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Experimental Analysis of IoT Based Camera SI-NDVI Values for Tomato Plant Health Monitoring Application

A. Avotins[1,*], K. Kviesis[1], J. Bicans[1], I. Alsina[2] and L. Dubova[2]

[1]Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, Azenes street 12/1, LV-1048, Riga, Latvia
[2]Latvia University of Life Sciences and Technologies, Faculty of Agriculture, Institute of Plant and Soil Science, Liela Street 2, LV-3001, Jelgava, Latvia
[*]Correspondence: ansis.avotins@rtu.lv

Abstract. This paper reveals an IoT based camera design to capture SI-NDVI parameters and describes first obtained data analysis regarding luminary spectrum impact on readings in real greenhouse application. For experimental comparison, measurements of Encore, Strabena, Audiance, Bolzano, Forticia and Chocomate tomato plants, both for the 'best' and the 'weakest' plant sample, using IoT based camera solution and portable leaf spectrometer. First experimental results show that this approach can be applied for tomato plant monitoring, and reveals some ideas about possible precision improvements.

Key words: SI-NDVI, tomato plant, industrial greenhouse, precision agriculture, IoT.

INTRODUCTION

Industrial greenhouses are large production buildings, having a lot of crops inside, where vegetation process is determined by natural and artificial light parameters, nutrition quality, indoor and outdoor climate parameters and many other factors. Normalized Difference Vegetation Index (NDVI) can be an important remote measurement in agriculture as it has a high correlation with plant growth and yield result. Currently, measurement methods, like chlorophyll Fluorescence and Multispectral imaging, are used to obtain many photobiological parameters done by experienced personnel. Greenhouse automation asks for more automated quality parameter measurements for feedback, and nowadays systems with Internet of Things (IoT) become more and more popular for such applications. Also non-destructive or non-contact sensing techniques of plant stress or 'health' status would enable continuous monitoring of plants and enable automated feedback for greenhouse control systems. A good overview of crop reflectance monitoring as a tool for water stress detection in greenhouses is given by (Katsoulas et al., 2016), it also reveals that most common approach is to use photochemical reflectance index (PRI) and the normalised difference vegetation index (NDVI) parameters, however it deals with precision measurement equipment. Spectral reflectance by vegetation (Botha, 2001) in ranges of 0.4 μm to 2.5 μm can indicate healthy, stressed or severely stressed vegetation, by using leaf spectrometer data. Also (Kharat et al., 2016) analyses the normalized difference vegetation index (NDVI), using the normalized ratio of red reflectance and near-infrared reflectance, as a vegetation index for tomato plant monitoring, indirectly also relating to nitrogen status. There are various literature sources on NDVI measurements as it is widely used metric for plants health monitoring, where healthy plants absorb light in the photosynthetically active and reflect at nearinfrared region. According to (Beisel et al., 2018) a single image NDVI (SI-NDVI) gives a new way to derive spectral character from a single RGB image, thus it can be applied to indoor greenhouses using artificial lighting such as LED. This is new technique, therefore this paper deals with practical application of developed IoT based Camera SI-NDVI data for tomato plant health monitoring and comparison to leaf spectrometer results in real tomato crop greenhouse.

MATERIALS AND METHODS

Description of experimental place

Experiments were conducted on 18.11.2019. in industrial greenhouse of Mezvidi, that grows several sorts of tomatoes (Encore, Strabena, Audience, Bolzano, Forticia, Chocomate) and therefore can be treated as a complex environment, as it has a relatively large growing area (5,062 sq. meters), 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, and uses GreenPower LED Interlighting module DR/B (115W) for tomato crop interlighting. More info about growing details can be seen in article (Rakutko et al., 2019), but due to industrial nature of the Mezvidi greenhouse, more detailed info is business sensitive. During the measurements only daylight and light from LED interlight modules were used. The tomato plants were grown already in production stage, thus this can be treated as a normal production process in greenhouse in autumn and winter start season. The proposed system and experiments is addition to the uMOL IoT sensor system described in previous articles (Avotins et. al., 2018), (Bicans et. al., 2019). Spectral measurements are used to determine nutritional quality of greenhouse vegetables (Olle & Alsina, 2019), but can be done only periodically and not every day.

