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# Selection of Number and Locations of Temperature and Luminosity Sensors in Intelligent Greenhouse

**Suman Lata [*], H.K.Verma**

*Department of Electrical and Electronics Engineering,*
*School of Engineering and Technology, Sharda University, 201310, India.*
*(Corresponding Author)*

## Abstract

Using a wireless sensor network (WSN) for the monitoring and control of parameters, like temperature and luminosity, inside an intelligent greenhouse is generally a better option rather than using a single sensor for each parameter. Distribution of the wireless sensors at random locations will generally yield an incorrect measurement of temperature/luminosity profile inside the greenhouse. In addition, it will unnecessarily increase the number of sensors and the complexity of WSN. In this paper, two approaches namely equal sensor-spacing method and trial-and-error method, for the selection of number and locations of wireless sensors nodes, containing temperature and luminosity sensors, in a greenhouse have been successfully investigated. In the equal sensor-spacing method, the individual errors in temperature and luminosity profile measurement as well as the combined error or rss error (root of sum of squares of individual errors) reduce as the number of sensor nodes is increased from 3 to 10. Although the error corresponding to ten sensors is quite small, such a large number of sensor nodes would make the WSN-based measurement system very expensive. In case of trial and error method, the least value of rss error comes out to be 2.2545% for 3 sensors, 1.2720% for 4 sensors and 3.6157% for 5 sensors. An interesting observation for this approach is that increasing the number of sensors does not necessarily reduce the error, and, therefore, an optimal number and optimal locations of sensors need to be determined by trial and error. Comparison of results for the two methods shows that the same order of error can be achieved with trial-and-error method using lesser number of sensors. The proposed approaches can be used for the measurement of profile along both the dimensions, i.e. the length and breadth, of the greenhouse.

**Keywords:** Intelligent greenhouse; Luminosity profile; Sensors; Temperature profile; Wireless sensor network

## INTRODUCTION

Monitoring and control in an intelligent greenhouse (IGH) can be considered as a three-step process. The three steps are sensing, generating control signals and actuating. Sensing involves appropriate distribution of specific sensors in IGH. Single sensor approach which was initially used in IGH installations is not preferred because it measures the value of the desired parameter at a single location rather than measuring the overall profile of the parameter.The solution to this issue is suitably distributing number of sensors in the greenhouse. However when the sensors are individually wired to a central data acquisition system, the result is an expensive profile measurement system. Moreover, addition and/or deletion of nodes in such cases would be very difficult. With fast developments in wireless sensor networks (WSN), these issues have been overcome through wireless networking of the sensors. This calls for developing techniques of selecting appropriate number and location of sensor nodes. Random deployment of wireless sensor nodes, would lead to large errors in profile measurement.

Algorithms for two techniques namely, Equal Sensor Spacing method and Trial and Error method, were proposed and investigated by the authors in their paper presented in 3rd International Conference on Conditional Assessment Techniques in Electrical Systems (CATCON-2017) [1]. Percentage error in average temperature measurement was considered as the performance evaluation indicator for the proposed techniques. It was concluded by the authors that Trial and Error method is a better approach to optimize the number and locations of the temperature sensors in an IGH. Present work is an extension of that paper, wherein an additional parameter of luminosity has been considered. Moreover the decision is based on the root of sum of squares of the two individual errors.

Technically greenhouse is considered as a multivariable interactive system [2, 3]. It is multivariable as the growth of the plants growing inside the greenhouse depends on many factors such as temperature and humidity of the atmosphere, temperature and moisture of soil, sunlight (luminosity) and carbon dioxide etc. Therefore sensor nodes deployed, generally include two or more sensors for these variables. This is the motivation for extending the work by incorporating an additional parameter of luminosity along with the temperature.

