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Selection of Number and Locations of Multi-Sensor Nodes Inside Greenhouse

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ABSTRACT

One of the possible solutions for meeting the rising food demands is to opt for wireless sensor networks (WSN) monitored intelligent greenhouses. Such greenhouses require wireless sensor nodes rather than individual sensors to monitor and control the various parameters responsible for the growth of the plants. The appropriate selection of the number of wireless sensor nodes and their placement is crucial for optimizing the cost of the wireless sensor network by minimizing the number of sensor nodes as well as the measurement error. This paper extends the two techniques, namely, equal step (ES) and equal segment area (ESA) techniques, reported earlier for the selection of the number and locations of sensors to suit multi-sensor nodes inside a greenhouse. It also compares these techniques with the equal-spacing approach. The multi-sensor nodes considered here have temperature and luminosity sensors. Initial locations of the multi-sensor nodes have been fixed on the basis of temperature profile on the premise that temperature is the most important parameter for the growth of the plants. Evaluation of these techniques has been done on the basis of the root of the sum of square errors (RSSE) of the individual parameters. The ESA technique has been found to be better than the ES technique for the assumed temperature and luminosity profiles. In the future, this work may be extended to other situations where other than temperature is the most important parameter. The other direction in which the work can be extended may be considering the 2D or even 3D distribution of sensors.

Keywords: Intelligent greenhouse, sensor node, sensor, wireless sensor network

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INTRODUCTION

Food security has always been and will remain a prime requirement of society at global, national and regional levels. It has been projected that the world is going to hold a whopping 9.6 billion people by 2050 (Ranganathan et al., 2014). As a result, crop production needs to be doubled by 2050 to meet the projected demands from the rising population as well as the shrinking of available land for cultivation. Thus, measures need to be initiated for boosting crop yield to meet these rising demands. One of the possible options to meet this rising demand for food is to opt for intelligent greenhouses (IGH) instead of traditional greenhouses. In intelligent greenhouses, monitoring and controlling the parameters responsible for the growth of plants are possible. The growth of the plants is dependent on various atmospheric factors like temperature, humidity, CO_2 level, luminosity of sunlight, as well as on soil parameters like macronutrient level and soil temperature and moisture. For the proper growth of plants inside the greenhouse, these parameters need to be maintained within the desired limits. To that end, these parameters must be continuously measured and monitored. In the initial stages of IGH development, a single sensor located in a greenhouse was used to sense the parameter of interest. This approach did not provide the true information of the micro-climatic condition of a greenhouse. A modification to the single-sensor monitoring technique was followed by a distributed arrangement of sensors and a data acquisition system to acquire an accurate profile of the variables. In such installations, there was a huge need for power and signal cabling to individual sensors, which resulted in huge costs in terms of both money and time. Adding new sensors was also difficult in this monitoring approach.

For monitoring multiple parameters that affect the plants' growth, it would be better to use sensor nodes that have multiple sensors for profile measurement of all such parameters rather than using individual sensors for different parameters. A single sensor node-based measurement system for the greenhouse is never advisable, as it will measure the physical parameters of interest at one point only and thus will not be giving the actual distribution profile of the parameter of interest. Hence, a number of sensor nodes should be appropriately distributed over the whole area and connected to form a WSN of the GH. Many authors have reported WSN based greenhouse monitoring (Barker, 1990; Holder & Cockshull, 1990; Zolnier et al., 2000; Burrell et al., 2004; Zhang et al., 2007; Ahonen et al., 2008; Park & Park 2011; Pahuja et al., 2013; Salleh et al., 2013; Nasre et al., 2014; Mekki et al., 2015; Konstantinos et al., 2017; Kareem & Qaqos, 2019; Lata et al., 2020).

In order to obtain the profile of the selected parameter inside a greenhouse with acceptable accuracy, the selection of a minimum number of sensor/ sensor nodes and their locations needs to be investigated. An insufficient number of sensors and/or sensor nodes and their random distribution would result in an incorrect measurement of the profile of the desired parameter inside the greenhouse. Increasing the number of sensors/

sensor nodes, on the other hand, will increase the cost of sensors/sensor nodes and sensor networks. It will also increase the complexity of WSN. So, it becomes very important to select the appropriate number and locations of the sensor nodes for monitoring and control of greenhouse parameters and thus to convert a traditional greenhouse into an intelligent greenhouse. In literature, many papers have been related to monitoring and control of greenhouse parameters based on wireless sensor networks. However, in these papers, the authors have considered either equal spacing or random placement of sensors. The distribution may either be in horizontal or in the vertical direction. Authors have also distributed the sensors in a grid (Kochhar & Kumar, 2019).

