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Greenhouse Management Framework based on Localization Using RGPSi and AoA

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Abstract

In this paper, the concept of the smart greenhouse control framework is proposed with the help of localization algorithm. The proposed smart greenhouse framework consists of the data aggregator with the database, the environment control part and the crop growth status control part. The data aggregator has been equipped with the various sensors to measure the data for crop growth. The sensors have ability of communication and calculation of location of target. As a localization algorithm, RGPSi is used. RGPSi uses the iteration algorithm similar to the GPS algorithm, but utilize the ratio of signal strengths instead of absolute strengths. To improve the accuracy of the localization, the method of AOA(angle of arrival) of signal will be added. The environment control part has the role to generate the control signals for the greenhouse to operate properly for satisfying the goal. Information for the status of crop growth is generated from the growth control part. With the help of the goal function two parts will be interacting each other and have fed back the sensed data from the greenhouse.

Keywords: *localization, monitoring, RGPSi, greenhouse and framework, USN*

1. Introduction

Recently, the application of the sensor networks to agriculture has been studied and essential to improve the productivity of crops and meet the needs of consumers. Combining USN(Ubiquitous sensor networks) with agriculture, intelligent farming in contrast with outdoor culture, which is cultivation under structure such as greenhouses has characteristics to monitor and control the environment data such as inside temperature, relative humidity, insulation and concentration of carbon dioxide, etc, which are vital to cultivate the crops. The optimal control of these environmental data causes the productivity and profit to be increased. The ultimate purpose of the greenhouse cultivation is to regulate the reasonable harvest time and the yield through the optimal control of these environmental data [1, 2, 3, 4].

In the greenhouse cultivation, various environmental data have been collected and used to control the environment in the greenhouse with phyto-monitoring, the feedback of the data for crop status. There have been lots of the monitored data which can become more important when combined with the location information, where the data have been measured. The measured data combined with position information will improve the energy consumption efficiency with cooling the exact place to cool down or heating the very place to heat up, which help accomplish the microclimate in the greenhouse. And the environment data with location can help to reduce the annual usage of pesticide.

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In general, the greenhouse monitoring system is now monitoring the harvesting related behavior using RFID(Radio Frequency Identification) and is equipped with some sensors for temperature, humidity and measuring soil. Then the sensed data is transmitted to server computer, where manipulated information will be sent to the famers' terminals to conform the information. In precision agriculture, the sensed data should be combined and managed with the location data, which makes the operation of the control system more accurate.

Greenhouse optimum management and climate control system have two levels, the control level and optimization level and utilize the famer's experience to build the cultivation plan and set the demand of plants. The optimum management has used three software models, greenhouse climate model, plat model, and climate prediction model [5].

In this paper, greenhouse monitoring framework combined with the localization will be proposed. The proposed framework consists of the environment sensors and crop growth monitors equipped with localization model. As the localization model, RGPSi (Ratiometric GPS iteration) combined with AOA (angle of Arrival) [6] will be used. RGPSi is a very simple localization algorithm similar to GPS (Global Positioning System) and the ratio of measured radio strengths and was developed to be used for indoor localization. Chapter II will explain the summary of RGPSi algorithm. In chapter III, the proposed framework will be explained. Finally, chapter IV shows the conclusion and future work.

2. Localization Algorithm

In outdoor localization, GPS (Global Position System) is representative. However, traditional GPS receivers seems impractical to use in sensor nodes because of constraints in size, form factor, and cost of construction of sensor nodes. Moreover, sensor networks may be deployed in regions where satellite signals may not be available. Hence, there has been a significant amount of work reported on algorithms for wireless nodes in a large ad hoc network to determine their locations without using GPS-like infrastructure [7,8,9]. Goals of these algorithms are to enable low cost, low complexity, small sensor nodes randomly deployed in a given target area to automatically determine their own positions with respect to some reference point.

Most of the localization algorithms have performed localization utilizing absolute point-to-point distance estimate. Cooperative with the sensor network, the target is able to know the original signal (interested signal) strength at the target source as a pre-defined parameter or through communication. However, if the target is not a member of the sensor network or intruder, it is hard to get the original signal strength information, which prevents the use of absolute distance estimates. In the non-cooperative cases, instead, the original signal strength has to be estimated by collecting and analyzing a number of sensing data, often requiring non-linear optimization techniques [10,11].