J.Balendonk et al. used low cost wireless sensors for investigating the horizontal distribution of temperature and relative humidity [4]. Authors had performed trials in four commercial greenhouses, with 100 sensors. The sensors were placed at equal distances. Authors concluded that nine sensors per hectare (±33 m spacing) can measure ΔT and ΔRH without missing a cold or wet spot. Katsoulas et.al developed wireless sensor network for monitoring of three parameters, namely, air temperature, relative humidity and leaf temperature in a commercial greenhouse [5]. The WSN used five nodes with random distribution of sensors. On the basis of data acquired from all the five nodes spatial variability of all the considered parameters was estimated. Thais Queiroz

Zorzeto, Paulo A Martins Leal, Eduardo Fernandes Nunes and Haroldo Ferreira de Araujo evaluated the homogeneity of distribution in two environmental parameters, temperature and humidity, as a function of the number and locations of the wireless sensors in a 1994 $m^2$ greenhouse with lettuce cultivation [6]. Authors had opted for randomized distribution of sensors. Three sensors were installed at various locations in the greenhouse for 11 days and the hourly averages were collected. However no methodology or algorithm was put forward for the optimization of the sensor number and locations in the papers reviewed above.

This paper presents an extensive study for optimizing the number and locations of temperature and luminosity sensors in a greenhouse with an objective of determining profiles of the two parameters with minimum combined error. The rest of the paper is organized as follows: Section 2 describes typical temperature and luminosity profiles inside a greenhouse. Section 3 describes the two approaches, namely Equal Sensor Spacing method and Trial and Error method, for selecting the number and locations of sensors in a WSN for the temperature and luminosity profiles. Results and discussions for profile measurement of the two parameters are presented in Section 4. Finally, concluding remarks are given in Section 5.

## TEMPERATURE AND LUMINOSITY PROFILES INSIDE GREENHOUSE

### Temperature Profile

The greenhouse considered here is 20 m long by 6 m wide. It has a door at the middle of one short side and a cooler is placed on the opposite short side. The temperature variation from the door to cooler, considering door to be open to atmosphere, is given by: (1)

$$T(x) = (mx + c) + (ae^{-x/b}) \quad (1)$$

$$= (y_1) + (y_2) \quad (2)$$

where x is the distance from the door along the length of the greenhouse, $y_1$ is the linear variation part of temperature whereas $y_2$ is an exponentially decaying part of temperature. 'm' is the slope of $y_1$ and c is its intercept on the temperature axis. 'a' is the temperature rise at the door in $y_2$ and 'b' is the space constant for the exponential decay. Further, as assumed in ref. [1], m= -0.5˚C/m, c=30˚C, a=10°C and b=2m. Substituting the values of various constants in equation (2), we get

$$T(x) = (-0.5x + 30) + 10e^{-0.5x} \quad (3)$$

Thus the overall temperature profile inside the greenhouse, after it has stabilized, will be as shown in Figure. 1.

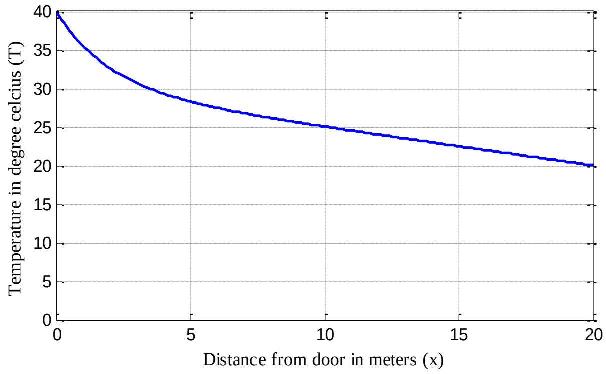


**Figure 1.** Temperature profile from door to cooler

### Luminosity Profile

On the basis of some simple experiments 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:

$$y = [Ax^2 + Bx + C] \quad (4)$$

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 theses values in equation (4), we get the profile as shown in Figure 2.

