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Development and testing results of IoT based air temperature and humidity measurement system for industrial greenhouse

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Abstract. Industrial greenhouse control systems are changing and getting new capabilities, due to the evolution of the Internet of Things (IoT) technologies, allowing wirelessly integrate various sensor technologies and create a cloud-based database and analytic solutions. Greenhouse systems typically are controlled by consuming single temperature and humidity measurement unit data (treated as an average value), this raises a question about the precision of such approach for application in a large industrial greenhouse. In this article IoT based temperature and humidity measurement system uMOL architecture is described and first measurement results of multi-point data collection with high resolution compared to existing single-point measurements.

Key words: Temperature, humidity, wireless data, IoT, Greenhouse automation systems.

INTRODUCTION

It is well known, that energy efficiency is one of Europe's and Latvia's economy actual problem, where electricity and heat energy costs are a significant components also in the industrial greenhouse sector, for main consumers like lighting, irrigation and climate control systems. For greenhouse illumination high pressure sodium lamps are widely used, having high electricity consumption and extra heat losses, and during plant growth process this heat can 'burn' top part of the plants stalk. As greenhouse environment control systems play an important role (Salazar et al., 2010) in tomato plant and crop growth, thus even small changes to their parameters can influence and result in undesired changes after a week, as the growth process is relatively slow and effect isn't noticeable immediately.

Existing industrial greenhouses are designed and their lighting systems are built to use high-pressure sodium vapour lamps, but nowadays due to recent LED technology advancement, they are replaced by LED luminaries to get electrical energy savings, at the same time increasing need for additional heating energy. Impact of LED lighting on crop quality can be investigated by calculating fluctuating asymmetry (Rakutko et al., 2017), as it is known to be minimal only under optimal environmental conditions, but it increases under any stress conditions, that is caused by electronic ballasts of RGB LED lighting sources (Tetervenoks & Galkin, 2012). The height of greenhouse is around 6 m, therefore temperature and humidity levels vary across greenhouse. Accordingly having an impact on plants and their crop growth rate. To determine the exact effect, more detailed studies must be carried out for relatively long period of time, by measuring temperature, humidity and crop growth rate, and analysing outdoor weather conditions impact on plants growth and tomato production. Furthermore, such study may play important role to notice changes in temperature and humidity readings in upper height levels of a greenhouse, in case if existing sodium vapour top-lighting is changed to LED technology. The freezing effect can happen, as with lower temperature and higher humidity, ventilation system opens the ventilation windows, letting inside the cool air, which in winter can damage upper plants stalk.

Greenhouse environment, in general, is determined by inside temperature, humidity and CO_2 levels, which are affected by sunlight, outside parameters, inside heat sources (heating, lighting). Energy and environmental parameters can be measured in real time using wireless IoT solutions like (Kondratjevs et al., 2016), and by adding parameters of crop measurements, can used to calculate cost function $J(u)$ as given in formula (1), where $\Phi(x, t)$ is the final cost determined by the crop dry weight parameters (2), and $L(x, u, t)$ is penalties costs for temperature, relative humidity and energy consumption (3), where t_f and t_0 are time domain period. Example of such calculation approach is given research done by (Van Ooteghem et al., 2003).

$$J(u) = -\Phi(x, t) + \int_{t_0}^{t_f} L(x, u, t)dt \tag{1}$$

$$L(x, u, t) = L_{Ta}(x, u, t) + L_{RHa}(x, u, t) + L_Q(x, u, t) \tag{2}$$

$$\Phi(\mathrm{x}, \mathrm{t}) = C_{Wf} \times (t_f - t_0) \times (W_f(t_f) - W_f(t_0)) \tag{3}$$

This study demonstrates the importance of temperature and humidity parameter measurements, and question raises how detailed the measurements should be in a time domain, and geographically in the greenhouse. Research done by (Chung et al., 2012), shows that greenhouse of 650 m^2 growing cherry tomatoes, has temperature variates from 2.12 °C to 6.20 °C in various greenhouse sectors at the same time, and humidity variates from 11.18% to 19.27%. As greenhouse systems typically are controlled by single temperature and humidity measurement point data (treated as an average value), this raises a question about the precision of such approach for control and prediction algorithm application in a large scale industrial greenhouse.

