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Testing outcomes of IoT based continuous crop weight and PAR sensors at industrial greenhouse

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Abstract. Industrial greenhouses have automated control systems for climate, lighting, irrigation, ventilation, and heating regulation using different types of feedback sensors. Nowadays it is a trend to increase the data precision and measurement data amount, thus various additional IoT sensors are installed, and the regulation becomes more precise, due to available data, which enables new analytical features to create new control rules or strategies. The general aim is to raise the level of process automation, quality, energy efficiency, and other important parameters. Still, further, we go into data resolution and amount, and the problem of data reliability and interpretation starts to become a challenging problem. In this article, authors focus on earlier developed PAR sensor modules and continuous tomato crop weight sensor modules (TWS) testing and received data analysis from an industrial greenhouse. Both sensors were tested in detail at the tomato greenhouse of 'Latgales Darzenu Logistika' in Mezvidi parish, with a total growing area of 5,062.4 m^2 from 1.05.2022 to 30.06.2022., and gathered data is analysed for this period. Received sensor data can be used as the main feedback signal to create a lighting control strategy, same time increasing energy efficiency and reducing also costs. As artificial lighting energy consumption costs make 20–40% of total greenhouse costs, it is worth having a more precise lighting control system algorithm, integrating the crop growth increase and accumulated light energy during the day from the sun, and then adding only the missing amount (also period) of light provided by artificial lighting. Experimental studies of both sensor data, show that plants reaction can be monitored, as by decreasing the lighting period and temperature setpoint by 6% each, the plants daily weight gain decreases by 14%, and it can be measured already in first day after the new settings were set in place.

Key words: greenhouse control systems, IoT, sensors, weight measurement.

INTRODUCTION

Nowadays industrial management systems are changing, using various Internet of Things (IoT) based sensor technologies, to create cloud-based databases. Industrial greenhouse control systems are no exception in this regard, as they have recently become more popular with the use of various sensors and cloud-based databases for the automation of vegetable and other crop cultivation processes (Singh et al., 2020; Blahins et al., 2021).

Each of these management systems has a control signal from a feedback loop, typically gained from some physical sensor, to control the vegetable growing process.

IoT technologies and sensors (Afzali et al., 2021; Potapovs & Avotins, 2022) are widely used in various fields of agronomy, for example for fermentation process of rice wine (Vošahlik & Hart, 2021; Vošahlik, 2023). Authors remark, that during the rice wine fermentation process, variety of measurable attributes are created which affect the quality of the resulting. With IoT they can be monitored with the help of automation elements (pH, temperature, humidity etc.) and the result is that, if the right environment is chosen, the quality of the fermented wine will improve. IoT sensor system can be used also for lighting system optimisation, where study (Afzali et al., 2021) shows, that electricity costs can be reduced by 4.16% reduction (winter) and 33.85% (spring).

The relevance of the importance of using and correct calibration of physical sensors is confirmed by studies of other authors, for example in the article (Shchuklina et al., 2021; Shchuklina et al., 2022) authors using optical sensors for efficient diagnostics of nitrogen nutrition. Results of their research show the efficiency of using optic sensors (N-testers) for efficient diagnostics of nitrogen nutrition of plants. Authors make conclusion, that such a modern optical device as N-tester, whose action is based on measuring the concentration of leafy chlorophyll, can replace chemical methods and increase the efficiency of nitrogen fertilization, which means increasing the productivity of plants and reducing the negative impact of unreasonable use of nitrogen fertilizers.

Also, popular sensor type is computer vision (CV). For example (Kurras et al., 2023) uses CV for automatic monitoring of dairy cows' lying behavior in open barns.

Authors in paper (Pažuls et al, 2018) describing system where using application of ultrasonic sensors in evaluation of distribution and depth of ruts in forest thinning, but (Bazhenov et al., 2021) using radar sensors for method for determining the moisture content of the upper layers of agricultural lands on the basis of mathematical modeling of a radar signal reflected from the soil.

Authors (Tkach et al., 2021) provide milk-meter based on electric capacitive sensors, where use of certain correction factors for sensor signal ensures sufficient measurement accuracy both for installations with stall milk pipelines and for milking parlors, including during milking of high-performance cows. Authors mark, that challenges include reliable approaches for object detection and tracking as well as pose estimation for images in the barn environment that are characterized by visual obstructions due to overlapping cows and barn infrastructure - occlusion. The authors also conducted studies about long-term testing and measurement data analysis of tomato crop weight sensor module (Potapovs & Avotins, 2022).

Also one of the parameters which is needed to monitor in exactly tomato greenhouses is photosynthetically active radiation (PAR) or photosynthetic photon flux density (PPFD) (Van Straten, 2011; Witkowski & Korzeniewska, 2019; Potapovs & Avotins, 2022).

PPFD monitoring allows recording the cumulative number of micromoles per day the plant has received, which in turn allows monitoring and analysing the impact of this parameter on other physical and technical parameters of the vegetable industrial greenhouse and, as a result, more effectively control the artificial lighting system and the parameters of the greenhouse.