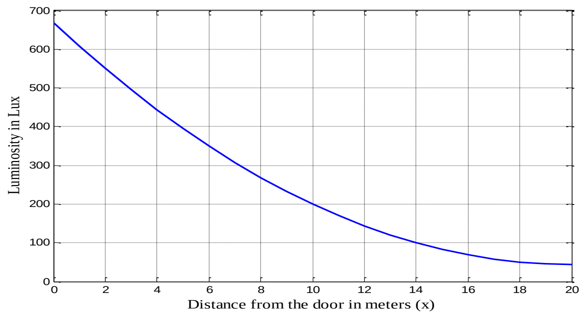


**Figure 2.** Luminosity profile in front of the door along the length

## DETERMINATION OF SENSOR NUMBER AND LOCATIONS

Following two approaches were proposed in reference [1] for determining the number and locations of temperature sensors.

Approach 1: Equal Sensor Spacing Method

Approach 2: Trial and Error Method

These approaches are extended below for determining the number and locations of the wireless sensor nodes containing both temperature and luminosity sensors.

**Approach 1 applied to temperature sensors**

In approach 1, the spacing between any adjacent sensors is taken equal to L/n (where 'L' is the length of greenhouse between the door and the air cooler and 'n' is the number of sensors). This spacing has been divided into two equal halves, i.e. L/2n, to fix the locations of the two extreme sensors from the respective wall. The principle is illustrated in Figure.3, where the number of sensors 'n' is equal to 4.

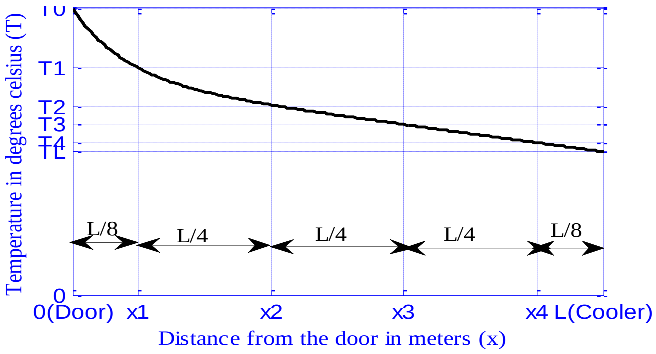


**Figure 3.** Principle of equal sensor spacing method

The locations of various sensors, as seen from Fig. 4, are:

$x_1$=L/8, $x_2$=L/8+L/4 , $x_3$=L/8+2L/4, and so on.

For generalized case of 'n' sensors, the location of j<sup>th</sup> sensor is given by

$$x_j = \frac{L}{2n} + \frac{L(j-1)}{n}, \text{ j=1 to n} \quad (5)$$

The temperature measured by each sensor can be determined from the temperature profile curve given by T(x) .Thus the temperature measured by $j^{th}$ sensor i

$$T_j = T(x_j) \quad \text{,where } x_j = \frac{L}{2n} + \frac{L(j-1)}{n} \quad (6)$$

Thus, the average temperature as measured by the 'n' sensors located as above is

$$T_{avm} = 1/n \sum_{j=1}^{n} T_j \quad (7)$$

The theoretical value of average temperature can be determined from the profile T(x) from the following equation:

$$T_{avth} = 1/L \int_0^L T(x) \quad (8)$$

Finally, the percentage error in the measured average temperature can be determined from

$$\%error = \frac{(T_{avm} - T_{avth})}{T_{avth}} * 100 \quad (9)$$

The minimum value of n is taken as 3, so that at least second order approximation of the profile curve is possible and the maximum values of n is taken as equal to L/2 (that is, 10), assuming a minimum gap of 2m between two contiguous sensors so as to keep the cost of sensors, wireless sensor nodes and WSN within reasonable limits.

**Approach 1 applied to luminosity sensors**

The technique has been applied with the number of luminosity sensors varied from 3 to 10 in exactly the same way as was done with the temperature sensors.