Zorzeto et al. (2014) evaluated the variations of temperature and humidity inside a greenhouse. The authors had considered random distribution of WS nodes for evaluation of variation of temperature and humidity inside the greenhouse. Ryu et al. (2014) have investigated the vertical, temporal and spatial variability of the ambient environment by performing experiments in two greenhouses with two different crops. The sensors were placed at equal distances assuming that the environmental conditions are symmetrical in the spatial domain. However, the authors did not focus on the selection of the number and distribution of sensors. Lamprinos et al. (2015) had developed a wireless sensor network consisting of six sensor nodes. Authors have used the random distribution of sensors to investigate the variation of temperature and humidity inside a greenhouse. Konstantinos et al. (2017) reported the development of a wireless sensor network using five sensor nodes. They have used the random distribution of sensors. In the vertical direction, again few authors (Akkaş & Sokullu, 2017; Lixuan et al., 2014) proposed to have all sensor nodes at a single height while suggested placing sensors at separate height levels (Ahonen et al., 2008; Raheemah et al., 2016; Pahuja et al., 2013; Harris et al., 2016; Zou et al., 2017). A WSN consists of 100 sensor nodes that have been placed on the regular rectangular grid along a horizontal plane for observing the humidity and temperature parameters of the greenhouse under various conditions (Balendonck et al., 2010). For a tomato greenhouse, Mancuso and Bustaffa (2006) proposed to place the six nodes in rows and columns crossing each other to form a grid. The grid covered an area of 20 by 50 m. A similar setup has with 900 sensors has been used by Konstantinos and Tsiligiridis (2007) to cover a larger greenhouse-like 30 by 30 length. In another approach, instead of placing sensor nodes in a grid layout, the authors proposed to divide the geographic area of the field into grids and locate 2–3 nodes in each grid. Nodes on the edge of the grid are shared with the neighboring grid. The base station is positioned on one edge of the greenhouse (Quynh et al., 2015). Nodes within a grid provide more flexibility and better free space coverage than a layout with nodes on junctions of the grid.

Lata and Verma (2017) proposed and investigated the trial-and-error method and compared it with the equal sensor spacing method for the selection of the number and locations of temperature sensors in a greenhouse. The authors compared two techniques on the basis of average percentage error and concluded that the trial-and-error technique is better than the equal sensor spacing method. The authors further observed that the trial-and-error method increases the number of sensors does not result in the reduction of %error. Thus, the best selection of sensors and their locations resulted from this approach. Lata & Verma (2018) investigated the equal spacing technique and trial-and-error technique for the selection of the number and locations of multi-sensor wireless sensor (WS) nodes in a greenhouse. The selected node in this work has a temperature and a luminosity sensor. Authors have used individual errors in temperature and luminosity profile measurement as well as the root of the sum of squares of individual errors for evaluation and comparison purposes. Comparison of results for the two methods shows that the same order of error can be achieved with a trial-and-error method using a lesser number of sensors. Lata & Verma (2019) reported the development of two novel techniques and algorithms for selecting the number and locations of temperature sensors for a greenhouse. These were named Equal Temperature-Step (ETS) and Equal Segment-Area (ESA) techniques.

In an actual scenario, multi-sensor wireless sensor nodes are used for the measurement of the several parameters responsible for the growth of the plants in a greenhouse. So, the authors have extended and validated the above two techniques for the selection of appropriate numbers and locations of multi-sensor nodes in the greenhouse. In this paper, the authors have renamed the Equal Temperature-Step (ETS) techniques as the Equal step (ES) technique as the parameter of interest may not be temperature alone. The authors have compared these techniques with the equal sensor spacing (ESS) technique. The authors have considered WS nodes containing temperature and luminosity sensors. The performance of these techniques is compared on the basis of a combined measurement error, which is the root of the sum of square errors (RSSE) for individual parameters.