Equipment used for measurements

Leaf spectrophotometer CID BioScience Cl-710 - wavelengths 350–1,000 nm and spectroradiometer RS3500 (Spectral evolution) wavelengths 350–2,500 nm were used for non-destructive determination of physiological and biochemical status of plants (Alsina et al., 2019). The measurement process can be seen in Fig. 1, c, and the measurements

Figure 1. Sample of measurements in Mezvidi industrial tomato greenhouse.

were performed for the same leaf both with spectrometer (see Fig. 1, a) and focusing on the same spot also with the SI-NDVI camera (see Fig. 1, b). For these experiments SI-NDVI camera was mobile and powered from battery pack.

In our experimental setup we used proposed SI-NDVI calculation method and deployed 5 NDVI sensors for long term plant monitoring which consists of Raspberry Pi Foundation produced single-board computer Raspberry Pi 3 Model B with PiNoIR Camera V2 sensor (see Fig. 2).

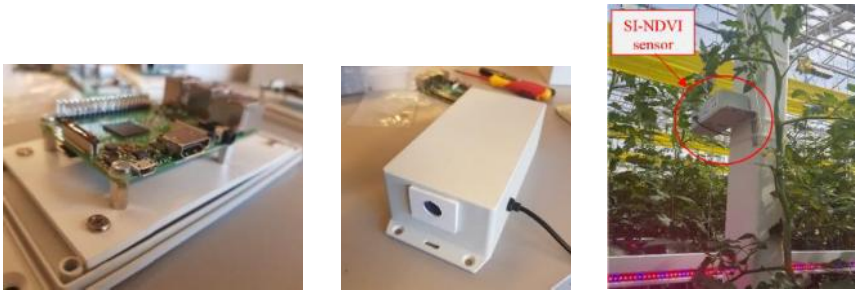


Figure 2. SI-NDVI sensor prototype and placement in the greenhouse.

Blue filter to the camera was added in order to meet SI-NDVI method requirements. SI-NDVI calculation method requires camera sensor with additional blue light filter which allow transmission in the 400–575 nm and 675–775 nm ranges. The SI-NDVI values were calculated according to common formula (1).

$$SI - NDVI = \frac{NIR - Blue}{NIR + Blue} \qquad (1)$$

Developed experimental NDVI sensor principal circuit diagram (see Fig. 3) consists the following elements: RPi – Raspberry Pi 3 model B; NoIR cam – Raspberry Pi NoIR Camera v2 with blue filter; Plant – tomato plant; Internet – Wi-Fi Router that is connected to the internet; API – IoT Cloud endpoint; AC/DC – power supply; EN – Electrical Network. RPi is powered by an AC / DC network voltage adapter with an output voltage of 5V and a maximum current of 1A. SI-NDVI calculation program is written in Python 3.5.

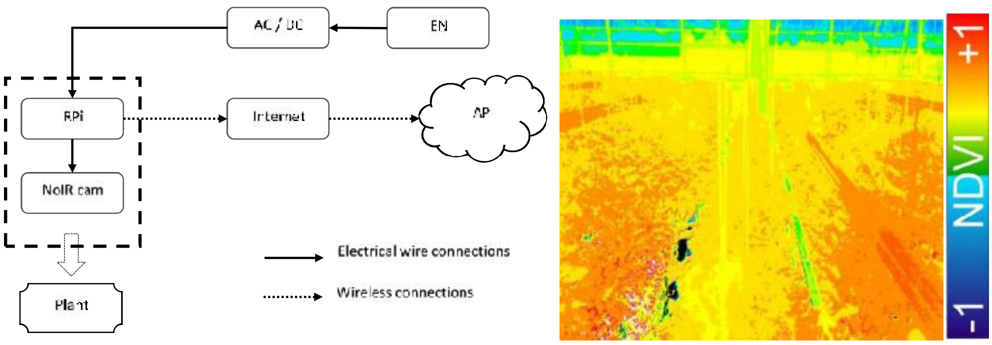


Figure 3. Architecture of the SI-NDVI sensor and IoT system and obtained picture.