There are several issues in making the location problem challenging. Size and construction costs prevent the use of complex hardware at sensor nodes. Densely deployed sensor nodes require fairly accurate estimation of sensor positions. Then, due the limited transmission range of sensor nodes can prevent direct communication with the beacon nodes which have their known position coordinates. Because sensor nodes will be deployed without a give localization pattern, they must determine their locations with respect to some fixed beacon nodes. Most of localization algorithm makes use of distance or angle measurements from a fixed set of reference points and apply multilateration or triangular techniques to determine the unknown location. Time-of-arrival and time-difference-of- arrival (ToA, TDoA) measurements and Angle of arrival (AoA) measurements are representative.

Utilizing absolute point-to-point distance estimate, most of the localization algorithms have performed localization. When cooperative with the sensor network, the target can

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know the original signal (interested signal) strength at the target source through communication. However, in the non-cooperative cases the original signal strength has to be estimated by collecting and analyzing a number of sensing data, often requiring non-linear optimization techniques [12,13]. The high computation and communication overhead will be a tough challenge in small, low cost sensor nodes. In order to tackle this problem, a light-weight localization algorithm, dubbed Ratiometric Vector Iteration (RVI) [14] was proposed. RVI algorithm is based on relative distance ratio estimates rather than absolute distance estimates. Ratiometric algorithm concept was combined with GPS algorithm, called Ratiometric GPS Iteration (RGPSi) [6,15].

There are conventional, widely used RSS based sensing models, where a simple exponential model [8] is used. From the simple exponential model, the ratio of distances can be expressed with the ratio of measured RSS values

$$P_i^{-1/\alpha} : P_j^{-1/\alpha} = |\rho_i| : |\rho_j| \tag{1}$$

target, Pi = r – Si means the Euclidean distance between r and Si where r is the location of a target and Si is the location of the i-th sensor in two dimensional coordinate system. a is the path loss exponent It is assumed Pi, Si and a are measured or known values. Then, update vector is calculated

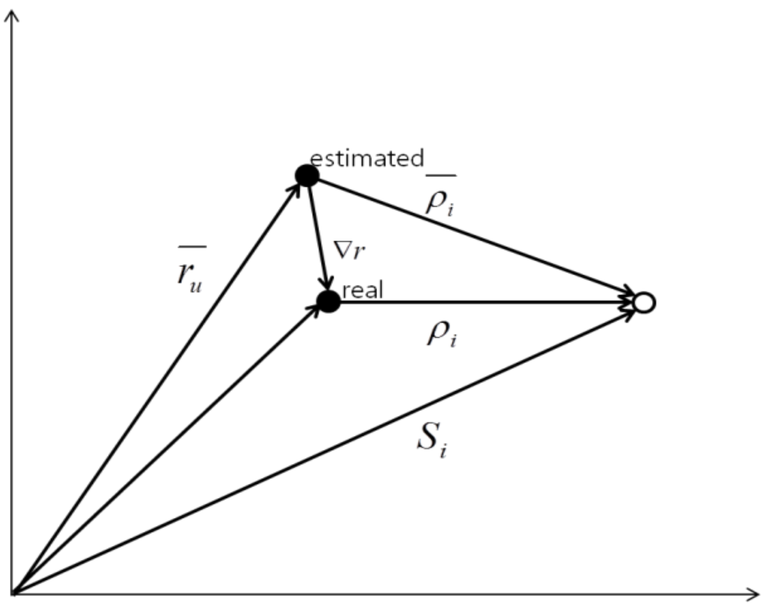

Figure 1. Simplified GPS System. A Filled Circle is a Target and Empty Circle is a Sensor Node (or Beacon Node)

$$\begin{aligned} \Delta r &= r_u - \overline{r_u} \\ \Delta \rho_i &= |\overline{\rho_i}| - |\rho_i| \cong \hat{I}_i \cdot \Delta r \end{aligned} \tag{2}$$

where Îi is the unit vector of |Îi|.