**Approach 2 applied to temperature sensors**

In trial and error approach, trials are made with different number of sensors (3, 4, and so on) and with their different placement options. The minimum number of sensors ($n_{min}$) is assumed as three and the maximum number sensors ($n_{max}$) as 10 in this approach also. For each option the average temperature that would be measured by the sensors is calculated and compared with the theoretical average temperature given by equation (8) and the percentage error is determined from equation (9). The principle of approach 2, i.e. Trial and Error method, is illustrated in Figure. 4, for number of sensors 'n' equal to 4.

The locations of the two extreme sensors are fixed at a distance of $L/2n_{max}$ = 1.0m from the door and cooler side walls. To begin with, second sensor (S2) from the door side, is placed at a distance of L/2n meters from the first sensor (S1) and moved further in steps of 1m in subsequent options. The successive sensors, if any, are separated by a distance of L/n meters.

**Approach 2 applied to luminosity sensors**

This technique has been applied to the luminosity sensors, exactly the same way as was done for the temperature sensors. In this case also, the numbers of sensors were varied from three to five with various placement options.

The performance evaluation of the above approaches is done on the basis of the combined error, which is the root of sum of square errors (%rsse) calculated from the two individual %errors using the following equation:

$$\%rsse = \sqrt{(\%error\ Tavm)^2 + (\%error\ Iavm)^2} \quad (10)$$

**RESULTS AND DISCUSSIONS**

**Results for Approach 1**

Percentage errors in the measured average values of temperature and luminosity have been determined by varying 'n' from 3 to 10 for the reasons given earlier. The theoretical value of average temperature (T*avm*) using equation (8) comes out to be 26.00˚C. The theoretical value of average luminosity (I*avm*), calculated in a similar fashion, is found to be 252.0833 lux. The average %error (for both temperature and luminosity) and %rsse vs. the number of sensors are presented in Table 1. Variations of various errors versus the number of sensors are plotted in Fig.5. As expected, the percentage error is reducing as the number of sensors is increased in both the profile measurements. Obviously the %rss error also reduces as the number of sensors is increased.

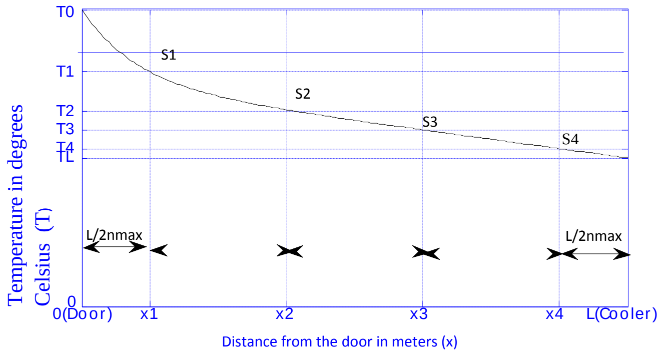


**Figure 4.** Principle of trial and error method for four sensors

**Table 1.** Results of calculations based on approach 1 for temperature and luminosity sensors

| No. of sensors | Locations of sensors (Distances from door in m) | T*avm* (˚C) | %error in temperature | I*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 | -0.8264 | 1.0058 |
| 6 | 1.667 5, 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 |

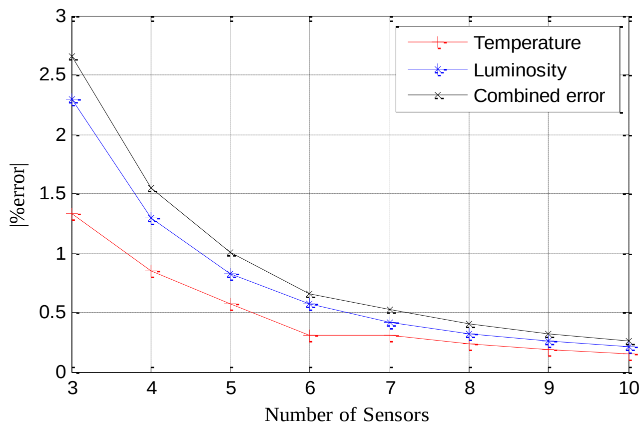


**Figure 5.** Errors vs. number of sensors for equal sensor spacing method

**Results for Approach 2**

For this approach, the minimum number of sensors selected was three as for approach 2. The positions of two extreme sensors were fixed at 1.0 m and 19.0 m as per the principle. The results for different number of sensors and the various options are discussed below:

*Three Sensors:* In this exercise, three sensors were placed in the greenhouse. In the first option, the second sensor S2 was placed at a spacing of L/2n=20/6=3.33m from S1. In subsequent options, this spacing was increased in steps of 1.0

m. The %error in temperature and luminosity and %rsse were calculated for each option and are shown in Table 2. Graphs between various errors and sensor options are shown in Fig. 6. From the Table 2 and the graph, it can be observed that option 10, where the sensors were placed at 1.0 m, 13.33m and 19.0m from the door, gives the least rrse of 2.254% and the individual errors were 1.8126% in temperature and 1.3407% in luminosity.

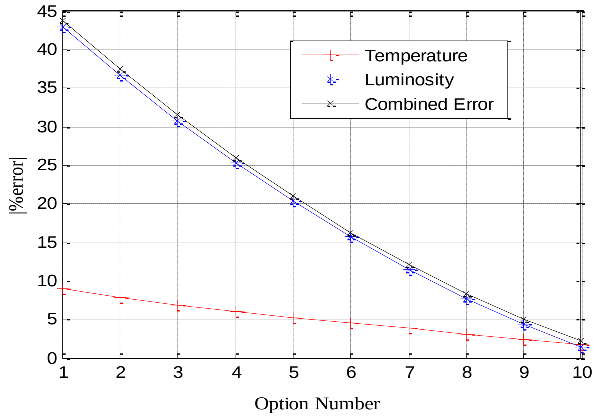


**Figure 6.** Errors vs. sensor placement option for three temperature and luminosity sensors

***ii) Four Sensors:*** In this exercise four sensors were placed in the greenhouse. The locations assumed for the extreme sensors were kept same as considered for three sensor placement options discussed previously. In the first option, S2 was placed at a spacing of L/2n = 20/8=2.5 m from S1. This spacing was increased in steps of 1.0 m again. Sensors S2 and S3 were separated by a distance of L/n= 20/5 = 5m. The %error in temperature and luminosity and %rsse for each option were calculated and are given in table 3.

**Table 2.** Placement options along with various error calculations for three sensors

| Option No. | S1 (m) | S2 (m) | S3 (m) | *Tavm* ˚C | %error in temperature | *Iavm* lux | %error in Luminosity | %rsse Combined error) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 4.33 | 19.0 | 28.3495 | 9.0366 | 360.1817 | 42.8820 | 43.8238 |
| 2 | 1.0 | 5.33 | 19.0 | 28.0323 | 7.8167 | 344.3796 | 36.6134 | 37.4385 |
| 3 | 1.0 | 6.33 | 19.0 | 27.7744 | 6.8246 | 329.6192 | 30.7580 | 31.5060 |
| 4 | 1.0 | 7.33 | 19.0 | 27.5524 | 5.9706 | 315.9005 | 25.3159 | 26.0104 |
| 5 | 1.0 | 8.33 | 19.0 | 27.3521 | 5.2005 | 303.2234 | 20.2870 | 20.9430 |
| 6 | 1.0 | 9.33 | 19.0 | 27.1651 | 4.4811 | 291.5880 | 15.6713 | 16.2994 |
| 7 | 1.0 | 10.33 | 19.0 | 26.9861 | 3.7925 | 280.9942 | 11.4688 | 12.0796 |
| 8 | 1.0 | 11.33 | 19.0 | 26.8119 | 3.1227 | 271.4421 | 7.6795 | 8.2901 |
| 9 | 1.0 | 12.33 | 19.0 | 26.6407 | 2.4642 | 262.9317 | 4.3035 | 4.9591 |
| 10 | 1.0 | 13.33 | 19.0 | 26.4713 | 1.8126 | 255.4630 | 1.3407 | 2.2545 |