The organization of the rest of the paper is as follows: Typical temperature and luminosity profiles inside a greenhouse have been considered in the next section, and the section after that discusses the evaluation process. Subsequent sections describe the extension of the two techniques and their performance when applied to WS nodes containing temperature and luminosity sensors. The techniques are then compared on the basis of %rrse. Conclusions and the scope of future work are presented in the last section.

MATHEMATICAL MODELS FOR TEMPERATURE AND LUMINOSITY PROFILES INSIDE GREENHOUSE

Dimensions of the greenhouse and the mathematical model of temperature profile T(x) inside it have been taken from Lata and Verma (2017). The greenhouse is assumed to be 20m in length and has a single opening in the form of a door. The temperature near the door is assumed as T_d. A cooler is assumed to be on the wall, which is opposite to the door, and the temperature there is assumed to be Tc. The schematic representation of the assumed greenhouse is as shown in Figure 1.

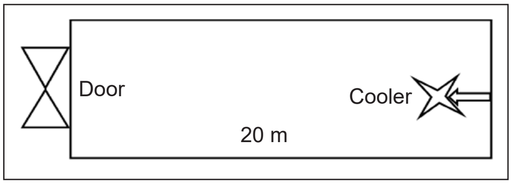

Figure 1. Schematic diagram of assumed greenhouse

The assumed temperature profile inside the greenhouse is shown in Figure 2 and mathematically represented by Equation 1.

$$\mathrm{T(x)} = 10\mathrm{e}^{-0.5\mathrm{x}} + (-0.5\mathrm{x} + 30) \quad (1)$$

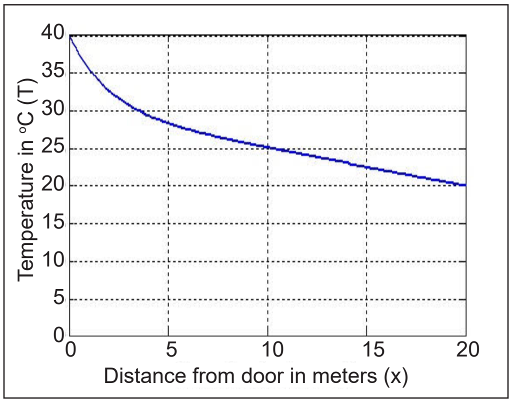

Figure 2. Assumed temperature profile along the length of the greenhouse

On the basis of some simple experiment conducted with a portable lux-meter, it was found that the luminosity profile along the length of a closed room of 20m x 6m size with a single door opening to sunlight can be represented by the following parabolic Equation 2:

$$L(x) = [Ax^2 + Bx + C] \quad (2)$$

where x is the distance from the door. The values of the constants A, B and C as determined from the experiment are A= (1.5625) lux/m^2, B= - 62.5 lux/m and C=668.75 lux. Substituting these values in Equation 2, we get the profile shown in Figure 3.

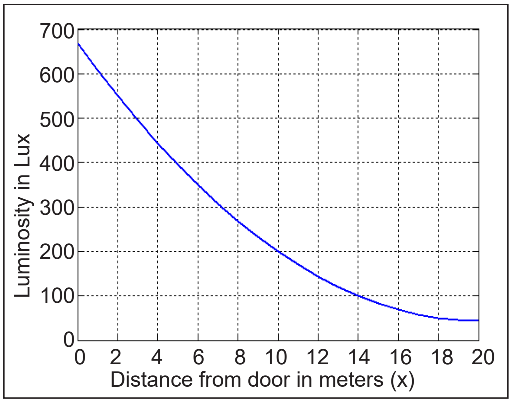

Figure 3. Assumed luminosity profile in front of the door along the length of the greenhouse

EVALUATION PROCESS

As the measurements of the individual errors are independent of each other, the right approach for the evaluation of these extended techniques has been done on the basis of a combined error, which is the root of the sum of square errors (%rsse). It is calculated from the individuals' %errors, namely, the average percentage error in temperature (%e$_T$) and average percentage error in luminosity (% e$_L$). Mathematically, this combined error is defined as Equation 3:

$$\%\mathrm{rsse} = \sqrt{(\%e_T{}^2 + (\%\ e_L)^2} \quad (3)$$

The steps for the calculation of % e_T are given below:

Step 1: On the basis of the chosen algorithm, temperature sensors are placed along the length (0 to L) of the greenhouse and measured temperature profile $T_m(x)$ is obtained. Mathematically, $T_m(x)$ can be represented by the following set of Equations 4 and 5.