Process of SI-NDVI value data obtaining in five steps is given in Fig. 4. In first step *.jpg format picture (640×480) is obtained remotely and saved on Raspbery device for further calculations and analysis. In step 2, the picture is split in three multispectral layers of R (red), G (green) and B (blue). As we have blue filter, NIR layer replaces the R layer. Thus three data matrix can be created, where we need only NIR and B matrix for further calculations by formula (1). Further we obtain a new matrix of SI-NDVI values (see Fig. 5) for each pixel of 640×480 resoltuion, that are further divided in 40 histogram intervals from -1 to +1 by step of 0.05.

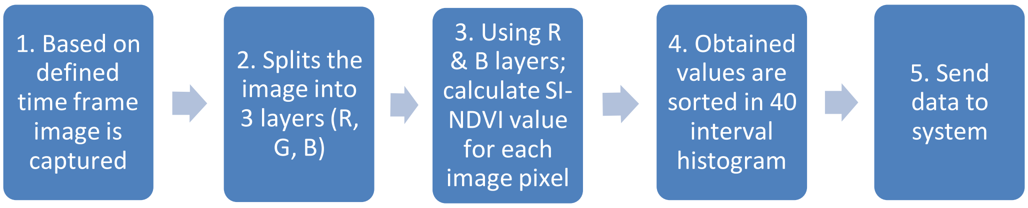
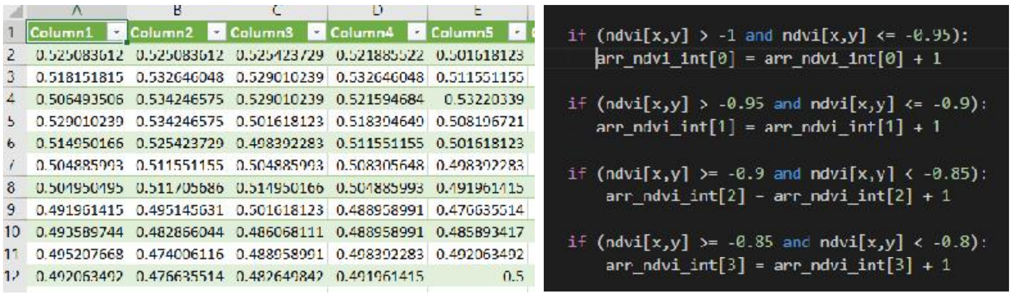


Figure 4. SI-NDVI value derivation process and initial calculation algorithm.



	A	B	C	D	E
1	Column1	Column2	Column3	Column4	Column5
2	0.525083612	0.525083612	0.525423729	0.521885522	0.501618123
3	0.518151815	0.532646048	0.529010239	0.532646048	0.511551155
4	0.506493506	0.534246575	0.529010239	0.521594684	0.53220339
5	0.529010239	0.534246575	0.501618123	0.518394649	0.508196721
6	0.514950166	0.525423729	0.498392283	0.511551155	0.501618123
7	0.504885993	0.511551155	0.504885993	0.508305648	0.498392283
8	0.501950195	0.511705686	0.514950166	0.504885993	0.491961415
9	0.491961415	0.495145631	0.501618123	0.488958991	0.470635514
10	0.493589744	0.482866044	0.486068111	0.488958991	0.485893417
11	0.495207668	0.474006116	0.488958991	0.498392283	0.492063492
12	0.492063492	0.476635514	0.482649842	0.491961415	0.5

```
if (ndvi[x,y] > -1 and ndvi[x,y] <= -0.95):
    arr_ndvi_int[0] = arr_ndvi_int[0] + 1

if (ndvi[x,y] > -0.95 and ndvi[x,y] <= -0.9):
    arr_ndvi_int[1] = arr_ndvi_int[1] + 1

if (ndvi[x,y] >= -0.9 and ndvi[x,y] < -0.85):
     arr_ndvi_int[2] - arr_ndvi_int[2] + 1

if (ndvi[x,y] >= -0.85 and ndvi[x,y] < -0.8):
     arr_ndvi_int[3] = arr_ndvi_int[3] + 1
```

Figure 5. SI-NDVI matrix (left) and histogram calculation algorithm (right).

Performed measurement and obtained results

Experimental measurements were performed on six sorts of tomato plants, where both leaf spectrometer measurements were done and also experimental prototype SI-NDVI readings with centred focus on same leaf. Measurements were taken for visually 'weakest' and 'best' (strongest) sample and in three levels of height: upper (close to flowers), middle and lower (close to fruits). Table 1 and Table 2 gives overview of samples taken and their allocation in the greenhouse.