The update vector Δr = [Δx Δy] is obtained from

$$\begin{bmatrix} \Delta\rho_1 \\ \Delta\rho_2 \\ \ldots \\ \Delta\rho_n \end{bmatrix} = \begin{bmatrix} \hat{I}_{1x} & \hat{I}_{1y} \\ \hat{I}_{2x} & \hat{I}_{2y} \\ \ldots & \ldots \\ \hat{I}_{nx} & \hat{I}_{ny} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \tag{3}$$

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From [3].

$$\Delta \rho_i \cong \Delta u_i \sum_{k=1}^{n} \left| \bar{\rho}_k \right| = \left| \bar{\rho}_i \right| - \frac{\sum_{k=1}^{n} \left| \bar{\rho}_k \right|}{\sum_{k=1}^{n} (P_k / P_i)^{-1/\alpha}} \tag{4}$$

As the update continues repeatedly, the sum of estimated ranges, ∑nk=1|P- k| will become equal to the sum of measured ones, ∑nk=1|Pk|.

Ratiometric GPS Iteration algorithm is to combine the ratiometric concept and GPS algorithm. Ratiometric GPS Iteration uses the simplified version of GPS [16] shown in Figure 1. Where r-u and ru is the estimated location and the real location of the target, respectively, and |P-i| and |Pi| indicate the estimated and measured ranges to the i-th sensor, respectively. The algorithm makes the difference between |P-i| and |Pi| smaller through updating the estimated location.

Sensor nodes equipped with directional antennas can measure the angle of incident signal from a target, where the angle will improve the location error.

$$\theta_i(r) = \tan^{-1} \frac{y_i - y}{x_i - x} + n_\theta = \bar{\theta}_i(r) + n_\theta \tag{5}$$

where, Θi is measured angle at the i-th sensor node and is related to the position of a target. r = [x, y] is the position vector of target, (xi, yi) is the coordinate of the i th sensor and nΘ is assumed to be the white Gaussian noise For simplicity, Θ-i (r) can be linearized with Taylor series.

$$\bar{\theta}_i(r) = \bar{\theta}_i(r_0) + \Phi_i \Delta r + n \tag{6}$$

where, ϕ i is the Jacobian matrix, and Δ r = (r - r0), where r0 is the initial estimated position. Considering the neighboring nodes around a target node and ignoring the higher order terms, Eq. (2) and (6) can expressed in the vector form

$$\begin{bmatrix} \Delta\rho_1 \\ \Delta\rho_2 \\ \cdots \\ \Delta\rho_n \\ \Delta\theta_1 \\ \Delta\theta_2 \\ \cdots \\ \Delta\theta_n \end{bmatrix} = \begin{bmatrix} \hat{I}_{1x} & \hat{I}_{1y} \\ \hat{I}_{2x} & \hat{I}_{2y} \\ \cdots & \cdots \\ \hat{I}_{nx} & \hat{I}_{ny} \\ \Phi_{1x} & \Phi_{1y} \\ \Phi_{2x} & \Phi_{2y} \\ \cdots & \cdots \\ \Phi_{nx} & \Phi_{ny} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} + \begin{bmatrix} n_{\rho_1} \\ n_{\rho_2} \\ \cdots \\ n_{\rho_n} \\ n_{\theta_1} \\ n_{\theta_2} \\ \cdots \\ n_{\theta n} \end{bmatrix} \tag{7}$$

Eq.(7) is able to be solved easily.

Fig.2 shows the procedure of calculating the position from initial condition in noiseless condition. Our algorithm seems to be simple to implement in real condition because the complexity of calculation is low. This method like other localization methods needs three known potions which is called beacons but can localize the position of unknown nodes within the circumscribed circle crossing of three beacon nodes. From this figure, we can see the procedure of calculation of position and conform that the positions of unknown nodes inside the circle are found within a few iterations regardless of assumed initial positions. However when the unknown nodes are near the circumference, the number of iterations is increased.