$$T_{m(x)} = \left.\begin{array}{ll} T_1 & for\ 0 < x < x_I \\ T_2 & for\ x_I < x < x_{II} \\ T_3 & for\ x_{II} < x < x_{III} \\ T_4 & for\ x_{III} < x < x_{IV} \end{array}\right\} \text{ and so on} \quad (4)$$

The weighted average temperature calculated from these values is given by

$$T_{avm} = [T_1(x_I - 0) + T_2(x_{II} - x_I) + T_3(x_{III} - x_{II}) + ----]/L \quad (5)$$

where L is the length of GH from door to cooler and x_I, x_{II}, x_{III} are the end of the segment length.

Step 2: The theoretical average value of the temperature, obtained along the length, can be obtained by integrating T(x) as given by Equation 6.

$$T_{avth} = \left(\frac{1}{L}\right)\int_0^L T(x)$$

$$= \frac{1}{20}(\int_0^{20} 10\mathrm{e}^{-0.5\mathrm{x}} + (-0.5\mathrm{x} + 30)$$

$$= 26.00°\mathrm{C} \quad (6)$$

Therefore, the percent average error in temperature (%e_T) in the profile obtained from sensor measurements can be written as Equation 7.

$$\%e_T = \frac{(\mathrm{T_{avm}} - \mathrm{T_{avth}})}{\mathrm{T_{avth}}} * 100 \quad (7)$$

Similar steps are to be followed to the calculation of actual average value of luminosity L_{avm} given by Equation 8.

$$L_{avm} = [L_1(x_I - 0) + L_2(x_{II} - x_I) + L_3(x_{III} - x_{II}) + ----]/L \quad (8)$$

where L is the length of GH from door to cooler and x_I, x_{II}, x_{III} are the end of the segment length.

The theoretical average value of luminosity L_{avth} is calculated by integrating the luminosity profile L(x) from 0 to L, as shown in Equation 9.

$$L_{avth} = \frac{1}{L\int_0^L L(x)}$$

$$= \frac{1}{20}(\int_0^{20}(Ax^2 + Bx + C)\,dx$$

$$= 252.0833 \text{ lux} \tag{9}$$

Finally, Equation 10 below will be used to obtain the percentage error in luminosity $\%e_L$ in the luminosity profile obtained from sensor measurements.

$$\%e_L = \frac{(\mathrm{L_{avm}} - \mathrm{L_{avth}})}{\mathrm{L_{avth}}} * 100 \tag{10}$$

SELECTION OF NUMBER AND LOCATION OF SENSOR NODES

ES Technique Applied to Temperature Sensors

The temperature profile curve has been segmented in equal temperature steps for applying the ES technique by Lata and Verma (2019). The step size is given by following Equation 11.

$$\Delta\mathbf{T} = (\boldsymbol{T_d} - \boldsymbol{T_C})/\boldsymbol{n} \tag{11}$$

Where T_d is the temperature at the door and T_c is the temperature at the wall, opposite the door wall and where a cooler has been kept, and n is the number of sensors.

The whole length of GH (L) has been divided into ‘n’ number of segments, and at the center of each segment, a sensor has been placed such that the weighted average of the temperatures measured by the sensors has a minimum error with respect to the theoretical average value. Following constraints were considered on a minimum and a maximum number of sensor nodes:

(a) A minimum number of sensors considered are three to fit at least a second-order temperature profile curve.

(b) The minimum average spacing between sensors has been kept 2m so that the maximum number of nodes required is GH length (m)/2(m) to keep the cost of sensor nodes and WSN within affordable limits.

The segmentation principle for ES Techniques is illustrated in Figure 4, where segment I is the narrowest, and the widest is segment n. The width of the segments progressively increases in between.