Table 1. Samples taken from Encore, Starbena and Audiance

Total rows:	1–22		half of 23		half of 23	
Sort:	Encore		Strabena		Audiance	
Row:	16		Start of 23		End of 23	
Plant sample visual quality	Best	Weakest	Best	Weakest	Best	Weakest
Height level:	NDVI picture sample timestamp:					
Upper	11:40	11:48	11:58	12:07	12:17	12:27
Middle	11:37	11:50	12:01	12:09	12:19	12:30
Lower	11:45	11:53	12:03	12:12	12:22	12:32

Table 2. Samples taken from Bolzano, Forticia and Chocomate

Total rows:	24–26		37– half of 38		half of 38–40	
Sort:	Bolzano		Forticia		Chocomate	
Row:	25		Start of 38		39	
Plant sample visual quality	Best	Weakest	Best	Weakest	Best	Weakest
Height level:	NDVI picture sample timestamp:					
Upper	12:37	12:46	13:09	13:17	13:27	13:37
Middle	12:40	12:58	13:11	13:20	13:30	13:39
Lower	12:43	13:00	13:14	13:23	13:33	13:42

Figs 6–7 show reflectance readings of all sorts in TOP level sample array from weakest and strongest (best) sample. According to data, it seems that Bolzano sort is more stressed than the other sorts. For comparison, one not entirely whithered leaf with light green color was measured of unknown sort, and included in Figures. Fig. 8 shows Bolzano readings in all levels, both for the weakest and best sample. Logically it should have the worst readings in terms of stress, it can be seen from wavelengths centered about 450 nm and 670 nm, as chlorophyll doesnt absorbs energy so good as attached tomato leafs.

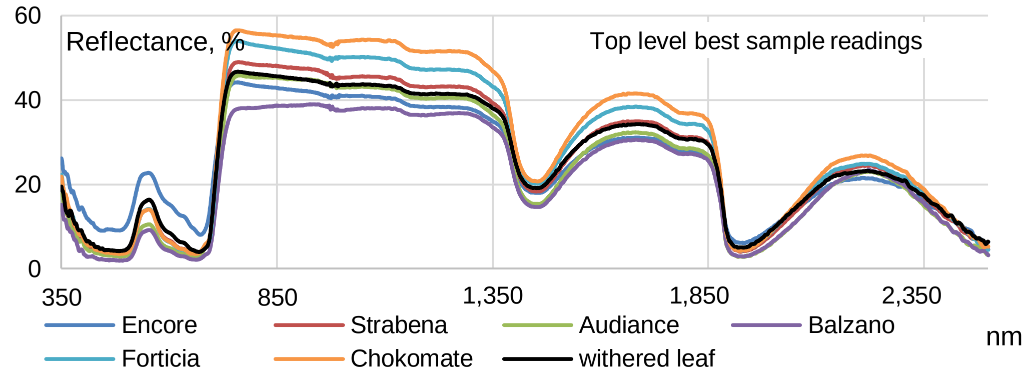


Figure 6. Reflectance values of Top level best sample of all tomato sorts.

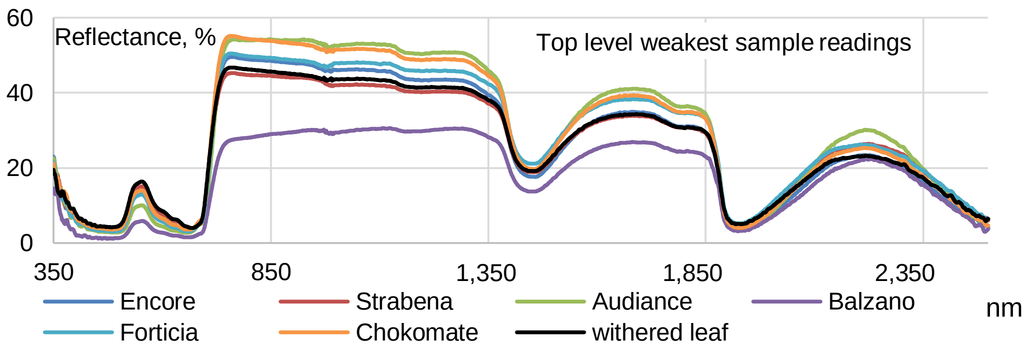


Figure 7. Reflectance values of Top level weakest samples of all tomato sorts.

