Optimal Placement of Camera Wireless Sensors in Greenhouses

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Abstract—**Stability of the ideal plant environment in a greenhouse can be maintained by using wireless sensor networks, which are used for monitoring and controlling temperature, light, and humidity. Tracking plant growth is the best method for early detection of disease thus preventing significant crop losses. Wireless Visual Sensor Network (WVSN) are used for monitoring plant growth with the added feature of a camera. This paper presents a mathematical formulation and an optimal solution for the placement of the WVSN cameras to guarantee *coverage of a large area* while maintaining *high quality images* and minimizing *overlap between cameras*. Simulation results show the effectiveness of the proposed model in finding the minimum number of cameras with the exact position to cover the entire monitored area of the greenhouse, with the desired image quality resolution.**

Keywords—Wireless Camera Sensors, resolution, overlapping, placement, images.

I. INTRODUCTION

Greenhouses are unique structures with walls and roof made primarily of transparent material, and they provide the perfect environment for plant growth. There is considerable research on how to control the environment of a greenhouse, the temperature, humidity, wind, pressure and dew point by using sensors [1] [2]. Conversely, there is much less research on the early detection of diseases that can damage greenhouse produced crops. The stability of the ideal environment for growing plants is guaranteed by using a Wireless Sensor Network (WSN), to monitor and control the conditions for optimum plant health and growth. Tracking plant growth is the best method for early detection of plant disease and preventing significant crop losses. A Wireless Visual Sensor Network (WVSN) is an efficient technology for monitoring plant growth with the added feature of wireless sensor cameras. The WVSNs are widely used for surveillance and detecting anomalies [3-5] and are poised to be the best solution for early detection of plant anomalies and diseases in greenhouse crop production.

The area inside a greenhouse that needs to be monitored is very large, and it would take large number of images to cover. To improve the performance in terms of storage and processing and reduce the response time of the image processing unit, we should place the WVSN cameras so that there is no overlap of images taken by the cameras. It is also necessary to capture images with high resolution for better processing and analysis. This paper presents a mathematical formulation and an optimal solution for the best placement of the WVSN camera nodes to cover a large area, produce high-quality images, and avoid overlapping between cameras.

Optimizing the number of sensor cameras will help in:

(i) Optimizing the limited storage space of the sensor camera nodes.
(ii) Decreasing the processing time to then be able to analyse these images quickly and isolate plants. showing signs of disease.
(iii) Producing high-quality images for avoiding false detections.
(iv) Minimizing the project cost since WVSN systems can be expensive to install and maintain.

The remainder of this paper is organized as follows. In Section II, we review the related work. Section III describes the ILP problem formulation. Section IV presents the ILP formulation. Section V presents the implementation and numerical results, finally, in Section VI, is the conclusion for this paper.

II. RELATED WORKS

Finding the minimum number of camera sensors and placing them to guarantee coverage is considered an NP problem. Most research on optimizing camera placement has been more on the practical side as opposed to optimal from theoretical analysis. Model with realistic practical assumptions can complex [6]. Several works had an interest in maximizing coverage, such as [7], where the authors studied the problem of maximizing coverage on a set of discrete targets by directional sensors that could turn around. This work aimed to maximize the network lifetime by maximizing the number of covered targets and minimizing the number of sensors activated at any given moment. The authors ensured that a target must be covered by at least one camera (tolerating overlapping images between the sensors) and did not consider optimal camera placement since they assumed that the cameras were placed randomly. In [8], the authors proposed a heuristic for the maximum coverage of an area when one of the existing cameras breaks down. The proposed algorithm is a decentralized control system that allows the communication between the cameras in other nearby locations to adjust their direction and field of view.