MATERIALS AND METHODS

Description of experimental place

IoT based temperature and humidity measurement system with detailed data resolution is created and installed at an industrial greenhouse, to monitor climate readings throughout a year. The industrial greenhouse grows several sorts of tomatoes and can be treated as a complex environment, as it has a relatively large growing area (5,062 sq. meters), same time having a height of 6 meters, 40 sections of tomato growing rows top-lighted by 1,760 pieces of Hellight Helturn 400 W high-pressure sodium vapour lamps. Total installed electrical power is around 809 kW including ballast losses, and in same time these electrical losses can be treated also as heat energy gains with same power affecting inside temperature and humidity levels. Clear horticultural glass of 3.8–4.2 mm thickness is used for greenhouse, inner temperature level is set from +19 °C in night and +21 °C, but in reality temperature varies from +16 °C to +24 °C, and relative humidity level around 60–92%. Outside the greenhouse is a meteorological data measurement system and, in order to collect readings of inside temperature, humidity and CO_2 levels, one measurement unit is placed in the centre of the greenhouse, collecting data every 5 minutes.

uMOL temperature and humidity measurement system

The developed IoT based air temperature and air humidity measurement system ‘uMOL’ consists of eight sensor poles, distributed evenly at greenhouse growing area, where each pole (A-G) has six sensors, measuring temperature and humidity values every 30 seconds (see Fig. 1). The vertical distance between each sensor is one meter, and the one sensor measures parameters above light curtains (see Fig. 2). With such approach, detailed data about greenhouse environment is obtained, analysed and correlated with other parameters from a photobiological perspective, crop yield and quality. Furthermore, data correlation between outside weather conditions can create necessary inputs in order to adjust greenhouse lighting, climate, irrigation and power system, more suited to local geographical conditions, enabling the creation of new greenhouse control system program and control algorithms.

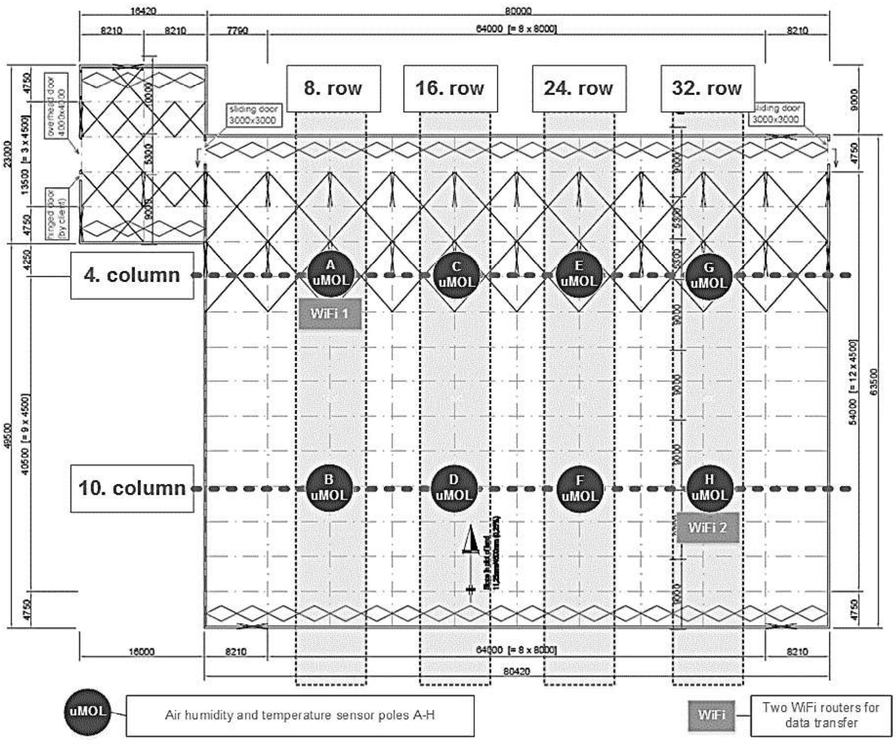

Figure 1. Typical industrial greenhouse layout and uMOL sensor pole A–H placement.