Other type of important sensors is different types of weight sensors (WS), thus to control irrigation process of tomatoes, it is needed to monitor weight of tomato plants and its soil pod (Witkowski & Korzeniewska, 2019). Weight measurements show tendency of water (fertilizer) consumption and gives precise timing when irrigation must be started and stopped (change in moisture level between start and the end of watering is about 7 to 13%).

Also, weight sensors can be used for tomato weight measuring and it helps to show tendency of crops biomass increase (Moon et al., 2022), plants overall health, balance between parts of the plant according to programmed greenhouse climate values (Van Straten, 2011; Afzali, 2021).

Control system with such type of sensors can enable new features (Afzali, 2021):

- decrease of electrical energy consumption;
- decrease lamp burning hours per year;
- decrease CO_2 emissions;
- new lighting strategies avoiding or minimizing lighting in peak hours of electricity market.

Photosynthesis is almost instantly dependant on light increase/decrease on plant leaves, also according to 'shading' impact on crop yield decrease (Reed et al., 1988) we can define research hypothesis that a plant reaction on light decrease will result also on yield gain loss, but this effect is shifted by several days and it is not instant. The goal is to create an IoT sensor-based measurement setup, obtain measurement data and analyse them to see the tomato plant reaction time.

After the conducted research and the experimental use of sensors in real working conditions, the authors put forward the following main tasks:

- Compare the data provided by PAR sensor modules in different types of greenhouses and compare them with the irradiance data of industrial weathering, evaluate the operation of PAR sensor modules from the point of view of their operational stability, as well as evaluate their interaction with the data storage server;
- Compare tomato weight sensor module (TWS) data with official harvest data, evaluate sensor performance from the point of view of their operational stability, as well as evaluate their interaction with the data storage server;
- To perform mutual data analysis of PAR and TWS sensor modules, to determine the possible correlation between these two parameters, and use the obtained information for further adaptive control of the artificial lighting system.

MATERIALS AND METHODS

Description of PAR sensor and analysis of accumulated server data

Testing environment, greenhouse and PAR sensor module development and testing process in detail was described in the authors© previous work (Potapovs & Avotins, 2022). In developed IoT sensor modules, to measure the PAR parameter in industrial greenhouse conditions, the Apogee ePAR sensor SQ-615-SS with an analogue signal output (Apogee Instruments, 2022) was chosen, which operates in the range of 383 to 757 nm (+/-5nm), and allows to classify it to ePAR for sensors.

As the selected ePAR sensor model SQ-615-SS is an analogue sensor, so for measuring, its output signal needs to be connected to the microcontroller or the external ADC module. In this particular case, the authors chose the connection to the analogue input of the microcontroller according to the following schematic given in Fig. 1.

Two types of PAR sensor modules were developed (see Fig. 2). First type of PAR sensor is for static measurements, but second type is for portable measurements, for example passing through the whole row of plants.

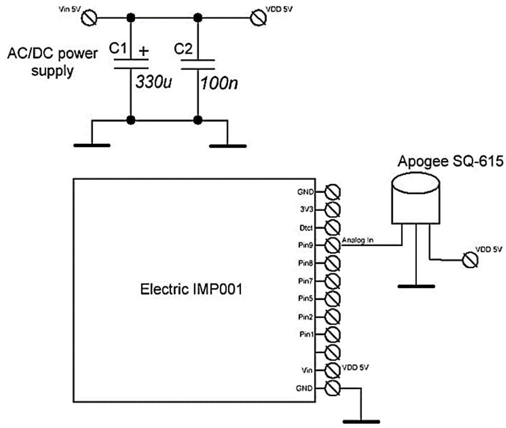
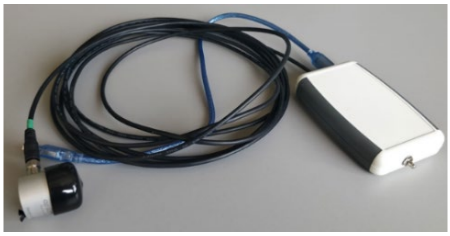


Figure 1. Electric scheme of PAR sensor prototype.

a) Static sensor



b) Portable sensor

Figure 2. Developed PAR sensor modules.

In IoT server side was developed data base, where was displayed following data (Fig. 3):

- current value PARmom,
- graph of PARmom historical data for the last 72 h,
- cumulative current day value PARsumm,
- graph of PARsumm of the daily cumulative values of the last month.

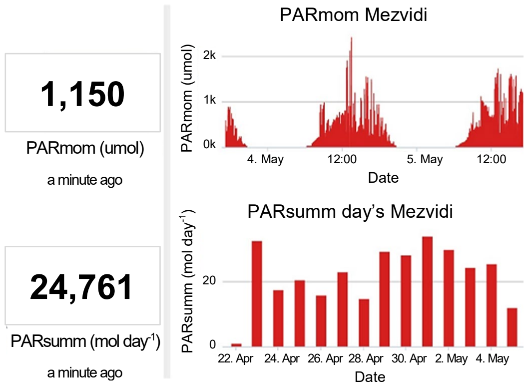


Figure 3. PAR sensor data example from the data server.