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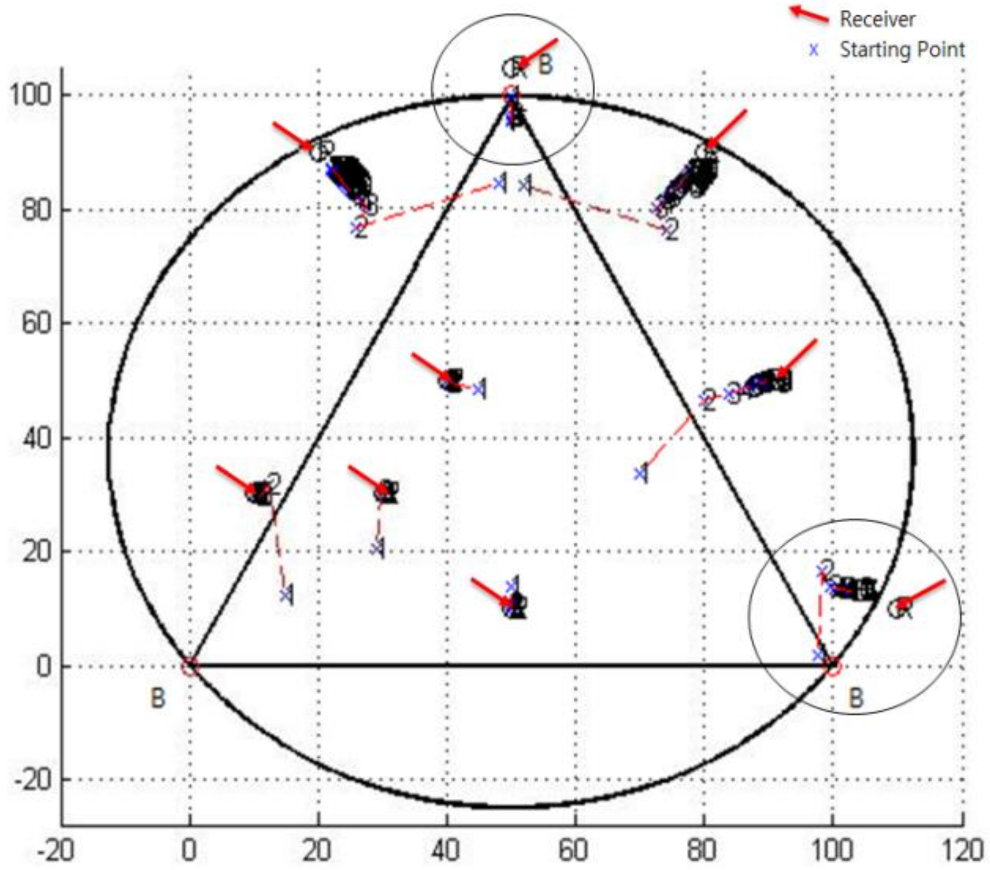

Figure 2. RGI Simulation Procedure

In Fig. 3, the example of the simulated position errors is shown. It is assumed that the target exists inside the triangle formed with sensors and the angle standard deviation is 10°. Calculation of RGPSi assisted with AoA is assumed that only one of sensor node of three sensors can measure the angle and other nodes have ability to only measure signal strengths. Then, as expected, because AOA algorithm doesn't depend on distance error, the position error shows nearly constant with respect to distance error. GPS, RVI, RGPSi and RGPSi assisted with AoA (RGPSi+AoA) show the nearly same position errors. However, entirely, GPS algorithm has the lowest position error and RVI does lowest. And RGPSi+AoA show better result than RGPSi. It can be known that AoA algorithm helps RGPSi improve accuracy.