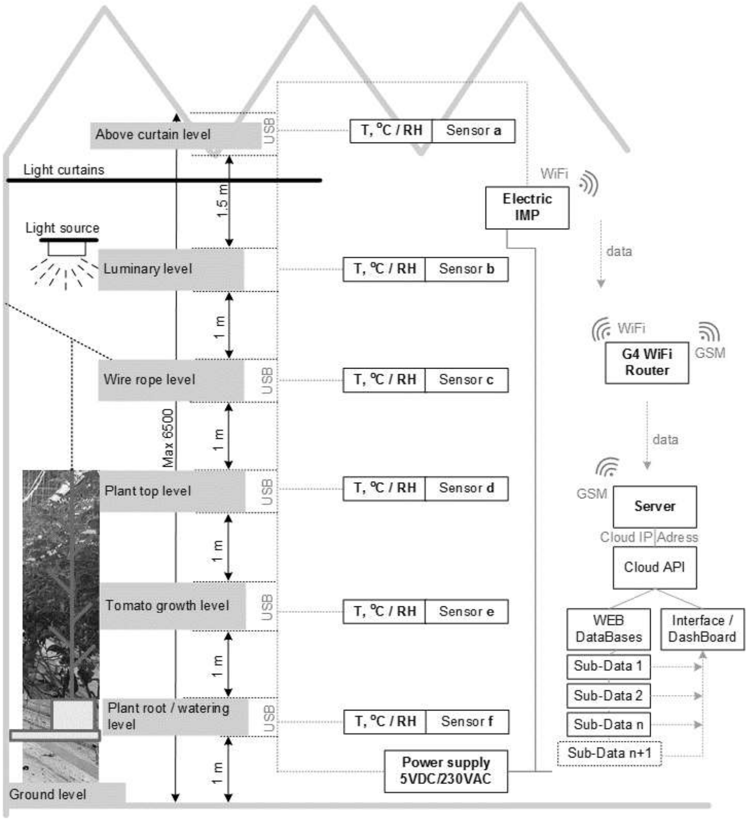

Figure 2. uMOL data system and temperature and humidity sensor pole schematic.

uMOL data system and temperature and humidity sensor pole schematic is shown in Fig. 2, where for each sensor pole A–H, six measurement levels (a-f) are selected to be observed in details. In this way 48 measurement points are placed around greenhouse, at different altitude and location. Each sensor measures both temperature and humidity. Sensor F is placed on level of plant roots and irrigation height, the next sensor E is placed at tomato growth level, then next sensor D is at plant top level. The next sensor C observes wire rope level, where tomato plant wire is attached and thus its top part is periodically moved further (length of tomato plant after 10-month vegetation period is around 14 m). Sensor B measures parameters at luminary mounting level and upper heating pipe level, but sensor (see Fig. 4) A gets readings above light curtains, used during nights to decrease heat losses through greenhouse glass and decrease solar radiation in summer during daytime. For sensor module development Sensiron SHT21S integral circuit is used (see Table 1).

Table 1. Technical parameters of temperature and humidity sensor Sensiron SHT21S

Parameter	Range	Accuracy	Resolution	Long Term Drift
Temperature sensor	-40 … +125 °C	+/- 0.3 °C	14 bit	< 0.04 °C per yr
Humidity sensor	0..100% RH	+/- 2% RH	12 bit	< 0.5% RH per yr

Temperature and humidity data are read by the ATtiny85 microcontroller and by means of multiplexing circuit sent to Electric Imp module Cortex micro-controller. Development imp001 module is used, where raw (binary) temperature and humidity data are converted to real values, that are wirelessly (WiFi) sent to logging file on the server. Electric Imp Platform is the first IoT platform to be independently certified to UL® 2900-2-2 (Standard for Software Cybersecurity for Network-Connectable Devices, Part 2-2: Particular Requirements for Industrial Control Systems). Thus we gain additional data security in addition to server side security means.

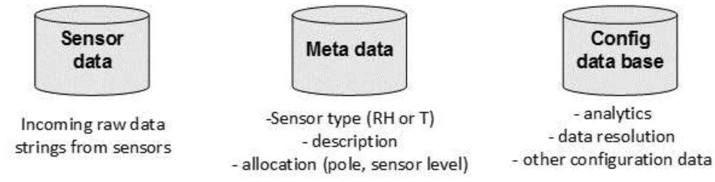

Figure 3. uMOL system data base main structure and functions.

Figure 4. uMOL sensors in Mezvidi greenhouse.

Sensors a-f are connected through USB cable and attached to data transmission and post-processing module (Electric Imp) with integrated WiFi transceiver, which is located at each Sensor pole (A-H). The obtained raw data strings are sent to Cloud based server using two 4G mobile network WiFi routers (4 poles (24 data points) are connected to one router), where they are stored in raw format in Sensor database (see Fig. 3), then deciphered in Metadata database, adding additional information, and then processed for data analysis in a Configuration data base. The software architecture uses Microsoft technologies and platform products, the development environment is Visual Studio, but its components are done in C#, XAML, JS, HTML5, CSS3 programming languages and stored on Microsoft Azure cloud computing platform server in Ireland datacentre. Data storage uses is stored in SQL relational databases.