Growing conditions are not studied in this research, as they are maintained unchanged during the tests, and overall production/growing process is according to industrial greenhouse control system (PRIVA) and growing procedures. In June/July average temperature in greenhouse is maintained in 23–25 °C range (16–17 °C during night and 25 °C+/-3oC during the day), CO_2 injection was not used, relative humidity level is maintained 75% (night: 85%, day: 55–60%), only 'vegetation' heating pipe is used during night time only (45 °C), artificial lighting is not used, irrigation system/ cycles follows sun, where first is started 2–3 h after sunrise and last 3 h before sundown. Main focus lies on ePAR and TWS sensor reading and data analysis. More details on the sensor are given in author previous research (Potapovs et al., 2021 and Potapovs & Avotins, 2022).

The obtained two PAR sensor PARsumm data (cumulative PAR by days) from 1.05.2022 to 30.6.2022 (Fig. 4):

- One of them was installed in tomato greenhouse Mezvidi, which has venlo-type glass cover;
- Second in nearby located greenhouse of Aberry, which has double-film cover material and is growing strawberries).

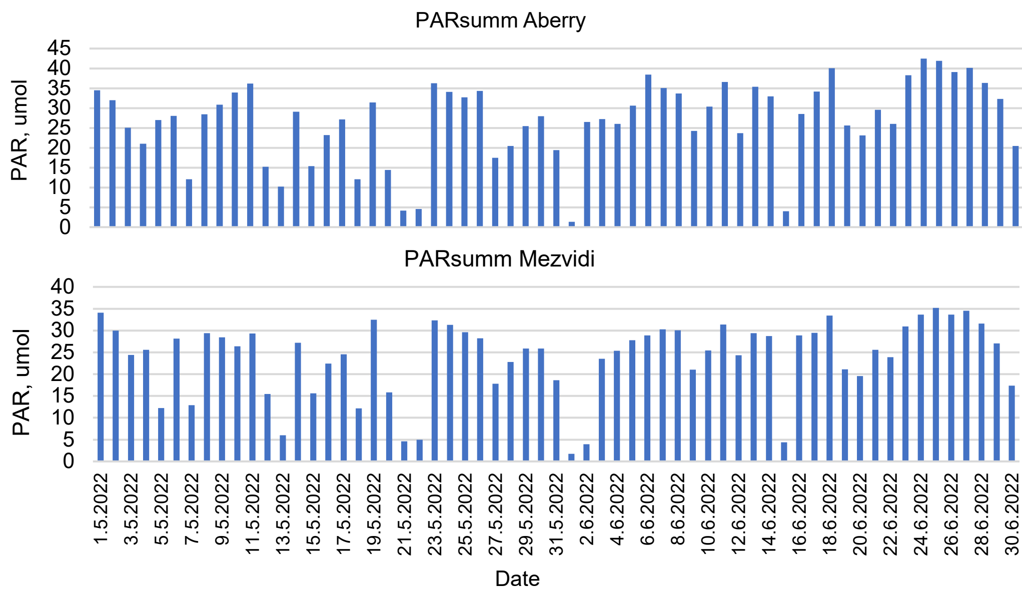


Figure 4. PAR sensor module PARsumm data of two type greenhouse from 1.05.2022 to 30.06.2022.

This data was compared with irradiation sensor data (Fig. 5) from weather station of the *Priva* industrial control system (see graphs below). The obtained data show that by installing PAR sensors inside the greenhouse, it is possible to measure the actual PAR value received by plants with much higher accuracy.

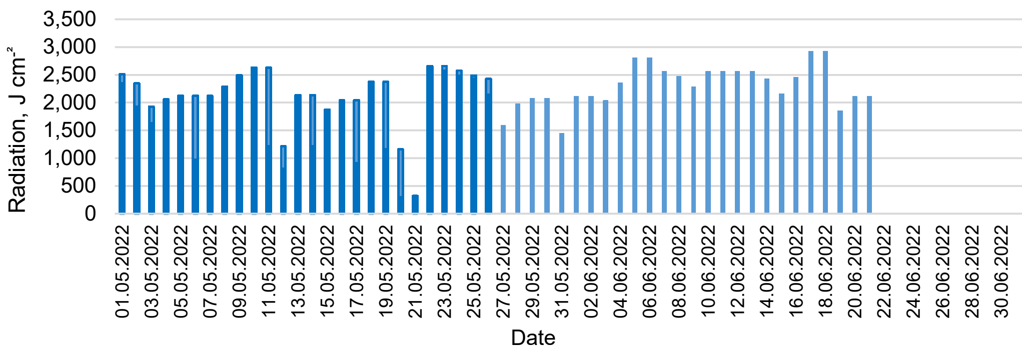


Figure 5. Industrial weather station data of irradiation.

Tomato weight sensors (TWSs)

Two types of weight sensor modules were developed and tested in industrial greenhouse conditions (Fig. 6):

- load sensor module (LSM),
- tomato weight sensor (TWS).