**Table 3.** Placement options along with various error calculations for four sensors

| Option No. | S1 (m) | S2 (m) | S3 (m) | S4 (m) | *Tavm* ˚C | %error | *Iavm* lux | %error | %rsse Combined error) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 3.5 | 8.5 | 19.0 | 27.9866 | 7.6408 | 343.1641 | 36.1312 | 36.9303 |
| 2 | 1.0 | 4.5 | 9.5 | 19.0 | 27.5516 | 5.9679 | 322.0703 | 27.7634 | 28.3976 |
| 3 | 1.0 | 5.5 | 10.5 | 19.0 | 27.1895 | 4.5748 | 302.5391 | 20.0155 | 20.5317 |
| 4 | 1.0 | 6.5 | 11.5 | 19.0 | 26.8714 | 3.3516 | 284.5703 | 12.8874 | 13.3161 |
| 5 | 1.0 | 7.5 | 12.5 | 19.0 | 26.5801 | 2.2313 | 268.1641 | 6.3791 | 6.7581 |
| 6 | 1.0 | 8.5 | 13.5 | 19.0 | 26.3051 | 1.1735 | 253.3203 | 0.4907 | 1.2720 |
| 7 | 1.0 | 9.5 | 14.5 | 19.0 | 26.0399 | 0.1535 | 240.0391 | -4.7779 | 4.7804 |

The graphs between the errors and sensor placement options are shown in Fig. 7. Least rsse is 1.2720% for option 6 with error in temperature as 1.1735% and error in luminosity as 0.4907%.

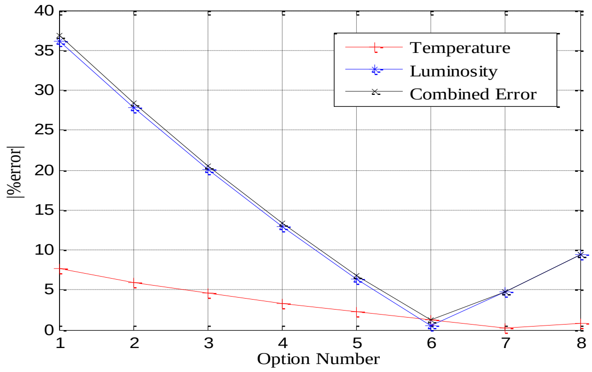


**Figure 7.** %error vs. sensor placement option for four temperature and luminosity sensors

***iii) Five Sensors:*** Five sensors (S1, S2, S3, S4 and S5) were placed along the length of the green-house. Spacing of S2 from S1 is L/2n =20/10=2.0m in the first option, which is increased in the steps of 1.0 m in successive options. S2, S3, and S4 are interspaced by L/n=20/5=4.0m. Various placement options along with the errors are given in table IV. The graphs between errors and sensor placement options are shown in Fig. 8. The least rss error is 3.6157% for option 4, which is very high as compared with the error for option 6 when only four sensors were considered.