RESULTS AND DISCUSSION

System setup was activated at industrial greenhouse at the end of September 2017. In September 2017 – January 2018 period sensors have generated over 5 million entries of sensor data readings. Along with the uMOL sensors system contains sensor data readings from Mezvidi greenhouse management system. We use both system sensor data to identify and illustrate differences in the measurements. As previously described, the sensor measurements are captured at various locations and altitudes in the greenhouse compare to a single sensor unit (at fixed height) that is used for greenhouse management system.

As uMOL system gets readings each 30 seconds, and existing single point measurement is done once per 5 minutes, temperature data post-processing is needed for comparison, and to get new temperature value (T) for new period (in this case 5 minutes), simple averaging formula (1) is applied:

$$T_{period} = \frac{1}{n}\sum_{i=1}^{n} t_i \quad (4)$$

where n – data-set extent for 5min period; t_i – variable at the i index of a data-set, n.

This approach allowed us to compare uMOL system sensor data reading with the ones captured by greenhouse native system. We choose for detailed discussion analysis 24 hours of 7th of January 2018. Temperature sensor data readings (see Fig. 5) demonstrates measured Max, Min and Average temperature values from all 48 uMOL sensors. Bolded line shows greenhouse single-point sensor data reading and it is mostly close with calculated average temperature across all uMOL temperature sensors. Largest deviations can be observed during high sun activity (12:00) period differing up to 10 degrees and up to 5 degrees during the night period (22:00 till 2:00). The figure shows, wide ranges in temperatures changes in all greenhouse levels.

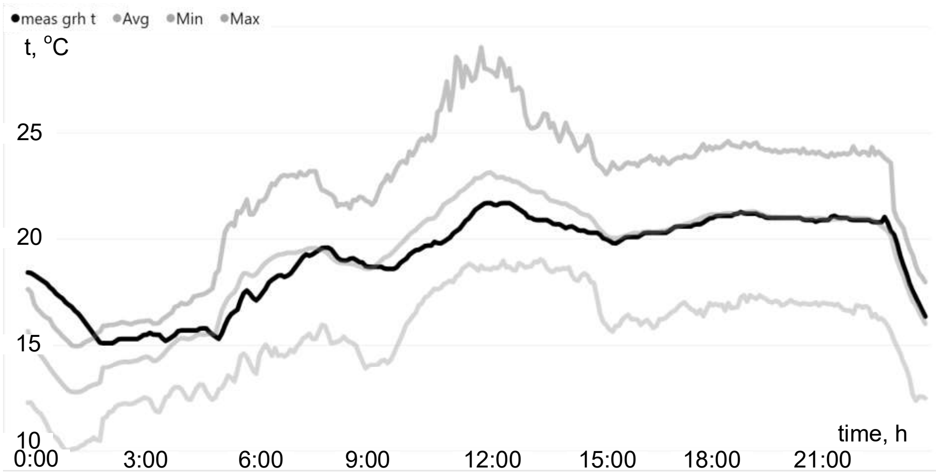

Figure 5. uMOL system and greenhouse system temperature data comparison using all levels.

Due to fact that heat is moving upwards, we could analyse the temperature sensor data readings same way as in Fig. 5, using only C, D and E levels to be compared against greenhouse single point sensor readings, thus obtaining results, shown in Fig. 6. The difference during high sun activity period (see Fig. 7) vary up to 5 degrees and up to 3 degrees during the night period. The greenhouse system value is more close to uMOL readings of E level.

Both figures clearly indicate best average temperature stability when artificial light is turned ON, but most differences when lights are turned OFF and sunlight is present. This effect can be taken into account, to create more precise heat and ventilation system control algorithms, and even more – it brings the idea, that highest (A,B) and lowest (F) level sensor data can be used to predict middle-level temperatures for next time periods.