Development and testing of both sensors in details is described in previous research of Potapovs et al. (2021). LSM sensors are designed for weighing the base of the tomato plant substrate, for evaluating the efficiency of the automatic watering system. Also, one of these modules (LSM3) is used for testing the stability of the WS readings of the selected weight sensors over a long time period.

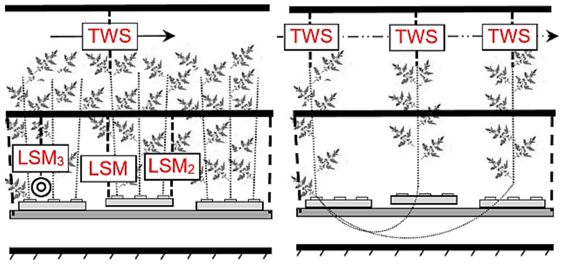


Figure 6. LSM and TWS testing schematic for real greenhouse environment: 1 – LSM sensors; 2 – TWS sensors.

On the other hand, TWS sensor, was developed to be used for measuring the weight of the specific/individual tomato plant, with the possibility to follow its overall (leaves, fruit, stem) mass gain in all its growth stages. The goal is to determine its yield or yield gain during daily period, especially in cases when conducting experiments with different types of lighting levels or periods, or, for example, the nutrient volume supplied and/or mix combination.

Developed and installed TWS sensor examples are shown in Fig. 7.

a)  b) 

Figure 7. Developed and installed TWS sensor examples: a) TWS internal design; b) installed TWS in greenhouse.

To store sensor data, a data base was developed at the IoT server side, where also following data can be displayed (Fig. 8):

- Graph of plant weight of the last 3 days, g (Fig. 8, a);
- Graph of plant weight growth of the daily cumulative values of the last 5 days, g d^{-1} (Fig. 8, b).

a)

b)

Figure 8. TWS sensor data example from the data server.

RESULTS AND DISCUSSION

For further analysis of stored data, we will use the readings of the first weight sensor W1 and calculated parameter W_{summ}, which is the daily (cumulative) weight gain in plant mass (Fig. 9). This sensor was installed in the row R16 of the Mezvidi greenhouse growing area with 40 growing rows in total.

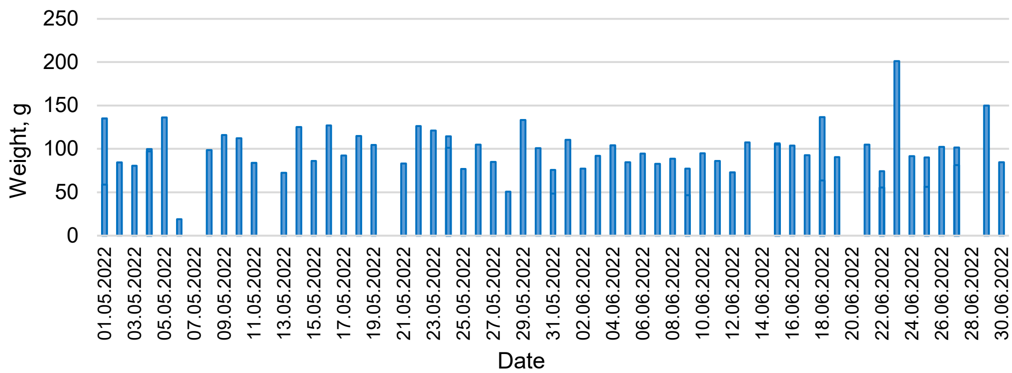


Figure 9. TWS sensor module W16 (R16) Wsumm data 01.05.2022–30.06.2022.

Fig. 10 shows harvested (manually measured) crop yield of a larger zone in the greenhouse, where the W1 sensor was installed. We can observe, that single sensor daily increase readings also show same tendency in reference zone weight increase or decrease. Normally 100 g per day gain is the targeted weight gain and could be accounted as good result for given situation (available solar light amount), thus everything above or below this threshold can give some predictive values. If we look at Fig. 9, at date 25.06.2022 we got twice the amount of daily weight increase, namely 200 g per day, and this is reflected also in Fig. 10 weekly harvest data of 29.06.2022. The 50 g and 0 g per day values in Fig. 9, can be explained by fruit cuts/drops in the morning or by leaf cuts during the day, as the weight can drop by 250 g or even more, so the cumulative daily plant mass gain value can get even negative (zero in our case, as logic rule is applied).