Authors in [9] solved the camera placement problem using dynamic programming to maximize the coverage area and use it in a surveillance application without considering the quality of the images' resolution. In [10], the authors tried to solve the same problem focusing on maximizing the coverage area and minimizing the cost. Authors in [11] used a graph-based approach to cover a larger area with less time. The authors in [12] model the sensor field as points on a grid (coordinates) and present an Integer Linear Programming (ILP) solution for minimizing the number, and therefore the cost, of the sensors it would take to completely cover the area to be monitored, taking into consideration that sensors vary in terms of field of view ranges and price. The authors did not solve the problem of overlapping between cameras. In [13], the authors address the problem of optimally placing multiple sensor cameras to cover a given area. They modeled the problem using a linear programming approach which determines the minimum number of cameras needed to cover the monitored area. This approach also determined the exact position of each camera. However, their solution does not manage the problem of overlapping between the cameras and image quality. In [14], authors propose a Computational Fluid Dynamics (CFD) solution using wireless sensor camera nodes and image processing to monitor the temperature in a greenhouse when physical measuring instruments are not available. In [15], the authors propose a global greedy search optimization method to look for the camera's optimal placement. However, the proposed method is very long and complex. It must explore all the possible solutions, and it tolerates overlapping between the cameras. In [16-18], the authors used a different approach to find the camera sensor placement. They solved the problem using Particle Filtering (PF), Resampling Particle Swarm Optimization (RPSO). While they achieved good coverage control, their solution did not consider the resolution of the images.

It is worth noting there remains a gap in research in terms of formulating a general problem for WVSN camera deployment management in greenhouses. Such a problem must consider finding the optimal placement for the camera sensors, reducing the number of cameras, increasing the quality of the images, avoiding overlapping views and covering a large area. Our proposed optimization problem manages to satisfy all these requirements.

III. Optimal Placement Camera Quality Problem Formulation

A. Preliminaries

In this work, we consider the angular field of view of the camera is, $\theta \in]0^o, 180^o]$. Meaning that if the camera is in the centre of a circle, the camera will collect images from the full arch within the angle range $]0^o, 180^o]$.

Each camera is characterised by the following parameters:

- Focal Length (FL): is the distance between the lens and the image sensor when the subject is in focus. In other words, it is the distance from the back of the lens to the plane of the image formed of an object placed infinitely far in front of the lens, usually stated in millimetres.
- Angle of View (AOV): is the angle subtended by the camera lens, i.e., the visible extent of the scene captured by the camera lens. A wide-angle of view captures a broader area, and vice versa.
- Resolution: is the number of pixels per image. The higher the number of pixels, the higher the image quality.

The Field of View (FOV) for the covered area in the WVSN can be specified by the Angular Field of View (AFOV), in degrees, or the Linear Field of View (LFOV), in metres. The AFOV is defined by the focal length, f, and the horizontal dimension of sensor in millimetres, b, as in Equation 1. The shorter the FL, the wider the AFOV, see Figure 1. Both the AFOV and the LFOV can be measured horizontally, vertically, or diagonally.

$$AFOV = 2\, tan^{-1}\left(\frac{b}{2f}\right) \quad (1)$$

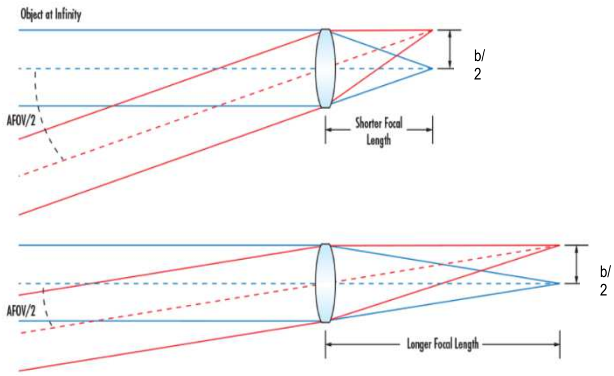

Fig 1: The Relation Between the AFOV and the FL

For a given sensor camera and without varying the FL, the AFOV remains constant in contrast to the LFOV which varies depending on the distance between the sensor and the monitored area. The larger the distance between the sensor and the monitored area, the larger the LFOV the poorer the quality of the collected images.

B. Assumption and Definition

Assume that the greenhouse is a rectangular area with length L and width W. In the beginning, we assume that there is no obstacle between the sensor camera and the plants, so we can place the cameras wherever we feel we need them.