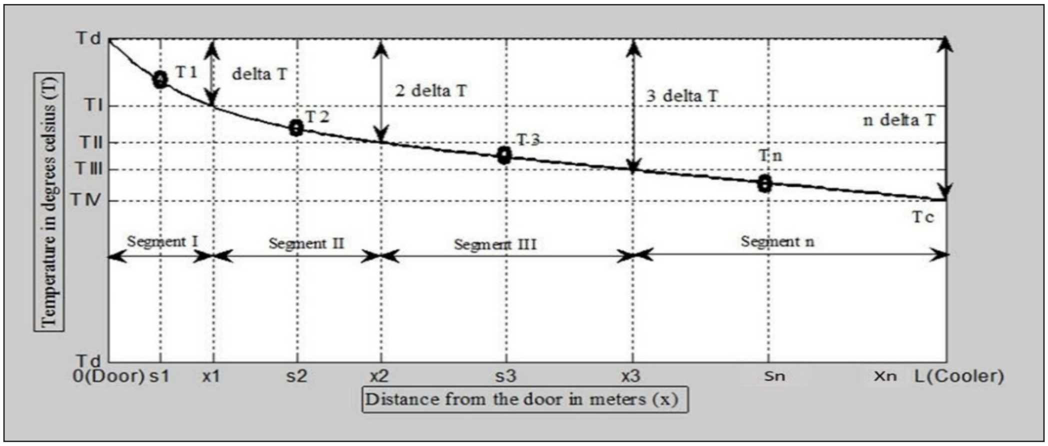

Figure 4. Generalized illustration of sensor locations for equal step technique

ES Technique Applied to Luminosity Sensors

The segmentation process was kept the same for the luminosity profile. While applying the approach to the luminosity profile, the locations of the sensor nodes are kept the same as is the location of the temperature sensors. The luminosity measured by sensor nodes placed at these locations is indicated as L_1, L_2, L_3 and so on. The weighted average luminosity has been calculated using Equation 8.

ESA Technique Applied to Temperature Sensors

This method involves optimization of a number of WS nodes in a greenhouse by splitting the area under the profile curve (A) into equal areas when applied to temperature sensors alone.

i.e. Area of each segment = A/n

ESA Technique Applied to Luminosity Sensors

However, while applying this method to the luminosity profile, the same segments were retained, which means that the location of the luminosity sensor was kept as same as that of the temperature sensor. Thus, the sensor node placement is the same as that of the temperature sensors. The luminosity measured by these nodes is calculated, and the weighted average luminosity is then calculated from the measured luminosity values using Equation 9 as was done in the case of temperature measurement.

RESULTS AND DISCUSSIONS

For ES Technique

For the various sensor nodes, segment length, sensor node locations, luminosity measured sensor node and weighted average of measured luminosity are given in Table 1 and plotted in Figure 5. The temperature measured by the temperature sensor of sensor node in ˚C, a weighted average of measured the temperature (T_{avm} in ˚C) along with % average error in temperature $\%e_T$ has also been tabulated for comparison purposes. From Table 1, it is observed that trends in $\%e_L$ are the same as that of the $\%e_T$. The %rsse is 5.9385 when three WS nodes are used for profiling of temperature and luminosity, and it reduces to 3.2940% when the WS nodes are four. Hence a sharp decrease in the %rsse is reported if the WS node number increases from 3 to 4. However, increasing the WS nodes from 4 to 5 does not show a sharp decrease in the %rsse. In case three, WS nodes are used for the profiling of temperature and luminosity; the average error in temperature is -0.5276 and for the luminosity is -5.9150. The %rsse, i.e., the combined error, in this case, is 5.9385%, which is on the higher side. Similarly, for four WS nodes, the individual percentage average errors in the profile measurement of temperature and luminosity have been calculated as -0.3375 and -3.2767 and the combined error was 3.2940%. Hence a sharp decrease in the individual, as well as combined errors, has been achieved by increasing the number of sensor nodes from 3 to 4. When the WS node number is increased from 4 to 5, the combined error decreases from 3.2940 % to 2.1618 % only. Hence the accuracy improvement in the profile measurement is not steep.