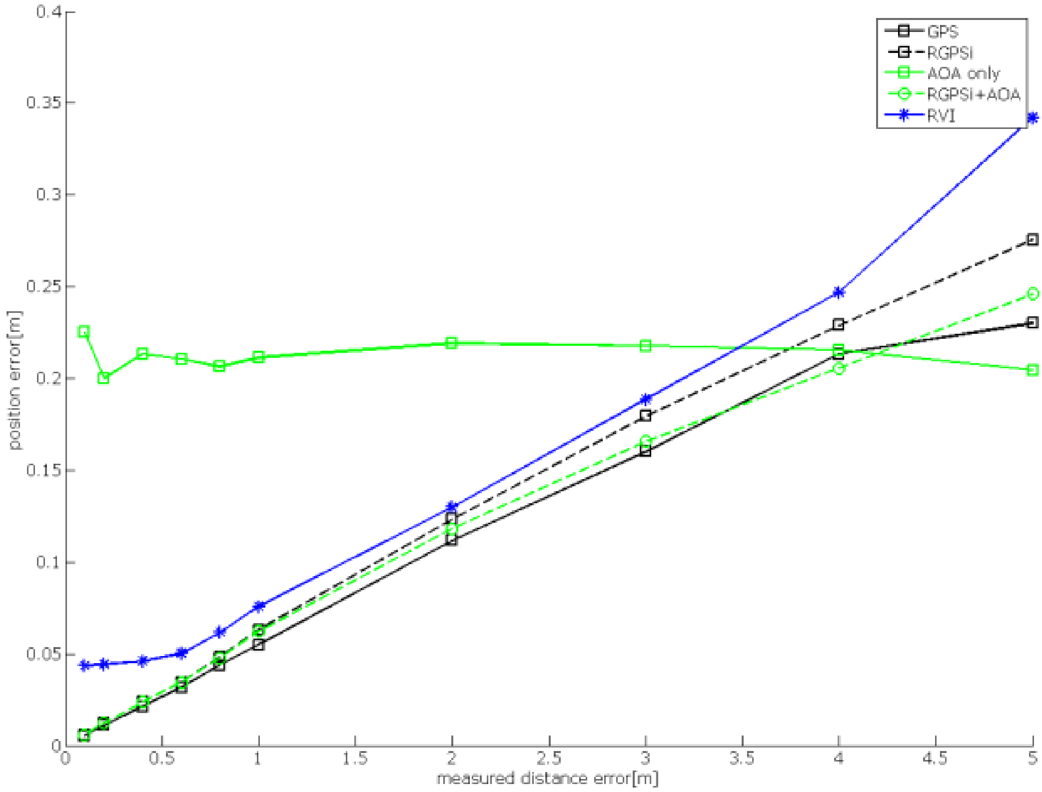

Figure 3. Position Errors with Angle Error of 10°where the Target is Inside the Triangle Formed with Sensor Nodes

In Fig. 4, the scenarios for distribute computing and centralized computing for localization are shown. In the figure, the green circles are sensors having role of a beacon and the red circles are the target. A beacon is assumed to know their coordinates. And the target is transmitting the signal in the air where the signal can include the sensed information or not. When calculating the position, only the signal strength are important regardless of the contents in signals. In distributed way, each beacon node has the ability to compute the proposed algorithm and communicate with other beacons. Each beacon, which catch the target signal send the measured target signal strength to neighbor beacons. And then the beacon that has the strongest signal strength will become the main beacon. The main beacon will broadcast that the beacon is the main beacon to the neighbor beacons and will choose the second and third place beacon from the neighbor beacons that received the target signal. The main beacon will calculate the position of target with the strength information from nearby beacons, which have the second and third RSS values. This procedure will continue repeatedly. In the centralized version, all beacons can communicate with the main server. All beacons will send the strength of the target and sensing information to the main server. The main server will choose the three beacons that have the strongest signal strength and try to calculate the position of the target.