The assumptions regarding the properties of the WVSN cameras are as follows:

- All the cameras have the same characteristics.
- The camera's field of view is an angle of $\theta \in]0^o, 180^o]$.
- The FL of the camera is fixed; in other words, all the cameras have the same AFOV.
- All the cameras have the same capture resolution $R = R_h * R_v$, where R is the number of pixels of the image. R_h is the horizontal number of pixels. R_v is the vertical number of pixels.
- The cameras can be fixed in a predefined position and placed at the same height.
- The monitoring area is a shape in two-dimensional Euclidean space.

C. Optimization Problem Formulation

In this work, we are interested in determining:

1) The optimal placement of cameras to have the desired quality of the image object.
2) The required number of cameras to cover the entire monitored area.
3) The positioning of the cameras so that there is no overlap between images taken by the cameras.

Table 1: Glossary of Notation

Symbol	Meaning
C	Set of cameras
θ	Angle of view
R	Image resolution, total number of pixels of the image
R_h	Number of pixels in the horizontal line of an image
R_v	Number of pixels in the vertical line of an image
Q	The image quality, number of pixels per unit distance
Q_{min}	The minimum accepted quality

We consider that the monitoring area is a rectangle in the two-dimensional Euclidean space defined by the points ABCD, such that $A = (x_a, y_a), B = (x_b, y_b)$, C= (x_c, y_c), and D = (x_d, y_d). We are interested in the covered area determined by the horizontal field of view of the cameras. In other words, we are interested in the part of the line defined by the points A and D. Denote the set of cameras by $C = \{1, \ldots, i, \ldots, c\}$. A camera i has an AOV denoted by θ_i, and we have $\forall(i,j) \in C^2, \theta_i = \theta_j$. Denote the coordinates of the camera i by (x_i, y_i). Our aim is to calculate the coordinates of the part covered by the camera, illustrated in (1) as a green line $[I' \, I'']$, where point I' is $(x_{i'}, y_{i'})$ and point I'' is $(x_{i''}, y_{i''})$. Coordinates of both points can be calculated as follows.

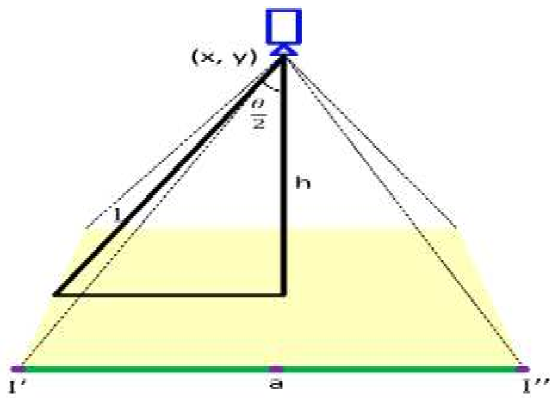

Fig 1: The Horizontal Field of View

$$x_{i'} = x_i - \frac{a}{2} \quad (2)$$

$$y_{i'} = y_i \quad (3)$$

$$x_{i''} = x_i + \frac{a}{2} \quad (4)$$

$$y_{i''} = y_i \quad (5)$$

The height, h, (or the distance from the camera to the sensed object or the ground), and the AVOF, θ, are known. But $\frac{a}{2}$ is unknown. Hence,

$$(x_{i'}, y_{i'}) = \left(x_i - h \times \tan\left(\frac{\theta}{2}\right), y_i\right) \quad (6)$$

$$(x_{i''}, y_{i''}) = \left(x_i + h \times \tan\left(\frac{\theta}{2}\right), y_i\right) \quad (7)$$

Given h and θ, $\frac{a}{2}$ can be found as follows:

$$sin\left(\frac{\theta}{2}\right) = \frac{a/2}{l} \Rightarrow a/2 = sin\left(\frac{\theta}{2}\right) \times l$$

and

$$\cos\left(\frac{\theta}{2}\right) = \frac{h}{l}$$

Hence,

$$a/2 = h \times \tan\left(\frac{\theta}{2}\right) \quad (8)$$

Initially, we are interested in finding the optimal placement of the cameras considering the horizontal field of view. For this reason, the value of the coordinates over the Y-axis of the covered area is equal to the value of the Y-axis of the camera. And the covered area on the X-axis is:

$$a = 2 \times h \times \tan\left(\frac{\theta}{2}\right) \quad (9)$$

which is characterized by the part: [I' I"] such that I' and I" are determined by the (6) and (7).