Table 1
Detailed evaluation results of WS node placement for ES

No. of Sensor nodes	**Segment number**	**End of segment (m)**	**WS node location (m)**	**Weighted average of measured temperature (T_{avm} in ˚C)**	**$\%e_T$ in temperature**	**Luminosity measured by luminosity sensor of WS node (lux)**	**Weighted average of measured luminosity (L_{avm} in lux)**	**$\%e_L$ in luminosity**	**%rsse (Combined error)**
3	I	1.7347	0.8673	25.8628	-0.5276	615.6691	237.1726	-5.9150	5.9385
	II	7.2051	4.4699			420.6600			
	III	20.0009	13.6030			107.6900			
4	I	1.1658	0.5829	25.9123	-0.3375	632.8496	243.8233	-3.2767	3.2940
	II	3.4911	2.3284			531.6960			
	III	10.1265	6.8088			315.6371			
	IV	20.0009	15.0637			81.8235			
5	I	0.8801	0.4400	25.9446	-0.2131	641.5525	246.6602	-2.1513	2.1618
	II	2.3079	1.5940			573.0951			
	III	5.3667	3.8373			451.9264			
	IV	12.0484	8.7075			243.0009			
	V	20.0009	16.0246			68.4434			

The percent average error in luminosity and temperature along with combined error for 3, 4 and 5 number of WS nodes have been tabulated in Table 2 and plotted in Figure 6.

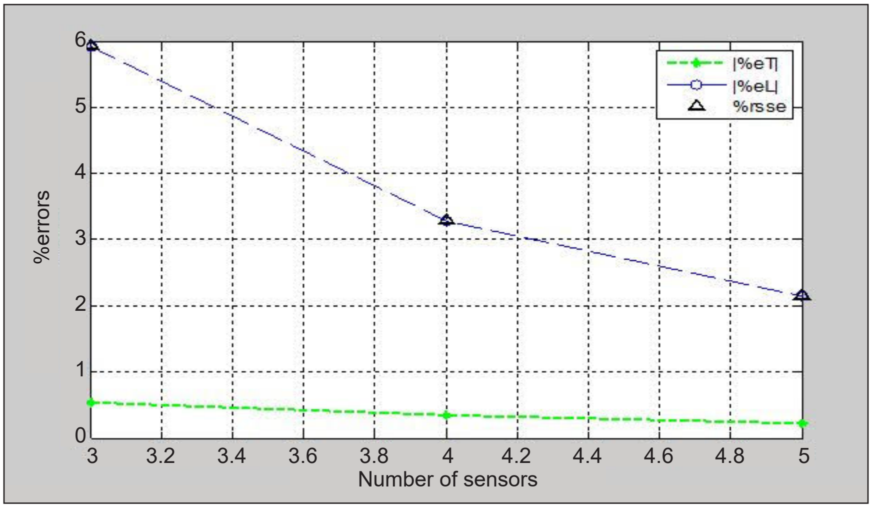

Figure 5. Plot of the number of sensors vs various errors for ES technique For ESA Technique

Table 2

Detailed evaluation results of WS node placement for ESA technique

No. of WS nodes	**Segment Number**	**End of the segment (m)**	**Location of sensor (m)**	**Weighted average of measured Temperature (T_{avm} in °C)**	**%AVM in temperature**	**Luminosity measured by luminosity sensor of WS node in lux**	**Weighted average of measured luminosity (L_{avm} in lux)**	**%AVM in luminosity**	**%rsse (Combined error)**
3	I	5.3988	2.6994	25.7435	-0.9867	587.2401	243.3301	-3.4723	3.6098
	II	12.1132	8.7560			291.5645			
	III	20	16.0566			68.0475			
4	I	3.8881	1.9440	25.8492	-0.5798	553.1549	248.5866	-1.3871	1.5959
	II	8.6295	6.2588			338.7822			
	III	13.9574	11.2934			162.1951			
	IV	20.0000	16.9787			58.0129			
5	I	3.0232	1.5116	25.9017	-0.3780	577.8452	249.8398	-0.8865	0.9637
	II	6.6602	4.8417			402.7720			
	III	10.6886	8.6744			244.1706			
	IV	15.1006	12.8946			122.6355			
	V	20.0000	17.5503			53.1266			

The % average error in the temperature and luminosity profiles is -0.9867 and -3.4723, respectively, while the combined error is 3.6098 for profile measurement using three WS nodes. When four WS nodes were used, the $\%e_T$ is -0.5798 and $\%e_L$ is -1.4869, and the %rsse is 1.5959. The individual percentage average error in temperature and luminosity were -0.3780 and -0.8865, and the combined error was 0.9637% when five WS nodes were used.

