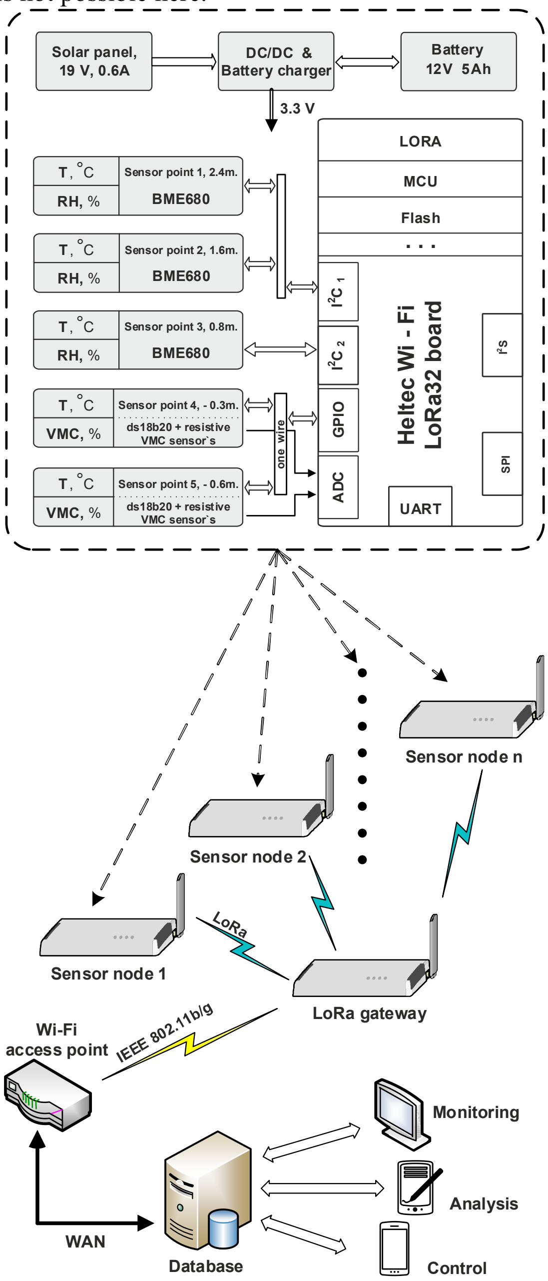

Fig. 1. Structure of the multi-sensor system

IV. DATA PROCESSING AND VISUALIZATION

Data were acquired, stored and processed in tabular form. The study period is from 17.03.2022 to 16.04.2022 inclusive. Calculations were made of the average temperatures and the average relative air humidity at the various points of interest for the entire study period. Average temperatures in the active root-inhabiting soil layer for two different depths were calculated. Mean daily air temperatures were calculated for each day of the study period. Average temperatures were calculated for the period of first ten-days, then for the second ten-days, and finally for the remaining eleven days. In order to understand the speed at which the monitored parameters change, we have calculated the Slope function separately for the change in the average daily air temperature and the change in the average daily soil temperature for the entire period of the study. Some of the results are visualized.

TABLE 1. AVERAGE DAY TEMPERATURES FOR THE STUDIED PERIOD

No	Date	Average Daily Air Temperature [°C]	Average Daily Soil Temperature [°C]
1	17 March	7,4	7,23
2	18 March	2,75	7,37
3	19 March	3,28	7
4	20 March	3,1	7,01
5	21 March	5,37	7,06
6	22 March	10,16	7,49
7	23 March	9	8,26
8	24 March	10,8	8,74
9	25 March	12,84	9,26
10	26 March	11	9,76