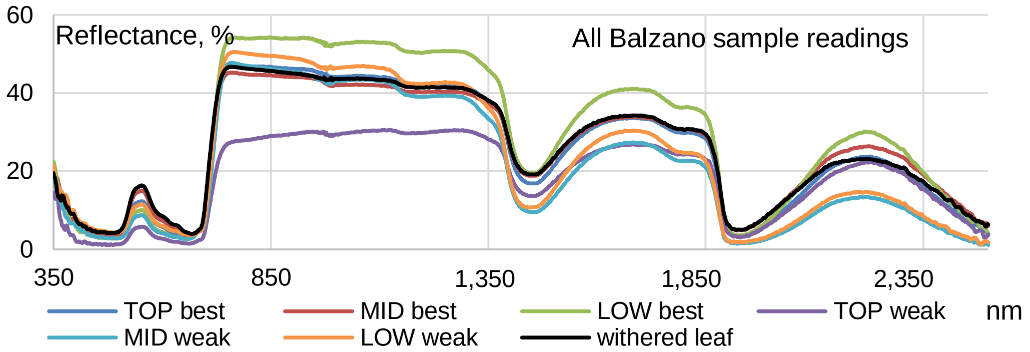


Figure 8. Reflectance values of all samples from Balzano tomato sort.

Table 3. NDVI values obtained from leaf spectrometer measurements for all tomato sorts and measurement levels

	NDVI	Leaf Chlorophyll Index		NDVI	Leaf Chlorophyll Index
Encore (best_TOP)	0.667	0.287	Encore (best_MID)	0.871	0.565
Encore (weak_TOP)	0.826	0.487	Encore (weak_MID)	0.838	0.568
Strabena (best_TOP)	0.826	0.469	Strabena (best_MID)	0.849	0.486
Strabena (weak_TOP)	0.818	0.427	Strabena (weak_MID)	0.841	0.462
Audiance (best_TOP)	0.821	0.539	Audiance (best_MID)	0.841	0.569
Audiance (weak_TOP)	0.852	0.590	Audiance (weak_MID)	0.841	0.586
Balzano (best_TOP)	0.821	0.539	Balzano (best_MID)	0.841	0.569
Balzano (weak_TOP)	0.852	0.590	Balzano (weak_MID)	0.841	0.586
Forticia (best_TOP)	0.823	0.490	Forticia (best_MID)	0.838	0.549
Forticia (weak_TOP)	0.827	0.471	Forticia (weak_MID)	0.854	0.511
Chokomate (best_TOP)	0.829	0.478	Chokomate (best_MID)	0.809	0.512
Chokomate (weak_TOP)	0.836	0.488	Chokomate (weak_MID)	0.807	0.470
Encore (best_LOW)	0.794	0.493	Balzano (best_LOW)	0.825	0.569
Encore (weak_LOW)	0.836	0.547	Balzano (weak_LOW)	0.816	0.559
Strabena (best_LOW)	0.848	0.514	Forticia (best_LOW)	0.812	0.475
Strabena (weak_LOW)	0.830	0.429	Forticia (weak_LOW)	0.835	0.577
Audiance (best_LOW)	0.825	0.569	Chokomate (best_LOW)	0.824	0.564
Audiance (weak_LOW)	0.816	0.559	Chokomate (weak_LOW)	0.803	0.491

NDVI values shown in Table 3 are calculated by formula (W800-W670)/(W800+W670), and Leaf Chlorophyll Index by formula (W850−W710)/(W850+W680). As it can be seen from the obtained data, NDVI values are ranging 0.79 to 0.85, with some exception of Encore (best sample at TOP level) with value of 0.667.

RESULTS AND DISCUSSION

Initial raw data calculations of proposed IoT camera based solution shows that pictures for the Encore, Audiance and Chokomate top (best sample) most pixels carry value of 0 to 0.25 (see Fig. 9. *'Encore Top Level', 'Audiance Top level' and 'Chokomate*

Top level'), which clearly is not the same as values obtained from leaf spectrometer measurements. As these calculations can be affected by picture quality, filter parameters, resolution and surrounding light spectrum (daylight and LED interlight), it can be assumed that correction coeficient must be applied to NIR value of calculation formula (1).