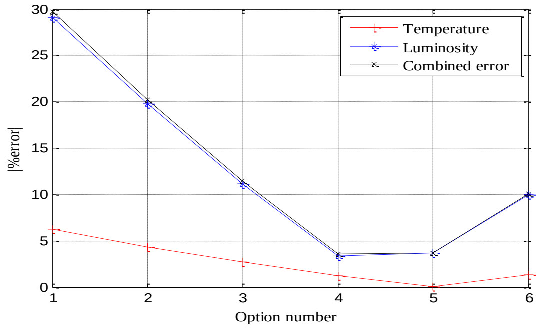


**Figure 8.** Errors vs. sensor placement option for five luminosity and temperature sensors

**Final Selection:**

For final selection of the number of sensors, a summary of the results for the two methods is given in table 4. The results for approach 2 clearly show that the minimum combined error (1.2720%) is achieved with 4 sensors placed as per option 6. For the same number of sensors for approach 1, combined error is higher (1.543%). On the other hand four sensors as per approach 2 and 5 sensors as per approach 1 give comparable values of the combined error. Hence 4 sensors, with option 6 with the sensor placement at 1.0, 8.5, 13.5, 19.0 m from door will make the best choice.

**Table 4:** Summary of results for the two methods

| Error | Approach 1 | | | Approach 2 (Least Errors) | | |
|---|---|---|---|---|---|---|
| | 3 Sensor | 4 Sensor | 5 Sensor | 3 *Sensors* *(option 10)* | 4 *Sensors* (option 6) | 5 *Sensors* *(option 4 )* |
| % rrse (combined error) | 2.6563 | 1.5432 | 1.0058 | 2.2545 | 1.2720 | 3.6157 |

## CONCLUSIONS

Two approaches proposed for the selection of number and location of sensor nodes in a greenhouse, namely equal sensor spacing method and trial and error method, have been successfully investigated for measuring temperature and luminosity profiles along the length of a greenhouse.

In the equal sensor-spacing method, the error reduces as the number of sensors is increased from 3 to 10. The error in the average value of temperature reduces from 1.3354% to 0.1559% that in the average value of luminosity reduces from 2.2962% to 0.2066% and the combined error or rss error reduces from 2.6563% to 0.2588%. Although the error corresponding to ten sensors is very small, the large number of sensors would make the WSN-based measurement system very expensive.

In case of the trial and error method, the least value of rss error comes out to be 2.2545% for 3 sensors (option 10 of placement of sensors), 1.2720% for 4 sensors (option 6) and 3.6157% for 5 sensors (option 4).

**Table 3.** Placement options along with various error calculations for five sensor

| Opt. No. | S1 (m) | S2 (m) | S3 (m) | S4 (m) | S5 (m) | *Tavm* °C | %error in temperature | *Iavm* Lux | %error in Luminosity | %rsse (Combined error) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 3.0 | 7.0 | 11.0 | 19.0 | 27.6280 | 6.2617 | 325.3125 | 29.0496 | 29.7168 |
| 2 | 1.0 | 4.0 | 8.0 | 12.0 | 19.0 | 27.1255 | 4.3287 | 301.8750 | 19.7521 | 20.2209 |
| 3 | 1.0 | 5.0 | 9.0 | 13.0 | 19.0 | 26.7026 | 2.7023 | 280.3125 | 11.1983 | 11.5197 |
| 4 | 1.0 | 6.0 | 10.0 | 14.0 | 19.0 | 26.3281 | 1.2619 | 260.6250 | 3.3884 | 3.6157 |
| 5 | 1.0 | 7.0 | 11.0 | 15.0 | 19.0 | 25.9829 | -0.0658 | 226.8750 | -3.6777 | 3.6783 |
| 6 | 1.0 | 8.0 | 12.0 | 16.0 | 19.0 | 25.6555 | -1.3251 | 183.2259 | -10.0000 | 10.0874 |

An interesting observation for this approach is that increasing the number of sensors does not necessarily reduce the error, and, therefore, an optimal number and optimal locations of sensors need to be determined through trial and error. A critical comparison of the results for the two methods shows: (a) that if four sensors are selected in either method, then the equal sensor spacing method gives a lower combined error, (b) that the same order of error can be achieved with trial-and-error method using lesser number of sensors i.e.4, against 5 sensors required in approach 1.

The two methods of selecting the number and locations of sensors, proposed and evaluated in this paper, can be applied along both the dimensions, i.e. length and breadth, of a greenhouse. However, selections along the length and breadth need to be treated separately.

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