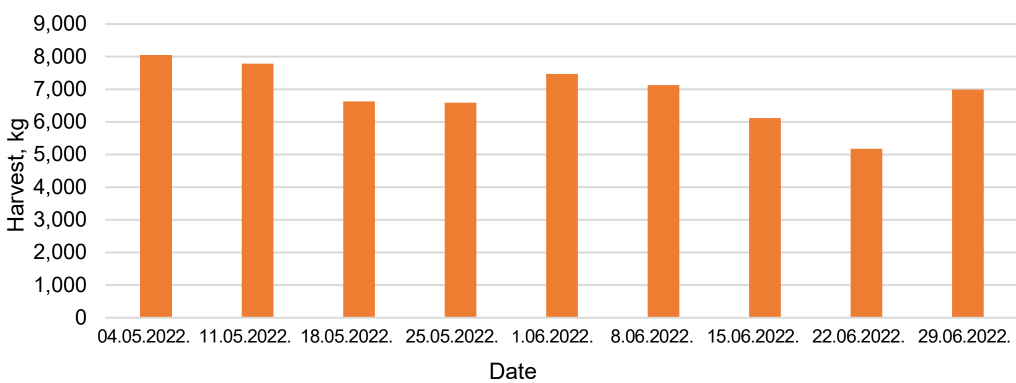


Figure 10. Reference harvest data from greenhouse 01.05.2022–30.06.2022.

Fig. 11. shows the effect of lighting period decrease by 1 hour per day (from 17.45 to 16.45 h) and temperature decrease by 1 °C (from 20.2 °C to 19.7 °C) starting from 01.01.2023. As we can see, the plants reaction happens much earlier - within few days, where before it was anticipated to have reaction in weeks.

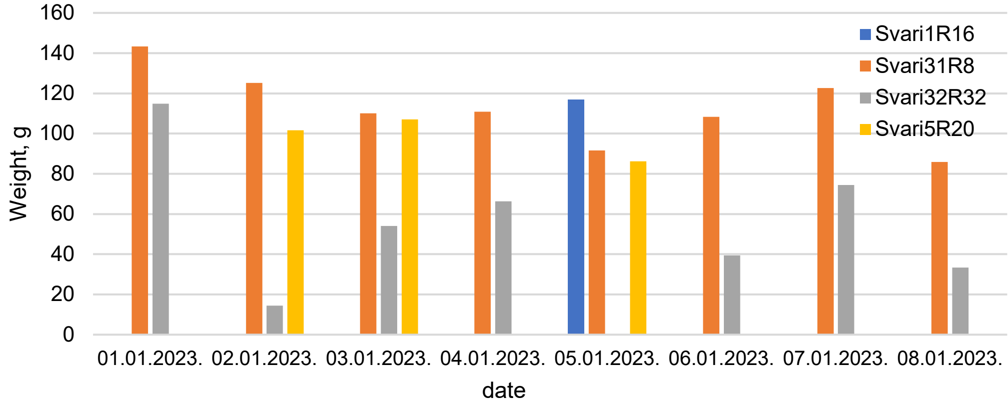


Figure 11. TWS sensor module readings in row 8 (Svari31R8), row 20 (Svari5R20), row 32 (Svari32R32) and row 16 (Svari1R16).

Analysing the data obtained from both installed PAR sensors, it can be concluded that their data differ significantly from each other and the characteristic curve differs even more from the data of the radiation characteristic curve of the external weather station (see Fig. 12), because the readings of the installed PAR sensors inside the greenhouse are influenced by such factors such as:

a) artificial lighting;
b) cleanliness of greenhouse windows;
c) the shadow cast by shading curtains;
d) greenhouse constructive materials;
e) greenhouse screens (motorised curtains for shading).

However, the installation of several such sensors inside the greenhouse above the top of the plants, might allow more accurate recording of the PPFD received by the tomato plants, than using the data of an external weather station, which does not observe all parameters in its readings.

In Fig. 12, we can see that Aberry greenhouse (growing strawberries) has double-film cover material, and Mezvidi tomato greenhouse has venlo-type glass cover, and for Aberry we observe 23–34% less instant PAR values, depending on sun's position during the day. These data were confirmed throughout the experiment lasting 2 months.

However, we can observe (Fig. 12) that the PAR sensor readings are also affected by the shadows cast by the greenhouse structures (they are more pronounced in the Mezvidi glass and metal frame greenhouse, but less in the Aberry greenhouse with less constructive elements), which introduces local drops in the sensor readings. Irradiation sensor, of the weather station, doesn't has such problem, as it is located outside the greenhouse, but it is unable to record the accumulated energy of the plants according to the 4 points described above.