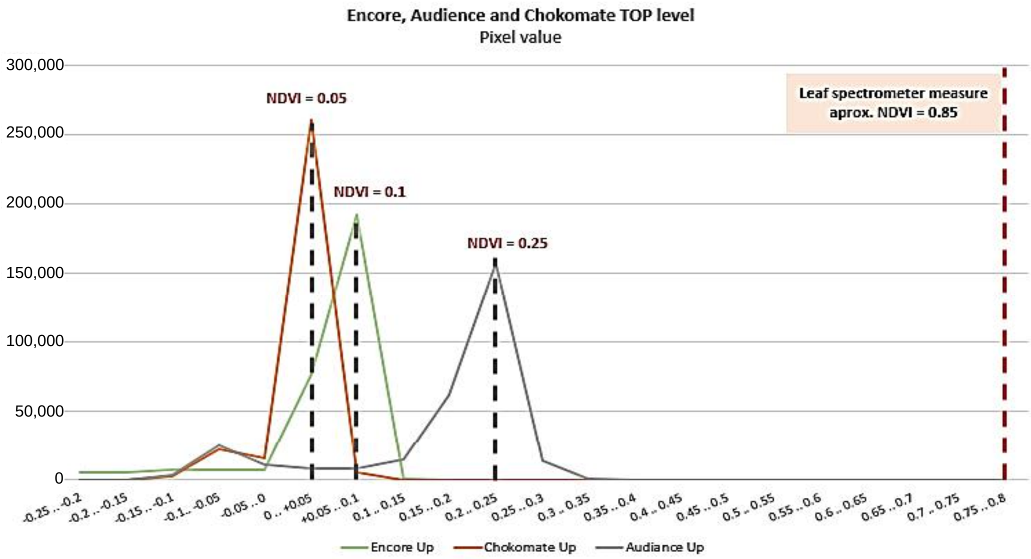


Figure 9. Obtained SI-NDVI histogram values without correction coefficient.

As we know that LED interlight module has one blue diode and four red diodes, we can assume that ratio could be 1:4, Based on this ratio, the settings are adjusted to take the necessary pictures, so the blue color gain is used 0.57 and the red chanel gain is used 2.26 (ratio 1:3.96).

Obtained new SI-NDVI histogram results (see Table 4) are shown in Fig. 10. where the blue areas are the raw measurements without the correction coeficient, whereas the red curve in each graph represents the readings after the coeficient adhibition. As can be seen in the following graphs, when applying the coefficient calculation method, the amount of values (peak values) deviates and is closer to the values which obtained by measuring with leaf spectrometer.

Table 4. NDVI values obtained from leaf spectrometer measurements for all tomato sorts and measurement levels

Level→	UP			MID			DOWN		
NDVI values	Spectr.	SI-NDVI	match, %	Spectr.	SI-NDVI	match, %	Spectr.	SI-NDVI	match, %
Encore	0.709	0.65	92%	0.896	0.65	73%	0.857	0.65	76%
Strabena	0.841	0.65	77%	0.854	0.65	76%	0.882	0.65	74%
Audiance	0.852	0.75	88%	0.875	0.65	74%	0.837	0.65	78%
Balzano	0.859	0.6	70%	0.858	0.65	76%	0.897	0.65	72%
Forticia	0.844	0.65	77%	0.832	0.65	78%	0.844	0.65	77%
Chokomate	0.855	0.65	76%	0.847	0.65	77%	0.859	0.65	76%