IV. ILP Optimization Problem Formulation

We present in this section the ILP formulation of our defined optimization problem above. We call the ILP problem as Integer Linear Programming-Optimal Placement Camera Quality (ILP-OPCQ). To solve the ILP-OPCQ problem we identify the workspace as a grid map; the monitored area (i.e., the monitored green line in Figure 1) corresponds to a vector line with $L = E[r2_x]$ lines. The space where the cameras can be placed is viewed as a grid map with $L = E[r2_x]$ lines and $K = E[h_{max}]$ columns, denoted it by $P(k,l)$, where $k = 0, \ldots, K$ and $l = 0, \ldots, L$. Resolution of the camera $R = R_h * R_v$. R_h number of pixels in the horizontal line of an image and R_v number of pixels in the vertical line of an image

A. ILP-OPCQ Objective Function Definition

We consider rephrasing the objective function as follows.

1) Minimizing the number of cameras needed for covering the entire monitored area:

$$\text{Min} \sum_{k=h_{min}}^{h_{max}} \sum_{l=r1_x}^{r2_x} P(k,l) \quad (10)$$

where $r1_x$, $r2_x$ are the X-axis coordinates of the horizontal line of the area.

$$P(k,l) = \begin{cases} 1, & \textit{if a camera placed at coordinates } (k,l) \\ 0, & \textit{otherwise} \end{cases}$$

2) Maximizing k in the Eq. (2), which stands for maximizing the covered area by each camera.

$$\text{Max} \sum_{k=h_{min}}^{h_{max}} \sum_{l=x_1}^{x_2} 2 \times k \times \tan\left(\frac{\theta}{2}\right) \times P(k,l) \quad (11)$$

3) Maximizing k in the Eq. (3), which stands for maximizing the resolution quality of images.

$$\text{Max}\left\{\frac{\sum_{k=h_{min}}^{h_{max}} \sum_{l=r1_x}^{r2_x} P(k,l) \times R_h}{\sum_{k=h_{min}}^{h_{max}} \sum_{l=x_1}^{x_2} 2 * k * \tan\left(\frac{\theta}{2}\right)}\right\} \quad (12)$$

4) By combining the three equations, the ILP-OPCQ objective function can be written as:

$$\mathrm{Max}\left\{\frac{\sum_{k=h_{min}}^{h_{max}}\sum_{l=x_1}^{x_2} 2\times k\times \tan\left(\frac{\theta}{2}\right)\times P(k,l) + \frac{\sum_{k=h_{min}}^{h_{max}}\sum_{l=r1_x}^{r2_x} P(k,l)\times R_h}{\sum_{k=h_{min}}^{h_{max}}\sum_{k=x_1}^{x_2} 2\times k\times\tan\left(\frac{\theta}{2}\right)}}{\sum_{k=h_{min}}^{h_{max}}\sum_{l=x_1}^{x_2} P(k,l)}\right\} \quad (13)$$

B. Constrains of the ILP-OPCQ Probloem

1. The cameras cannot be placed at a height less than h_{min} and greater than h_{max}.
   $P(k,l) = 0,\ \forall k \in [\![0, E[h_{min}] - 1]\!],$ and $l \in [\![0, L]\!]$ (14)

2. We can place at most a single camera in a column
   $\sum_{k=0}^{K} P(k,l) \leq 1,\ \forall l \in [\![0, L]\!]$ (15)

3. The left sight covered area of any camera should be greater than the X-axis coordinate of the beginning of the covered area.
   $$\forall (k,l) \in [\![1,K]\!] \times [\![1,L]\!]$$
   $$P(k,l) \times \left(l - k \times \tan\left(\frac{\theta}{2}\right)\right) \geq E[r1_x] \quad (16)$$
   The right sight covered of any camera should be lower than the X-axis coordinate of the end of the covered area.