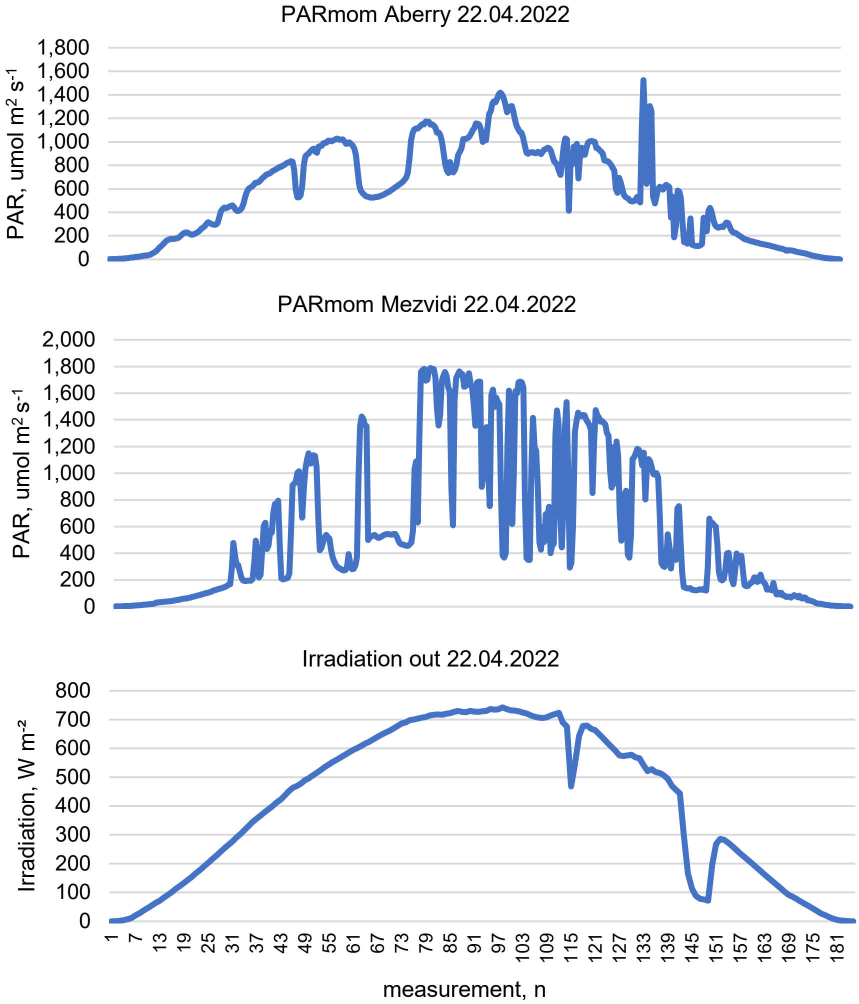


Figure 12. PAR and irradiation sensors data detailed comparison for 1 day.

During the processing of the data accumulated on the server after the 2-month experiment, the problem of the PAR sensor module, which was not resolved in time when developing the algorithm of recording and saving the daily cumulative reading, manifested itself in such a way that the value of the PARsumm previously accumulated in the current day becomes zero if the power voltage disappears. This can be addressed in two ways:

• Periodically saving this value in the energy-independent memory, thereby minimizing the lost volume of the cumulative value;

• Summation of several PARsumm inventory amounts (if its zeroing has been detected) in one day on the data storage server before saving the final value of PARsumm in the database.

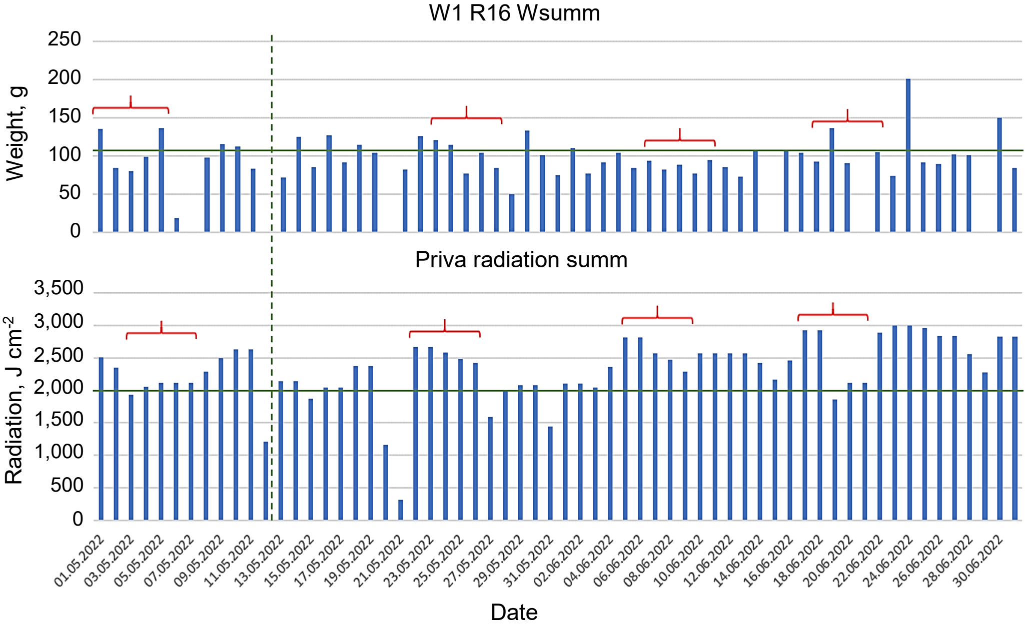


Figure 13. Obtained solar radiation values from greenhouse PRIVA control system and weight sensor data.