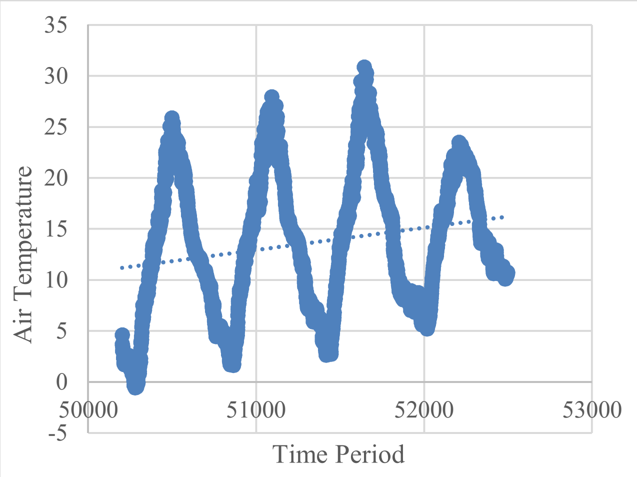

Fig. 2. Air temperature fluctuations for the period from 13.04 to 16.04 at a height of 160 cm.

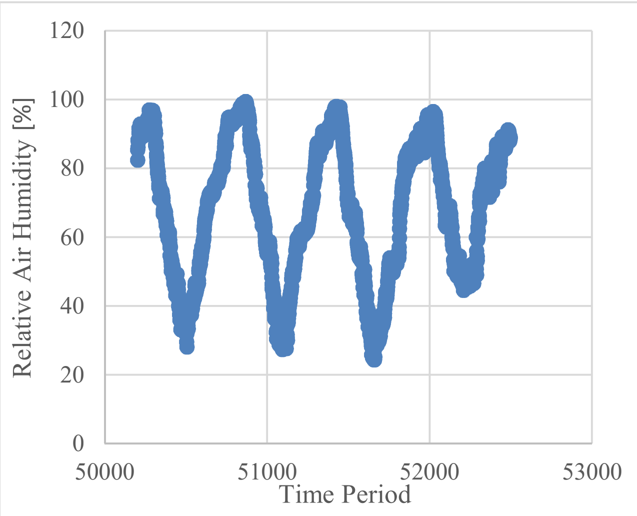

Fig. 3. Relative air humidity for the period from 13.04 to 16.04 at a height of 160 cm.

Figure 2 shows the change in the air temperature for one of the zones of interest for the period from 13.04 to 16.04 at a height of 160 cm.

On figure 3 are shown in graphic form the values of the relative air humidity in one of the zones of interest, measured in percentages at a height of 160 cm.

Figure 4 shows the distribution of the average daily air temperature for one of the areas of interest at a height of 160 cm, for the entire period of the study.

Figure 5 shows the fluctuations of the average daily soil temperature at a depth of 30 cm for one of the areas of interest for the entire period of the study.

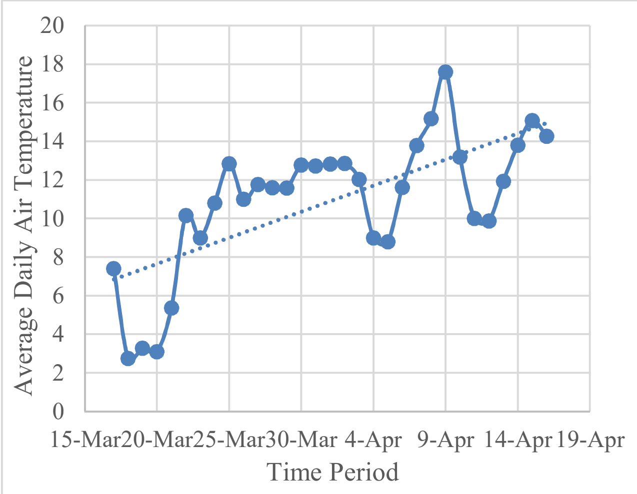

Fig. 4. Average daily air temperatures for one of the zones of interest, at an height of 160 cm, for the entire surveyed period