   $$\forall (k,l) \in [\![1,K]\!] \times [\![1,L]\!]$$
   $$P(k,l) * \left(l + k \times \tan\left(\frac{\theta}{2}\right)\right) \leq E[r2_x] \quad (17)$$
   $$P(k,l-1) \times \left(l - 1 + k \times \tan\left(\frac{\theta}{2}\right)\right) \leq P(k,l) \times \left(l - k \times \tan\left(\frac{\theta}{2}\right)\right) \times P(k,l) \times \left(l + k \times \tan\left(\frac{\theta}{2}\right)\right) \leq P(k,l+1) \times \left(l + 1 - k \times \tan\left(\frac{\theta}{2}\right)\right)$$
   $$P(k,l) \times \left(l + k \times \tan\left(\frac{\theta}{2}\right)\right) \leq P(k,l+1) \times \left(l + 1 - k \times \tan\left(\frac{\theta}{2}\right)\right)$$
   And
   $$\sum_{k=h_{min}}^{h_{max}} \sum_{l=x_1}^{x_2} 2 \times k \times \tan\left(\frac{\theta}{2}\right) \times P(k,l) = E[r2_x] - E[r1_x] \quad (18)$$

Consequently, with the aid of the constrains, the optimization problem can be rephrased as follows:

Objective:

$$Max\left\{\frac{\sum_{k=h_{min}}^{h_{max}}\sum_{l=x_1}^{x_2} 2\times k\times \tan\left(\frac{\theta}{2}\right)\times P(k,l) + \frac{\sum_{k=h_{min}}^{h_{max}}\sum_{l=r1_x}^{r2_x} P(k,l)\times R_h}{\sum_{k=h_{min}}^{h_{max}}\sum_{l=x_1}^{x_2} 2\times k\times\tan\left(\frac{\theta}{2}\right)}}{\sum_{k=h_{min}}^{h_{max}}\sum_{l=x_1}^{x_2} P(k,l)}\right.$$

Subject to: *Eqs. (14)-(18)*

V. EXPERIMNATL CASES AND RESULTS

Three test cases are considered in our experiments as explained below. For all the three cases, we consider a greenhouse with a grid area of side length L distance-unit. We set L = 1000in (distance-unit). Our goal is to have a big number for L to show better results scale regardless of what unit can be assigned to L. Some camera sensors are deployed in each line of the grid area at the same height. The height will be determined in test case one, and the exact number of cameras will be determined in test case two. Sensor cameras capture images with the desired resolution once a day. Camera sensors transmit captured images to the base station. Single-hop and/or multi-hop communication can be used depending on the number of cameras and their locations. The communication protocol can be based on standard WiFi or Zigbee.

A. Test Case One

In the first case, we determine the optimal distance between the cameras and the plants, while guaranteeing a good quality image and wider area coverage. In this case, we set the cameras AFOV, θ = 120º, and the value of R_h varies from 100 pixels to 1024 pixels, to study the effect of camera quality in terms of the resolution of the collected images on the number of cameras necessary to cover the entire area and the optimal distance between the cameras and the plants.

In Figure 2, we plot the necessary number of cameras to cover the area L in function of the quality of cameras. The Y-axis represents the optimal number of cameras and the X-axis represents the quality of cameras, i.e., the resolution (R_h) of the collected images. We note that the optimal number of cameras varies from 38 cameras, for a resolution of 100 pixels, to three cameras for resolution of 1024 pixels.