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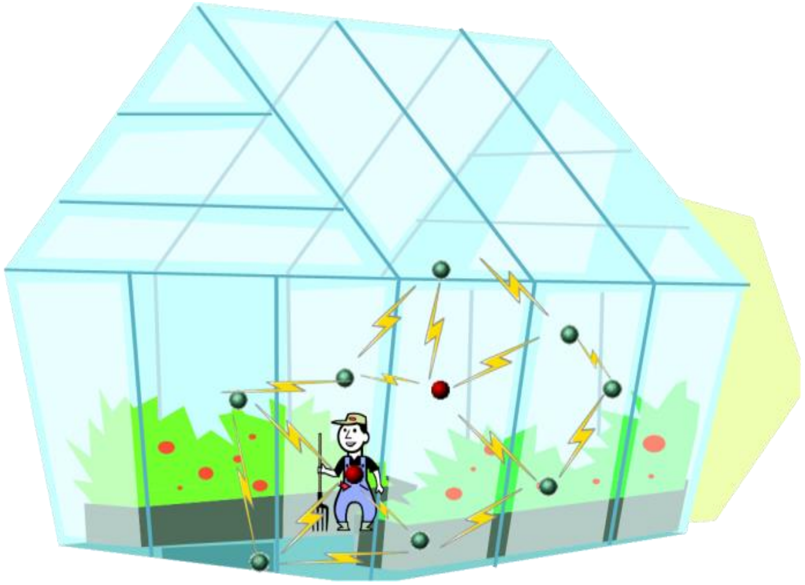
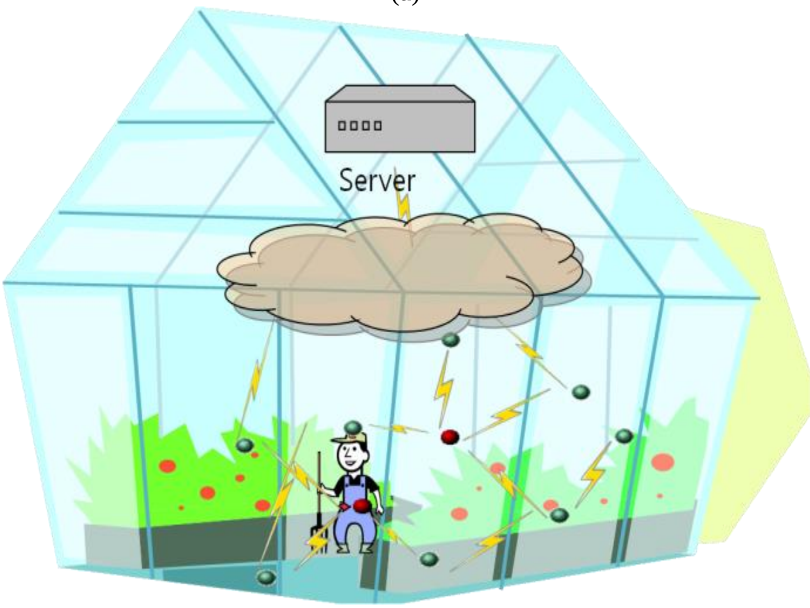


(a)



(b)

Figure 4. (a) Distributed Computing, (b) Centralized Computing, in the Figure, the Green Circles are Sensors having Role of a Beacon and the Red Circles are the Target

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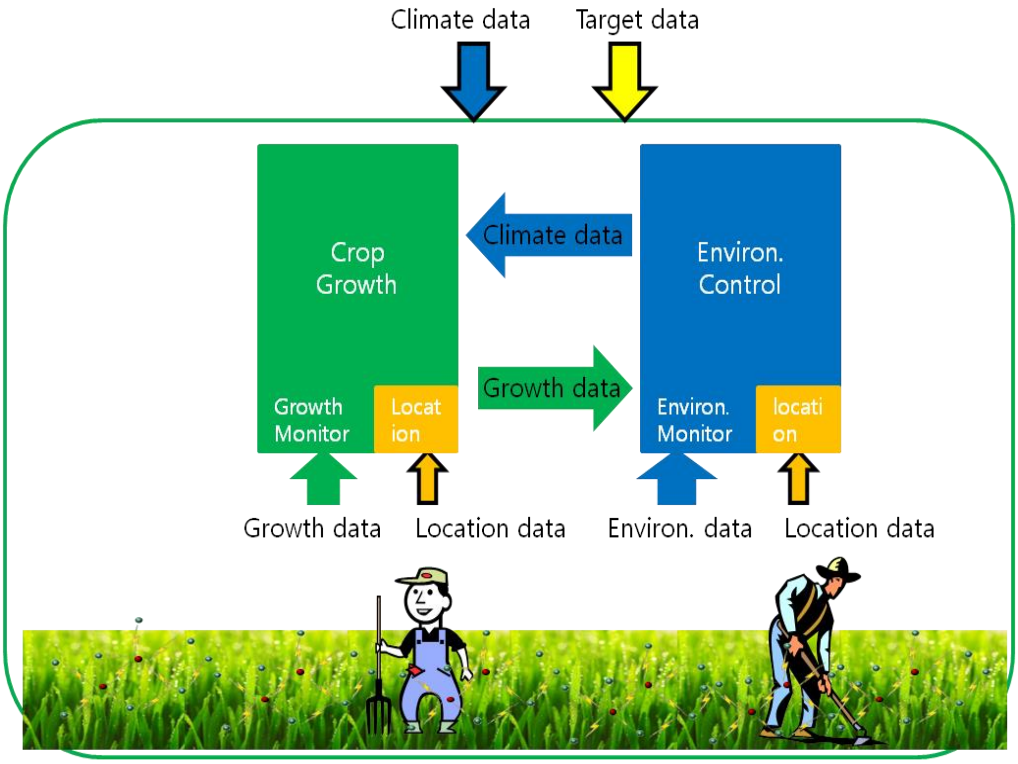