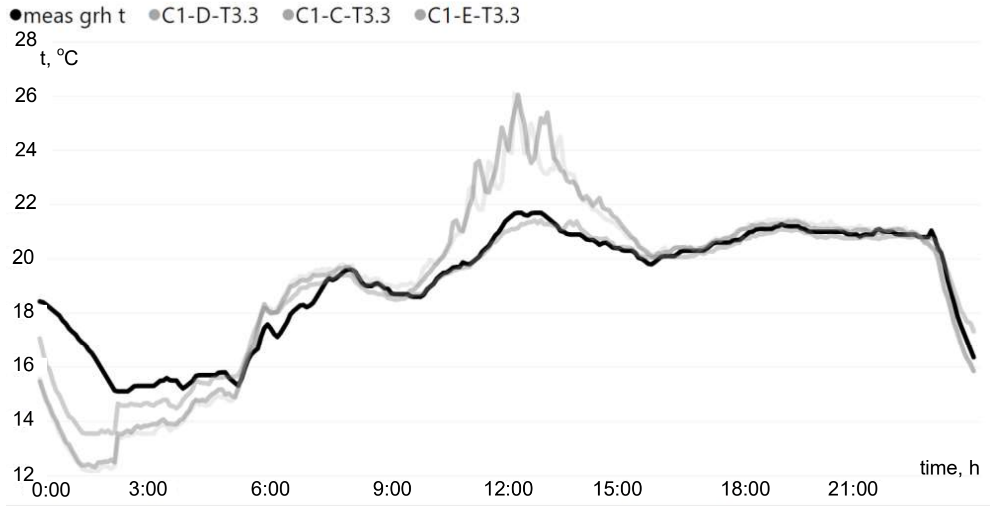

Figure 6. uMOL system and greenhouse temperature data comparison using only levels C,D,E (plant area).

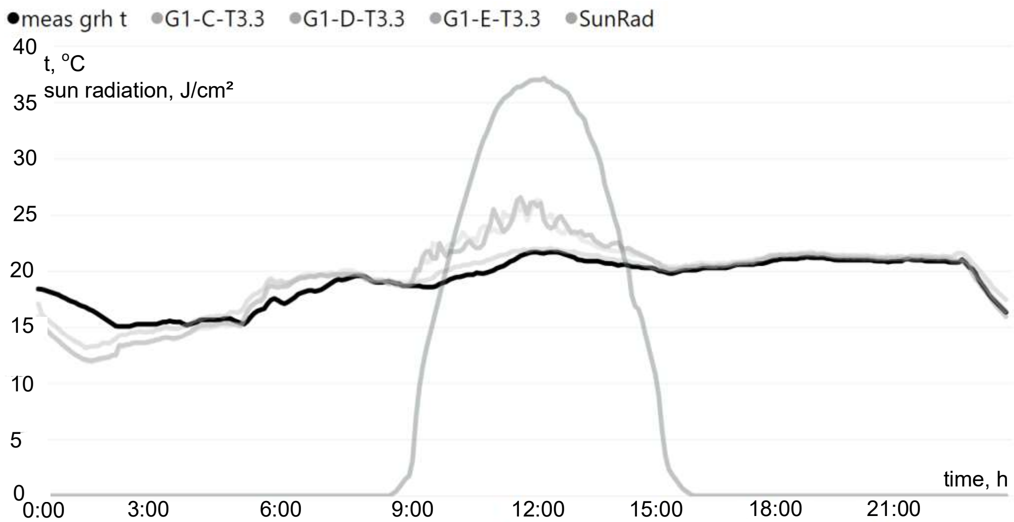

Figure 7. uMOL system G pole C,D,E sensor level, greenhouse temperatures (M=1:1) and sun radiation readings (M=1:20).

As the greenhouse measures humidity deficit value (see Fig. 8), it looks very stable (amplitude is 2.5%) but variation between values is 58%, same time all pole D level relative humidity readings (%) look more dynamic (amplitude 14%–28%), and giving variations between readings around 65.7%. If looking on average monthly readings of relative humidity and temperature (see Fig. 9), in both cases it shows difference between the various greenhouse zones (around A-H poles).