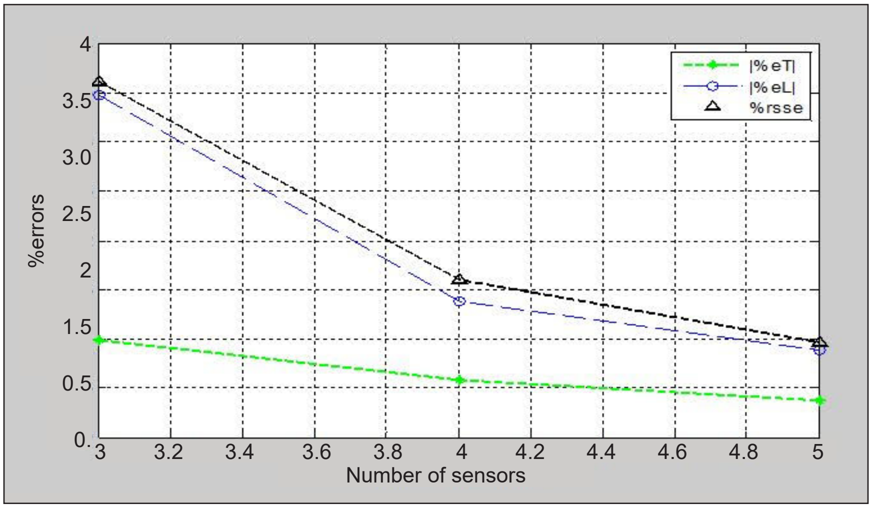

Figure 6. Plot of the number of sensors vs. various errors for ESA technique

From Table 2, it can be observed that the trends in % average error in temperature, as well as luminosity, are similar. Again, the combined errors, as well as individual errors, are minimum when the number of sensor nodes is 5. However, the fall in all three errors is steeper when the number of sensor nodes is increased from 3 to 4 as compared to 4 to 5. Thus, four-sensor nodes may be chosen as the profile measurement accuracy is within acceptable limits.

For ESS Technique

The percentage error in the measured average luminosity values has been determined by varying 'n' from 3 to 10 for the reasons given earlier. The average percentage errors (for both temperature and luminosity) and %rsse against various sensors are presented in Table 3 for the ESS technique. Variations of various errors versus the number of sensors are plotted in Figure 7. As expected, the percentage error reduces as the number of sensors increases in the profile measurements. The %rss error also reduces as the number of sensors is increased.

Comparison of ES and ESA Techniques with Equal Spacing (ESS) Technique

Individual and combined errors for four multi-sensor nodes have been tabulated for ES, ESA, and equal sensor spacing technique in Table 4. It can be seen that the value of %rsse is 32940 for the ES technique when four multi-sensor nodes have been considered. However, for the ESA technique, the value of this error is 1.5959 for the same number of nodes. While using the ESS technique, for 4 WS nodes, %AVE in luminosity is almost the same but values of %AVE and %rsse are more in comparison with ESA.

Table 3
Detailed evaluation results of WS node placement for ESS technique

No. of sensors nodes	Locations of sensor nodes (Distances from door in m)	T*avm* (˚C)	%error in Temperature	L*avm* Lux	%error in Luminosity	%rsse (Combined error)
3	3.3334, 10.0000, 16.6667	25.06528	-1.3354	246.2950	-2.2962	2.6563
4	2.5, 7.5, 12.5 ,17.5	25.7803	-0.8450	248.8281	-1.2913	1.5432
5	2.0 ,6.0, 10.0, 14.0, 18.0	25.8509	-0.5734	250.0000	-0.8264	1.0058
6	1.6667, 5.0, 8.3333, 11.6667, 15.0000, 18.3333	25.9186	-0.3131	250.6363	-0.5740	0.6538
7	1.4285 ,4.2857 ,7.1429, 10.0000, 12.8571, 15.7143, 18.5714	25.920	-0.3076	251.0210	-0.4214	0.5217
8	1.25 ,3.75, 6.25 ,8.75, 11.25 ,13.75 ,16.25, 18.75	25.9377	-0.2396	251.2695	-0.3228	0.4020
9	1.1111 ,3.3333, 5.5556, 7.7778, 10.0000, 12.2222, 14.4444, 16.6667, 18.8890	25.9503	-0.1911	251.5625	-0.2551	0.3187
10	1.0 ,3.0 ,5.0 ,7.0 , 9.0,11.0, 13.0, 15.0, 17.0 ,19.0	25.9595	-0.1559	198.4071	-0.2066	0.2588