Figure 5. The Concept of Smart Greenhouse with Localization

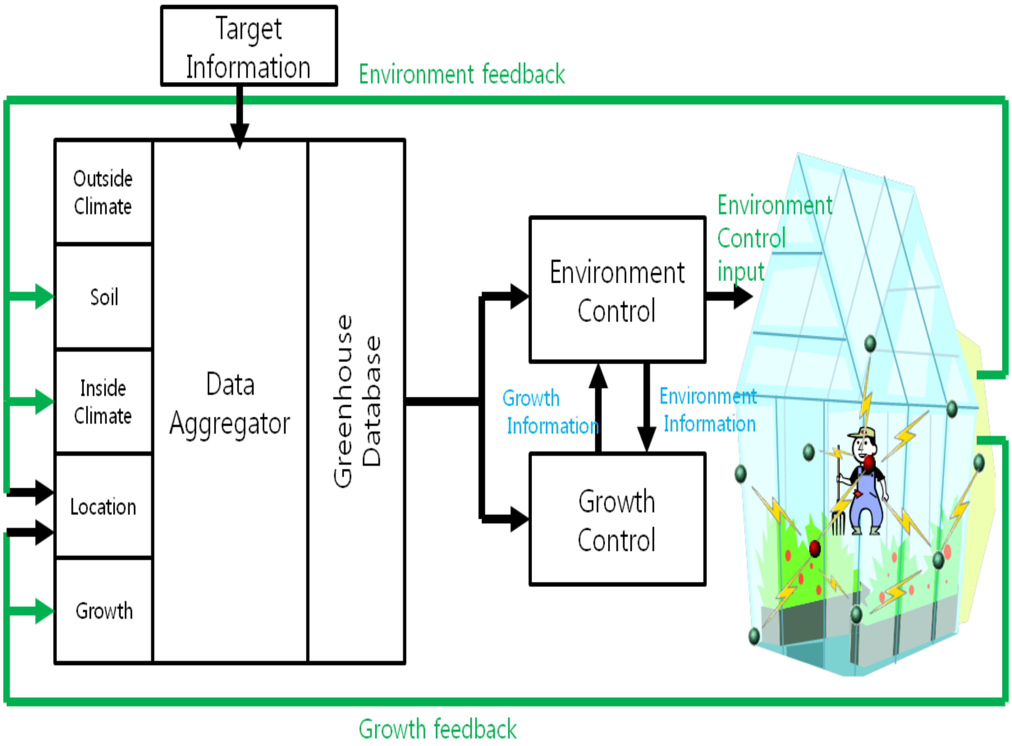

Figure 6. Detailed Description of Intelligent Greenhouse

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3. The Greenhouse Monitoring Framework with Localization Algorithm

The Fig. 5 shows the concept of the smart greenhouse, where the purpose of the system control of the growth of the crops in the structure. The ultimate target can be the reduction of energy consumption, the control of the harvesting season or the usage of harvesting. In Fig. 5, target data will be the goal of the system such as explained before. To achieve the goal, with the help of outside climate data, the entire system will be operating automatically. The environment climate data and soil data will be sensed with the proper sensors with the location information. The information about crop growth status can be measured. Goal function that depends on climate information and growth status information will be satisfied with the interaction and feedback between the crop growth controller and environment controller. Combining the sensing data with the location could improve the yield of the greenhouse. The localization will help the precision cultivation and can help make the yield and time of harvesting crops uniformly in entire greenhouse area.