Fig. 13. shows solar radiation data from weather-station (located on greenhouse roof) stored by PRIVA system used for greenhouse control and developed weight sensor obtained daily weight increase data. It doesn't show clearly visible and repeatable relationship between light loss and daily weight decrease, but surely, we can observe some correlation here. According to greenhouse and growing technology manuals, this effect is considered to be one week, but we can see it happens between 1–4 days, which is much faster than prescribed. Also, we can observe, that some weight data are missing (around 16%), due to communication problems between hardware and database, thus raising the question about data reliability, which must be improved further in order to obtain more precise data for further evaluation and analytic method development. Sensor readings time to time were affected by the human factor, i.e. the workers who perform the operations around the plants (harvest, care for the plant, hang it, etc.), sometimes didn't hang the plant back in the scale after the last-mentioned operations, so further data from them were lost or faulty. The further use of this type of sensors within creates additional demands on the greenhouse service personnel. With TWS and PAR sensor application and data monitoring, plants reaction can be monitored, as we found out that in one row, the light period and maintained greenhouse temperature decrease by 6% each, resulted in decreased plants daily weight gain by 14% already in first day after the new settings were set in place. This effect dynamics must be studied further, also placing a focus on predictive algorithm studies and testing.

As stated in Perin et al. (2018), the accumulated incoming light radiation has larger impact on plant growth variables than temperature. The shading experiments by other researchers also confirm that tomato is sensitive to light decrease, where measured plant dry matter decreased by 19%–31% and yield loss was observed (Kläring & Krumbein, 2013).

For tomato greenhouse manager, the yield predication is an important parameter, as it directly affects the income or contract demands fulfilling for supermarkets. One of the IoT sensor benefits is the data that can be obtained in hourly, daily or weekly basis, enabling automatic data recoding and feeding into prediction algorithms (Higashide, 2009) or enabling new control algorithms for supplemental LED lighting, as it can compensate the yield decrease if reacted in advance (Tewolde et al., 2018). In case of neural network variant application, the research by Rajashree et al. (2022) indicates, that Vanilla GRU method gives higher precision prediction results, but as it is used in different field, it should be confirmed also for tomato crop prediction application.

CONCLUSIONS

When analysing the collected data from the TWS sensors, it became clear that the not all data were recorded, and after deeper analysis we can conclude, that possible issues for this problem are related with availability of AC mains voltage, WiFi router connectivity or data packet collisions, microcontroller code (program or sequence), instability of reference voltage value or human factor (tomato harvesters). As the data are obtained distantly, it would be advisable to integrate internal system self-check routines and parameters that are also sent to the database - to have more details about failure type for further improvements.

The second factor affecting full data collection from several TWS was the operating algorithm of the data server version used at the time, which was unable to record the sent data packets from several sensors at the same time (under certain conditions of synchronization of the working modes of the sensors, the data of the first sensor was recorded, the rest were ignored). This factor strongly influenced the fixation of the daily cumulative value, which was sent only once a day.

Experimental studies of PAR and TWS sensor data, show that plants reaction can be monitored this way, as by decreasing the lighting period and temperature setpoint by 6% each, results in decreased plants daily weight gain by 14%, already in first day after the new settings were set in place. The dynamics of this effect must be studied further, also placing a focus on predictive algorithm studies and testing.

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REFERENCES

Afzali, S., Mosharafian, S., Van Iersel, M. W. & Velni, J.M. 2021. Optimal Lighting Control in Greenhouses Equipped with High-intensity Discharge Lamps Using Reinforcement Learning. *2021 American Control Conference (ACC)*, pp. 1414–1419. doi: http://dx.doi.org/10.23919/ACC50511.2021.9482964

Afzali, S., Mosharafian, S., van Iersel, M.W. & Mohammadpour Velni, J. 2021. Development and implementation of an IoT-enabled optimal and predictive lighting control strategy in greenhouses. *Plants* **10**(12), 2652. doi: http://dx.doi.org/10.3390/plants10122652

Apogee Instruments, SQ-610 Datasheet, internet website: *https://www.apogeeinstruments.com/content/SQ-610-spec-sheet.pdf* (last accessed 28.11.2022.)

Bazhenov, A., Sagdeev, K., Goncharov, D. & Grivennaya, N. 2021. Bistatic system for radar sensing of soil moisture. *ERDV*, 919–925. doi: http://dx.doi.org/10.22616/ERDev.2021.20.TF207

Blahins, J., Kalnins, G., Kalnins, K. & Zabasta, A. 2021. IoT smart add-on for small-farms milking machine. *ERDV*, 1494–1500. doi: http://dx.doi.org/10.22616/ERDev.2021.20.TF320

Higashide, T. 2009. Prediction of Tomato Yield on the Basis of Solar Radiation Before Anthesis under Warm Greenhouse Conditions. *HortScience horts* **44**(7), 1874–1878. doi: https://doi.org/10.21273/HORTSCI.44.7.1874

Moon, T., Kim, D., Kwon, S., Ahn, T.I. & Son, J.E. 2022. Non-Destructive Monitoring of Crop Fresh Weight and Leaf Area with a Simple Formula and a Convolutional Neural Network. *Sensors* **22**, 7728. doi: http://dx.doi.org/10.3390/s22207728