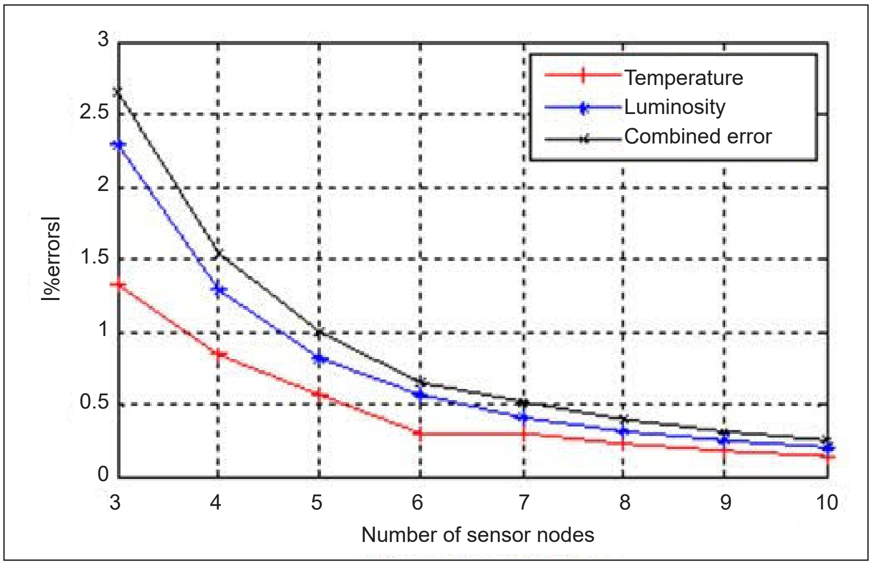

Figure 7. Errors vs. number of sensor nodes for ESS technique

Table 4
Summary of errors for ES and ESA techniques in WS node placement

Type of error	***ES (4 Multi-Sensor Nodes)***	***ESA (4 Multi-Sensor Nodes)***	***ESS (4 Multi-Sensor Nodes)***
%AVE in temperature	-0.3375	-0.5798	-0.8450
%AVE in luminosity	-3.2767	-1.3871	-1.2913
%rrse (combined error)	3.2940	1.5959	1.5432

Again, ES and ESA techniques have been compared on the basis of minimum %rsse and corresponding maximum error in temperature $|\Delta T_{max}|$ and maximum temperature in luminosity $|\Delta L_{max}|$ and these results have been presented in Table 5 along with the values for the ESS technique. From this data also, ESA turns out to be the best technique for placement of multi-sensor WS Node.

Table 5
Comparison of errors in ES and ESA techniques with ESS technique

Name of the Technique	**Minimum %rsse**	**Number of sensors**	$\mathbf{|\Delta T_{max}|}$	$\mathbf{|\Delta L_{max}|}$
ESS	**1.0058**	5	7.3212	200.00
ES	2.1618	5	4.1604	208.9255
ESA	0.9637	5	6.0595	175.0732

ESAT turns out to be a better option for the placement of multi-sensor nodes for the assumed temperature and luminosity profiles among the three techniques.

CONCLUSIONS

The equal step technique (EST) and equal segment area technique (ESAT) have been extended for the selection of a number of multi-sensor nodes containing temperature and luminosity sensors for a greenhouse of length 20m. For both techniques, the evaluation was done on the basis of %rsse, which is a combined error. Out of the two techniques, the value of this error was lower for the ESA technique. Also, the individual errors are less for ESAT in comparison with EST. So, the former is a better option for the selection of the minimum number of sensor nodes for the assumed temperature and luminosity profiles. Again, on comparing this technique with the ESS technique, ESA turns out to be a better technique for the selection of the number and locations of wireless sensor nodes in the greenhouse. In the present work, it has been assumed that temperature is the most important parameter for the growth of plants and the locations of the multi-sensor nodes have been fixed with reference to the temperature sensor. Alternatively, the initial locations of the nodes may be fixed on the basis of the luminosity profile or profile of any other parameter that is considered most important in the given application, and then a final selection between EST and ESAT can be worked out based on the minimum rsse.

In the future, this work may be extended to other situations where other than temperature is the most important parameter. The other direction in which the work can be extended may be considering the 2D or even 3D distribution of sensors.

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