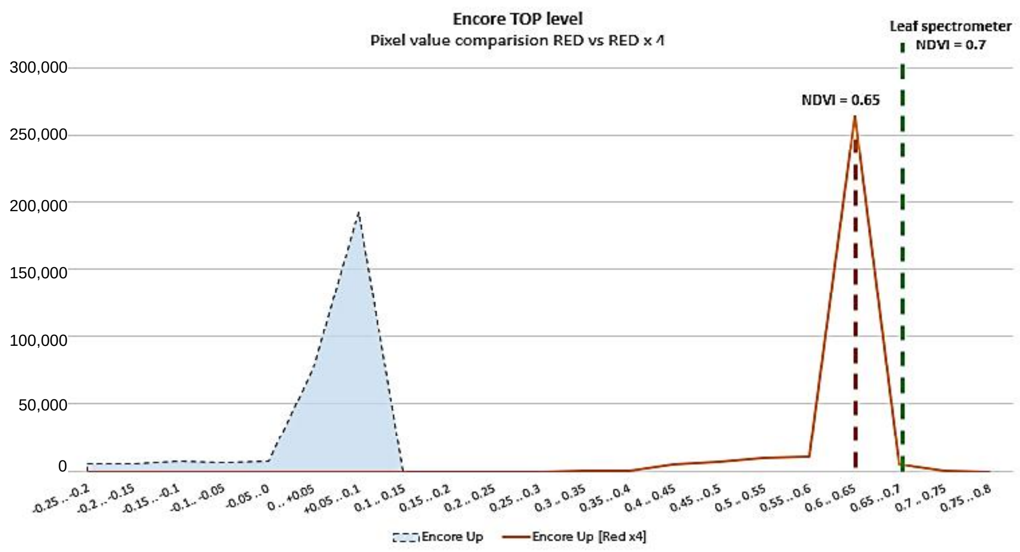


Figure 10. Obtained SI-NDVI value comparison with and without correction coefficient.

In our case we are not interested into photosynthesis activity in particular individual pixel of the image opposite to a satellite or an aerial imaging where each pixel represents area on the ground. We propose to use histogram data representation method. This method provides an accurate representation of the distribution of SI-NDVI numerical data, and seems to represent plants development tendency or processes.

If we look at the whole day measurments and to the solar raddation at the same time (see Fig. 11), then we obtain plants activity data when solar radiation is higher, at the period when lamps are swirched ON (around 2:00 UTCC time), dominant are values in the region +0.35 to + 0.6, showing that process is maintained, but not with high activity. This aproach must be studied further in more details, comparing data with plants behaviour.

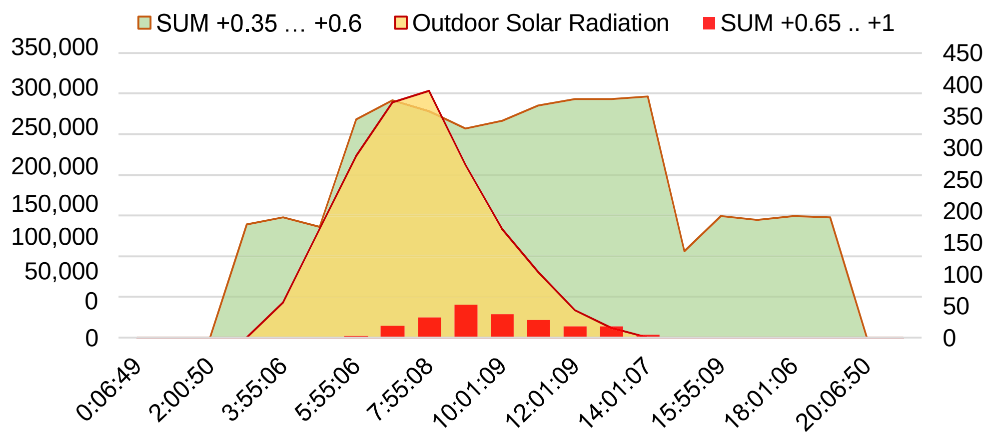


Figure 11. Obtained SI-NDVI value data from camera #1 with correction coefficient throughout whole day in the industrial Mezvidi tomato greenhouse.

CONCLUSIONS

It can be stated, that histogram approach of SI-NDVI sensor can be used as monitoring tool and indicate the daily NDVI value. From the single picture measurements, comparing them to the NDVI results measured by leaf-spectrometer, we obtained 73%–92% precision, if using the leaf-spectrometer result as reference value. After application of corrective coefficients, similar value pikes was obtained also for Encore, Strabena and others sorts.

Nevertheless the precision can be improved, by applying more precise correction coefficients. To determine its linear or non-linear nature is scope of the future research of the authors.

Furthermore obtained results shows potential application of this approach for controlling the greenhouse environment, same time monitoring the tomato plant growth quality parameters remotely and using long term hourly measurements. Data processing algorithm allows to get numerical values that are also comparable to those obtained by leaf spectrometer and calculated from certain wavelength data reflectance values.

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