Table 1. Elements Related to the Control Parts

Categorization		Detailed classification
Environment	Inside	Temperature, humidity, CO2, intensity of illumination and etc
	Outside	Temperature, humidity, insolation, rainfall, wind direction, etc
	Soil	Temperature, humidity, conductivity , etc
Devices	**Monitor**	Sensors with transceiver, server
	Controller	Cooler, heater, CO2 supplier, aggregator, screens, etc

Table 2. The Parameters Related to the Crop Growth Control Part

Categorization	Detailed classification
Growth environment	Temperature, humidity, CO2, intensity of illumination and etc
Growth status	Leaf area, leaves, weight, fruits, size of fruits
Environment buildup	Harvesting date, price at the harvesting, yield prediction, fuel price
Climate data	Yearly weather, weekly weather, today forecast

The growth of crops have been affected by the internal climate soil environment. The mutual relationship between inside growth environment and the disturbances has dictated to control important environment variables to make and maintain the optimum growth environment, where the crops will be grown effectively. Detailed description of the proposed greenhouse framework is shown in fig. 6. The elements for control parts have been shown in table 1[2]. The table 2 shows the parameters for growth control part. This framework consists of the data aggregator, environment controller and crop growth controller. The data aggregator is gathering the sensed data for various sensors such as temperature, humidity, dioxide carbon concentration and etc., the crop growth status data and the location from localization algorithm. The sensors have been deployed in all area and may be movable, that means the farm machines or farm tools can have sensors and transmitters. So, the positions of farm tools or machines can be traced, which can help develop the automatic cultivation available. Then, the collected data will be stored in the greenhouse database and the location will be tagged at the sensed environment data and growth data. Also, in greenhouse database, the goal (target) information will be stored.

The target information will be used to calculate the goal function in the growth control part with the present status of the crop and environment climate data. The growth control part will make the information to be used in the environment control part with the help of the goal function. The growth control part will, also, use the information from the greenhouse database and interact with the environment control part. The role of the environment control part is to generate the signals that can control the greenhouse climate. The environment control part has the algorithm to forecast the future climate with the present inside climate data and outside climate information. With the help of the information from the growth status part, the environment control part will control the signal for the greenhouse. Because the system is based on the location of sensed data, it could be able to achieve the local heating or cooling or local watering control or local pest control inside the greenhouse.

4. Conclusion

The concept of the smart greenhouse control framework combining with localization algorithm has been proposed. The proposed smart greenhouse framework consists of the data aggregator with the database, the environment control part and the crop growth status control part. The data aggregator has been equipped with the various sensors to measure the data for crop growth. The sensors have been deployed in all area and may be movable, that means the farm machines or farm tools can have sensors and transmitters. The greenhouse database has stored the sensed climate, soil data and crop status data based on their own coordinates. As a localization algorithm, RGPSi is used. RGPSi uses the iteration algorithm similar to the GPS algorithm, but utilize the ratio of signal strengths instead of absolute strengths. To improve the accuracy of the localization, the method with the help of AOA(angle of arrival) of signal will be added.

The environment control part has the role to generate the control signals for the greenhouse to operate properly for satisfying the goal. To make the control signals, the environment control unit is using the data of climate inside and outside greenhouse and the information for status of crop growth. Information for the status of crop growth is generated from the growth control part with the help of the goal function. The goal function is for satisfying the need of farmer, where there are the control of harvesting time, yield of crops, consumption of energy, and etc. the growth control part is generating the data for the environment climate part. Two parts will be interacting each other and have fed back the sensed data from the greenhouse.

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