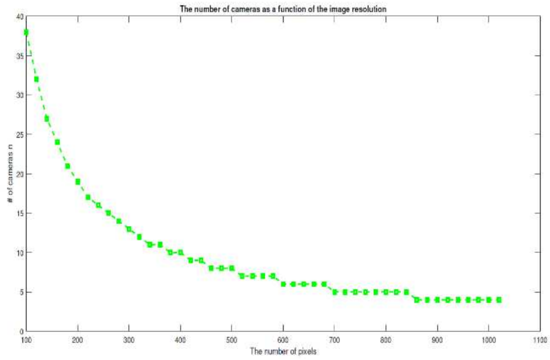

Fig 2: The Minimum Number of Cameras to Cover the Area L in Function of the Quality Image

Hence, if the quality of cameras increases, the number of cameras decreases. Increasing R_h (the quality of cameras) will result in increasing the optimal distance X, therefore, decreasing the number of cameras. Increasing the distance between the cameras and the ground X will allow the coverage of a larger area and hence, decreases the number of cameras.

This result is supported by the results plotted in Figure 3. It shows the optimal distance X as a function of the quality of cameras. The optimal distance increases by increasing the quality of cameras; it goes from 8.33 distance-unit for the image quality resolution 100 pixels to 85 distance-unit for the image resolution quality 1024 pixels. So, increasing the cameras' quality will increase the covered area by each camera and hence, decrease the number of cameras.

B. Test Case Two

In the second case, we find the exact positions of the needed cameras, n, taking into consideration of avoiding redundancy and overlapping views between the collected images. In this case, we set the horizontal coordinates of the side L to $x_a = 0$ and $x_d = 1000$, the cameras AFOV, θ = 160º, and the value of R_h to be either 1000 pixels or 1500 pixels. Figure 4 shows the obtained results where the green curve represents the exact position of the cameras that capture images of R_h=1000 pixels, and the blue curve represents the exact position of each of the cameras that capture images of R_h= 1500 pixels.

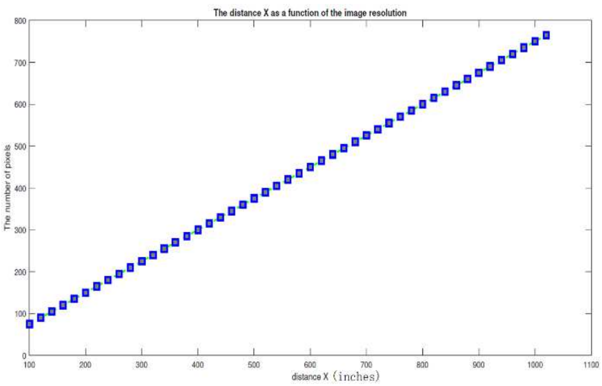

Fig3: The Optimal Distance X in Function of the Quality of Camera R_h

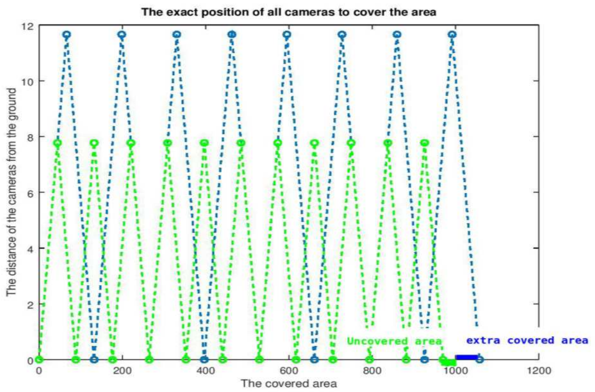

Fig 4: The Distance from the Camera to the Ground of the Greenhouse in the Covered Area

From figure 4, in order to cover the entire area, we need either 11 cameras of quality R_h = 1000 pixels (each camera covers an area of 88.16 distance-unit) or eight cameras of quality R_h = 1500 pixels (each camera covers an area of 132.25 distance-unit). It is worth mentioning that the 8th camera will cover an extra part of area of approximately 57.96 distance-unit (the blue highlighted section in Figure 4). This is explained by the fact that the number of cameras n is equal to the integer part of ($\frac{1500}{2\times 11.66\times \tan 80}$) plus 1, which is $E(7.56) + 1 = 8$. Whereas, if choosing the second type of camera, i.e., cameras of quality R_h = 1000 pixels, an area of about 30.20 distance-unit will not be covered (the green highlighted section in Figure 4), since the number of cameras n is equal to the integer part of $\frac{1000}{2\times 7.77\times \tan 80} = 11.34$ which is 11.