Kläring, H.-P & Krumbein, A. 2013. The Effect of Constraining the Intensity of Solar Radiation on the Photosynthesis, Growth, Yield and Product Quality of Tomato. *Journal of Agronomy and Crop Science* **199**(5). doi: http://dx.doi.org/10.1111/jac.12018

Kurras, F., Gravemeier, L.S., Dittmer, A., Kümper, D. & Jakob, M. 2023. Automatic Monitoring of dairy cows lying behaviour using a computer vision system in open barns. *Agronomy Research* **21**(S2), 482–493. doi: https://doi.org/10.15159/AR.23.029

Perin, L., Marins, R.P.N., Trentin, R., Streck, E.A., Schulz Bergmann da Rosa, D., Hohn, D. & Silveira Schaun, W. 2018. Solar radiation threshold and growth of mini tomato plants in mild autumn/winter condition. *Scientia Horticulturae* **239**, 156–162, ISSN 0304-4238, https://doi.org/10.1016/j.scienta.2018.05.037

Potapovs, A. & Avotins, A. 2022. ePAR Sensor Testing for Industrial Greenhouse Lighting Control System Application, *2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)*, pp. 1–6. doi: http://dx.doi.org/10.1109/RTUCON56726.2022.9978897.

Potapovs, A., Avotins, A., Gruduls, J, Čeirs, R. 2021. Long-term testing and measurement data analysis of tomato crop weight sensor module *ERDV*, 1590–1597. doi: http://dx.doi.org/10.22616/ERDev.2021.20.TF339

Rajashree, K.; Prema, K. V.; Rajath, G.; Angad, S. 2022. 'Prediction of fruit rot disease incidence in Arecanut based on weather parameters'. *Agronomy Research* **20** (S1), 1117–1133. doi: https://doi.org/10.15159/AR.22.076

Reed, A., G. Singletary, J. Schussler, D. Williamson & A. Christy, 1988. Shading effects on dry matter and nitrogen partitioning, kernel number, and yield of maize. *Crop Science* **28**(5), 819–825. doi: http://dx.doi.org/10.2135/cropsci1988.0011183X002800050020x

Shchuklina, O., Afanasiev, R., Voronchikhina, I., Klimenkova, I. & Komkova, A. 2021. Differentiated application of nitrogen fertilizers based on optical sensor readings. *Agronomy Research* **19**(2), pp. 595–600. doi: https://doi.org/10.15159/AR.21.093

Shchuklina, O., Afanasiev, R., Gulevich, A., Baranova, E., Kvitko, V. & Kvitko, O. 2022. Using data of optic sensors and pigment content in leaves for efficient diagnostics of nitrogen nutrition. *Agronomy Research* **20**(4), 805–813. doi: https://doi.org/10.15159/ar.22.048

Singh, R.K., Berkvens, R. & Weyn, M. 2020. Energy Efficient Wireless Communication for IoT Enabled Greenhouses. 2020 International Conference on COMmunication Systems & NETworkS (COMSNETS*)*, pp. 885–887. doi: 10.1109/COMSNETS48256.2020.9027392

Tewolde, F.T., Shiina, K., Maruo, T., Takagaki, M., Kozai, T. & Yamori, W. 2018. Supplemental LED inter-lighting compensates for a shortage of light for plant growth and yield under the lack of sunshine. *PLoS One* **13**(11). doi: http://dx.doi.org/10.1371/journal.pone.0206592

Tkach, V., Achkevych, V., Bratishko, V. & Achkevych, O. 2021. Milkmeter based on electric capacitive flow sensor. *ERDV*, 528–533. doi: http://dx.doi.org/10.22616/ERDev.2021.20.TF108

Van Straten, G., Van Willigenburg, G., Van Helten, E. & Van Ooteghem, R. 2011. *Optimal Control of Greenhouse Cultivation*. Book (318 pp.). Taylor & Francis Group, pp. 26. doi: http://dx.doi.org/10.1201/b10321

Vošahlík, J. & Hart, J. 2021. Measurability of quality in fermentation process of rice wine by IoT in the field of industry 4.0. *Agronomy Research* **19**(S3), 1318–1324. doi: https://doi.org/10.15159/AR.21.063

Vošahlík, J. 2023. IoT and measurement of fermentation process of rice wine. *Agronomy Research* **21**(3), 1419–1426. doi: https://doi.org/10.15159/ar.23.081

Witkowski, P. & Korzeniewska, E. 2019. Comparative analysis of HPS and LED luminaries in terms of effectiveness of greenhouse plant lighting and light emission. *2019 Applications of Electromagnetics in Modern Engineering and Medicine (PTZE)*, pp. 254–257. doi: http://dx.doi.org/10.23919/PTZE.2019.8781713

Pažuls, K., Štāls, T., Zimelis, A. & Lazdiņš, A. 2018. Preliminary conclusions on application of ultrasonic sensors in evaluation of distribution and depth of ruts in forest thinning. *Agronomy Research* **16**(S1), 1209–1217. doi: http://dx.doi.org/10.15159/ar.18.051