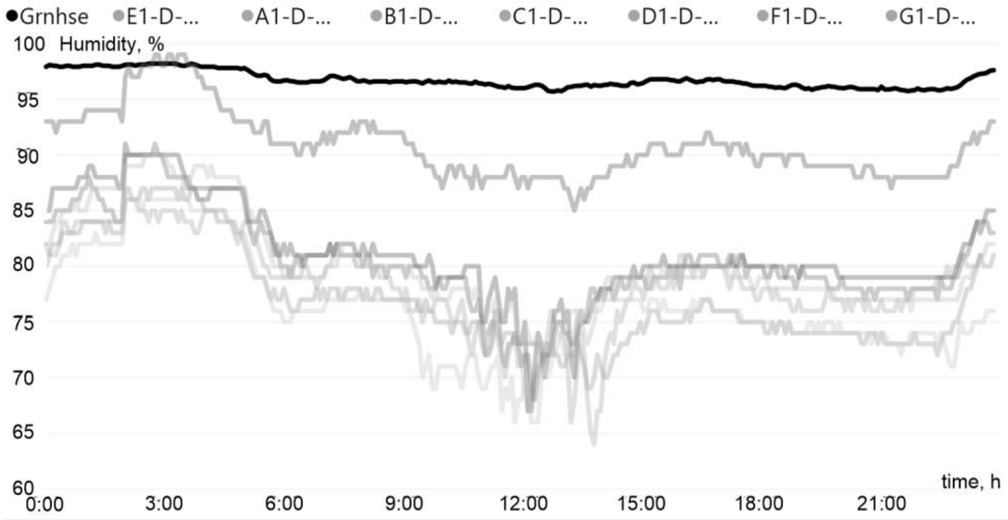

Figure 8. uMOL system D level relative humidity readings per poles A-H comparing to humidity deficit values (bold).

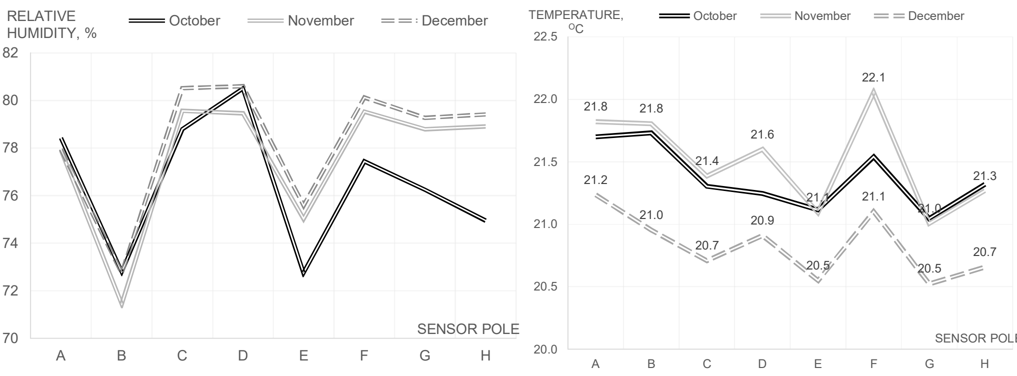

Figure 9. uMOL system monthly average relative humidity (left) and temperature (right) readings per sensor poles A-H.

CONCLUSIONS

Research clearly shows that industrial greenhouse zones/areas have a noticeable difference in climate conditions, showing a detectable impact of solar radiation on inside temperature and relative humidity. uMOL system architecture works properly in heavy humidity conditions. Further studies are needed, to analyse climate differences impact on tomato crop yield and biological growth parameters. uMOL multi-point measurement system joint with pre-emptive control of heat and ventilation systems climate system management may improve greenhouse environment stability and have impact on the tomato plant performance.

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REFERENCES

Salazar, R., Rojano, A., Lopez, I. & Schmidt, U., 2010. A Model for the Combine Description of the Temperature and Relative Humidity Regime in the Greenhouse. In: *Ninth Mexican International Conference on Artificial Intelligence*, Pachuca, 2010, pp. 113–117.

Kondratjevs, K., Kunicina, N., Patlins, A., Zabasta, A. & Galkina, A., 2016. Vehicle weight detection sensor development for data collecting in sustainable city transport system. In: *57th International Scientific Conference RTUCON*, Riga, 2016, pp. 1–5.

Rakutko, S., Rakutko, E., Kaposhko, D., Vaskin, A. & Tranchuk, A., 2017. Influence of light quality on fluctuating asymmetry of bilateral traits of forced parsley leaves. In: *16th International Scientific Conference Engineering for Rural Development*, Jelgava, Latvia, 2017. Volume **16**, 2017, Pages 42–47.

Tetervenoks, O. & Galkin, I., 2012. Evaluation of efficacy of light sources combined of different color LEDs. In: *13th Biennial Baltic Electronics Conference*, Tallinn, 2012, pp. 231–234.

Chung, S., Kim, K., Huh, Y., Hur, S., Ha, S., Ryu, M., Kim, H & Han, K., 2012. Determination of Sensor Locations for Monitoring of Greenhouse Ambient Environment. In: *11th International conference on Precision Agriculture.* Indianapolis, Indiana, U.S.A.

Van Ooteghem, R.J.C., Stigter, J.D., Van Willigenburg, L.G. & Van Straten, G., 2003. Optimal control of a solar greenhouse. In: 2003 European Control Conference, Pages 2739–2746.