C. Test case Three

In the third case, we consider finding the camera's position with respect to a given image quality to satisfy the purpose. For this case, we set the image quality to a specific value, Q_{req} = 20 pixels per distance-unit. Other input parameters, θ and R_h are set to the same values used in test case two (i.e., θ = 160º, and R_h = 1000 pixels or 1500 pixels). Based on the R_h value we consider two types of cameras:

- Type 1: cameras that can capture images of R_h = 1000 pixels
- Type 2: cameras that can capture images of R_h = 1500 pixels

Figure 5 shows the exact position of type 1 cameras in order to cover the area of L=1000 distance-unit. Each camera is placed at X = 4.41 distance-unit from the ground of the greenhouse, and the necessary number of cameras needed to cover the whole area is 20. Thus, each camera covers an area of 50 distance-unit.

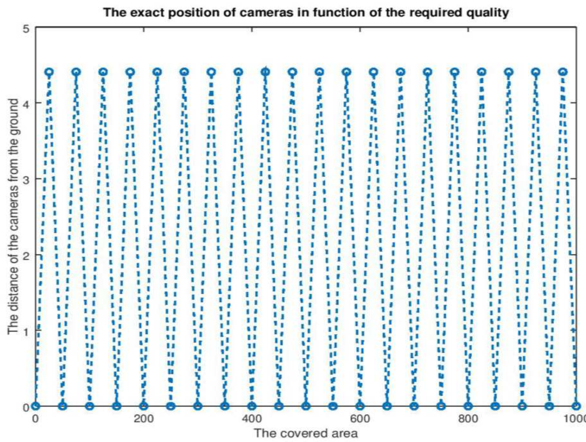

Fig 5: The Exact Position of Cameras

Figure 6 shows the exact position of type 2 cameras in order to the same area of L = 1000 distance-unit. For this camera, type 2, X, for each camera, is found to be at X = 6.61 and 13 cameras are needed to cover the whole area. This gives 75 distance-unit coverage area for each camera.

Comparing the two types of cameras, the first type of camera is closer to the ground of the greenhouse and can cover smaller areas compared to the second type of camera, which is higher up from the ground of the greenhouse and can cover larger areas. Hence, this confirms that the camera's quality and the required image quality are two important factors for determining the cameras' exact position.

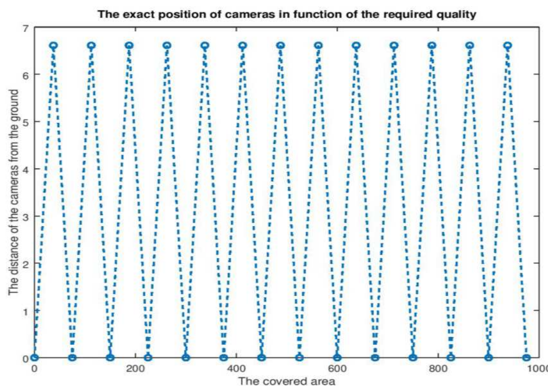

Fig 6: The Exact Position of Cameras in Function of the Required Quality

VI. Conclusion

In this paper, we discussed deploying WVSN in a greenhouse, with the objective of finding the optimal number and position of the sensor cameras to cover the entire greenhouse area while maximizing both the quality of the images and the area covered by each camera. We formulated the problem as an ILP-Optimal Placement Camera Quality problem. Experimental results show the effectiveness of the proposed solution in finding the minimum number of cameras, the exact placement of each camera to cover the entire area being monitored in the greenhouse with the required image quality resolution to detect signs of plant disease.

REFERENCES

[1] N. Harris, A. Cranny, M. Rivers, K. Smettem, E.G. Barrett-Lennard, "Application of distributed wireless chloride sensors to environmental monitoring: Initial results," *IEEE Transactions on Instrumentation and Measurement*, 65(4), pp. 736-743, 2016.