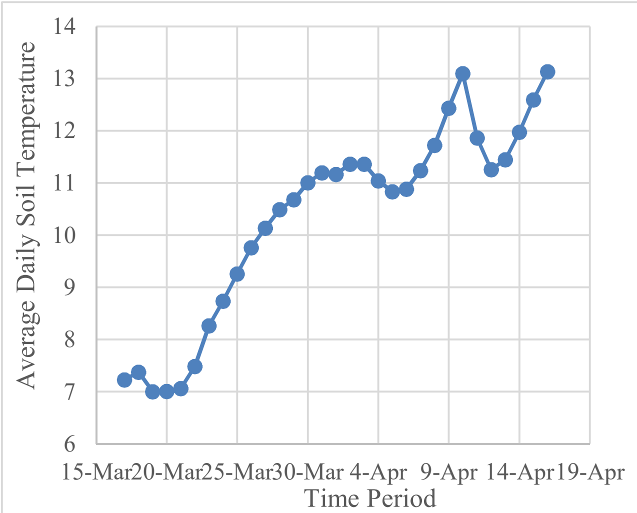

Fig. 5. Average daily soil temperatures for one of the areas of interest, for a depth of 30 cm, for the entire period tested

V. RESULTS

The average air temperature for the period from 17.03.2022 to 17.04.2022 inclusive was 10.9 ° C. The average daily air temperature for the first ten days of the period (from 17.03.2022 to 26.03.2022 inclusive) was 7.57 ° C. The average daily air temperature for the second ten days of the period (from 27.03.2022 to 05.04.2022 inclusive) was 11.6 ° C. The average daily air temperature for the last part of the studied period (from 06.04.2022 to 16.04.2022 inclusive) was 13.3 ° C. The lowest temperature measured for the period was -6.6 ° C, at 04:34 in the morning on 20.march, while at the same time the relative air humidity was 82.3 %. At that night, temperatures become negative after 21:02 on 19 march and remained negative until 06:10 on on 20 march, with humidity varying between 60% and 82%,. Between 02:25 and 05:30 in the morning of 20 march, the temperature was between -4°C and -6.6°C, and the relative humidity during this period was between 70% and 82%. The next evening, the situation was repeated with minimal differences. During the study period, the measured peak positive temperatures were up to 32 ° C. The average soil temperature at a depth of 30 cm was 10.14 ° C and at a depth of 60 cm was 9.92 ° C. The average daily soil temperature at a depth of 30 cm for the first ten days of the period (from 17.03.2022 to 26.03.2022 inclusive) was 7,92 ° C. The average daily soil temperature at a depth of 30 cm for the second ten days of the period (from 27.03.2022 to 05.04.2022 inclusive) was 10.93°C. The average daily soil temperature at a depth of 30 cm for the last part of the monitored period (from 04/06/2022 to 04/16/2022 inclusive) was 11.97°C. The speed of change of the average daily air temperature with advancing dates for the entire study period was 0.27. The speed of change of average daily soil temperature for the period was 0.19. The correlation coefficient between the average daily air temperatures at a height of 160 cm and the average daily soil temperatures for a depth of 30 cm in one of the zones of interest, for the entire period of study is 0.82.

VI. Conclusion

The system provides detailed and accurate information on the tracked parameters, on the basis of which forecasts and analyzes can be made. Prolonged night and early morning negative temperatures in the monitored period, combined with high relative air humidity, can cause disturbances in the formation of fruit buds, which affects the coming harvest. The calculations show that the temperature fluctuations of the air are more dynamic than those of the soil for the studied period. This is also seen in diagrams 4 and 5, where the soil temperature partly follows the air temperature, but more smoothly and with a certain delay.

IT and multi-sensing technologies make it possible to improve the conditions for growing crops, to increase the quantity and quality of the harvest. In conditions of constant climatic changes, remote sensing systems will have an increasing importance as a source of valuable and accurate real time information. They will help to build relatively stable and adapted to the specific natural conditions agricultural practices. They will play an increasingly important role in increasing food security.

Acknowledgment

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

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