[2] M. Kang, X. Fan, J. Hua, H. Wang, X. Wang, F. Wang, "Managing traditional solar greenhouse with CPSS: A just-for-fit philosophy," *IEEE Transactions on Cybernetics*, 48(12), pp. 3371-3380, 2018.

[3] European Commission, "Directorate-General for Agriculture and Rural Development, Ddirectorate H. Sustainability and Quality of Agriculture and Rural Development, H.3," *Organic Farming*, 2013.

[4] E. Eriksson, G. Da´n, V. Fodor, "Predictive distributed visual analysis for video in wireless sensor networks," *IEEE Transactions on Mobile Computing*, 15(7), pp. 1743-1756, 2016.

[5] Y. Wang, Z. Liu, D. Wang, Y. Li, J. Yan, "Anomaly detection and visual perception for landslide monitoring based on a heterogeneous sensor network," *IEEE Sensors Journal*, 17(13), pp. 4248-4257, 2017.

[6] J. Liu, S. Sridharan, C. Fookes, "Recent advances in camera planning for large area surveillance: A comprehensive review," *ACM Computing Surveys*, 49(1), 2016.

[7] A.I. Jing, A. Abouzeid, "Coverage by directional sensors in randomly deployed wireless sensor networks," *Journal of Combinatorial Optimization*, 11(02), pp. 21- 41, 2006.

[8] M. Hoffmann, M. Wittke, J. Hahner, C. Muller-Schloer, "Spatial partitioning in self-organizing smart camera systems," *IEEE Journal of Selected Topics in Signal Processing*, 2(4), pp. 480-492, 2008.

[9] A. Altahir, V. Asirvadam, "Optimizing Visual Surveillance Sensor Coverage Using Dynamic Programming," *IEEE Sensors Journal.* 17(11), pp. 3398-3405, 2017.

[10] P. Natarajan, K. Pradeep, Atrey, M. Kankanhalli, "Multi-camera coordination and control in surveillance systems: A survey," *ACM Transactions on Multimedia Computing, and Applications,* 11(4), 2015.

[11] P. Munishwar, N. Abu-Ghazaleh, "Coverage algorithms for visual sensor networks," *ACM Transactions on Sensor Networks,* 9(4), 2013.

[12] K. Chakrabarty, S.S. Iyengar, H. Qi, E. Cho, "Grid coverage for surveillance and target location in distributed sensor networks," *IEEE Transactions on Computers*, 51(12), pp. 1448-1453, 2002.

[13] E. Horster, R. Lienhart, "Approximating optimal visual sensor placement," *IEEE International Conference on Multimedia and Expo*, pp. 1257-1260, 2006.

[14] C. Valdivia, J. Escobedo, H. Mun˜oz, J. Berumen, A. Herna´ndez, O. Guirette, A. Arroyo, J. Mendoza, F. Becerra, A. Ortega, H. Azcaray, M. Ortiz, "Implementation of virtual sensors for monitoring temperature in greenhouses using CFD and control," *Sensors*, 19(01), pp. 1-13, 2019.

[15] A.A. Altahir, V.S. Asirvadam, N.H. Hamid, P. Sebastian, N. Saad, R. Ibrahim, S.C. Dass, "Modeling multicamera coverage for placement optimization," *IEEE Sensors Letters*, 1(6), pp.1-4, 2017.

[16] X. Wang, H. Zhang, S. Fan, H. Gu, "Coverage Control of Sensor Networks in IoT Based on RPSO," *IEEE Internet of Things Journal*, 5(5), pp. 3521-3532, 2018.

[17] X. Wang, H. Gu, H. Zhang, H. Chen, "Novel RPSO Based Strategy for Optimizing the Placement and Charging of a Large-Scale Camera Network in Proximity Service," *IEEE Access,* vol.7, pp. 16991-17000, 2019.

[18] X. Wang, H. Gu, Y. Liu, H. Zhang, "A Two-Stage RPSO-ACS Based Protocol: A New Method for Sensor Network Clustering and Routing in Mobile Computing," *IEEE Access*, vol.7, pp. 113141-113150, 2019.