MyGreen: An IoT-Enabled Smart Greenhouse for Sustainable Agriculture

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***Abstract*—This article presents the potential of Internet-of-Things (IoT) in the area of greenhouse farming and leading to the smart agriculture. The different parameters, such as humidity, water nutrients solution level, pH and electrical conductivity (EC) value, temperature, UV light intensity, CO_2 level, mist, and amount of insecticides or pesticides, are monitored through various sensors so that significant knowledge can be captured and early fault detection and diagnosis can be done. A decision support system (DSS) acts as the central operating system that governs and coordinates all the activities. Furthermore, this work also accounts for the different challenges of greenhouse rose farming and highlights a new IoT-based solution, which is smart and sustainable. The model presented in this work is well adapted to the changing environment, thereby redefining the terms of sustainability.**

Over the years, agriculture has seen many revolutions, be it the improvement in farming practices or an extension in the field of modern agriculture. The technical improvements in agriculture have driven the wave of green revolution. Green revolution has created opportunities for the farmers to learn and adopt the scientific way of operating the farms, thereby decreasing the manual form of labor and embracing automation. Greenhouse farming has become the key to smart and sustainable agriculture as it relies on data. Data-centric approach can help agriculture

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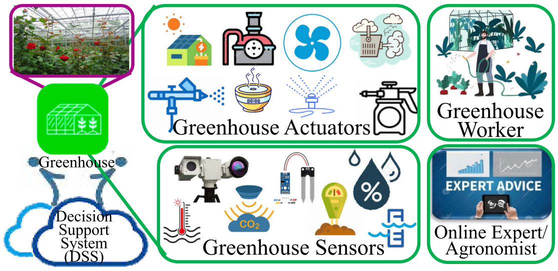

Figure 1. IoT-enabled greenhouse.

in making it precise and accurate, thereby consolidating the overall farming process.

Conventional methods of agriculture pose a variety of threats to the growth and nourishment of the plants. Availability of manpower, precision in the percentage of disease detection accuracy, the decision regarding the time interval of irrigation, feeding the plants with the correct proportion of fertilizers, and pesticides are some of the challenges that the farmers go through during the production. The growth of plants mainly depends on environmental parameters, such as humidity, soil moisture, and CO_2 level. It is impossible to monitor and control all the parameters together in an open environment. However, greenhouse farming is a good alternative technique that helps in a higher yield of crops and balances the parameters (see Figure 1).

The cultivation of roses inside greenhouse faces several challenges that include: the correct proportion of nutrients available to the plant, variability in temperature and humidity, accurate monitoring of the soil and its moisture, detection, and prevention from diseases, and information collection periodically. Although these problems are addressed in the literature,[1–3] it includes manpower involvement and does not have a precise rate of accuracy. This article proposes an (IoT)-based infrastructure to encounter the various problems mentioned. The solution aims at decreasing the involvement of manpower and automate the farming.

OUR VISION OF IoT-ENABLED GREENHOUSE

Our vision of greenhouse farming aims at developing an extensive automated system of smart agriculture wherein the involvement of manual labor is minimal and productivity is maximum (see Figure 1). Our model is framed in such a fashion that it involves less cost, has an effective risk management plan, and is focused upon better precision in decision making. Our model is sustainable and data centric, which relies on the data and constantly learns from it, hence giving a better user experience. The proposed IoT-based solution is responsible for allocating resources, optimization of resources, coordinating the activities, time management, and human effort management, gathering information, and taking decisions by using the data analytics. Thus, our model will aid to the existing methods of farming and will help in better growth and development.

SMART AND SUSTAINABLE AGRICULTURE-RELATED WORKS

The IoT is making the fabric of the world around us smarter and more responsive, merging the digital and physical universes. Several studies and extensive research have been conducted in the area of smart farming.[3–7] IoT forms the backbone of automated smart farming. It is oriented toward analytics and sensors.[2,7] The approach presented by Chanak and Banerjee[4] uses IoT in agriculture through sensors, optimization of the use of water, energy, and fertilizers through automated smart irrigation, monitoring environmental factors using different sensors to improve the yield and control the environmental parameters,[3] proposing a smart farming system for a closed area such as greenhouse and to enhance the productivity using different kinds of sensors, and monitoring plant growth and development using the leaf as an indicator called the Internet of Leaf Things (IoLT) in the work by Udutalapally *et al.*[5] An automated system of plant disease detection is proposed by Yakkundimath *et al.*[8] Similar work is carried out by Kim *et al.*[9] which proposes farm-as-a-service-integrated system and analyzes environmental and growth information of strawberry plants using IoT. Modern agriculture deals with yet another advanced form of farming, precision agriculture. It uses IoT, cloud computing, and edge computing to enhance the production of crops and interact and monitor with the plants in real-time using cyber-physical system (CPS).[3] In the work by Saiz-Rubio and Rovira-Más,[1] the status of the advanced farm management systems is reviewed and an insight into the crucial steps needed for sustainable agriculture is given. The following article emphasizes the IoT-enabled automation of rose farming inside a greenhouse.

CHALLENGES OF TRADITIONAL GREENHOUSE FARMING

The proportion of nutrients made available: Conventional farming incurs manual labor and consumes a great amount of time, hence at times, it is not possible to feed the plant with the desired amount of nutrients (NPK), which slows down the growth of the plants and does not give proper yield.

Temperature and Humidity: Excess high temperature and humidity affect the development of leaves and shoots adversely. It also results in discoloration of the petals and the blackening of the leaves. Higher temperature also affects the size of the flower and fewer and smaller petals.

Accurate monitoring of the soil and its moisture: Too little moisture can result in yield loss and plant death and too much of it causes root diseases and wasted water. It is seen that the bare-dry or over-wet soils may damage the roots of the rose plants; hence, rich and well-draining soil is required for better and quality produce.

Detection and prevention from diseases: Rose plants may suffer from diseases because of low temperature, insufficient light, chemical residues and insects, pets, or bacterial diseases. Almost 90% of the plant's diseases can be identified through the nature of the leaves such as color fading, bullheads, limp neck, blackening of rose petals, pale foliage, black spot, powdery mildew, and downy mildew. However, manual monitoring of these diseases is a cumbersome task.

Data collection at regular time intervals: Trivial methods of rose farming require manual investigation and collection of data related to the growth and development of the plant. Collection of data such as soil moisture, need for fertilizers, pesticides, or insecticides, humidity, and temperature manually affect the accuracy and precision adversely.

MyGreen: THE PROPOSED NOVEL IoT-ENABLED GREENHOUSE

Major parameters that influence the proper growth of rose plants and flowers in a greenhouse are proper control of environmental temperature, humidity, soil and environmental moisture, environment CO_2 level, water level, UV-light density, and free from heavy dew. Along with these parameters, the visual health monitoring of leaf and flower, and proper supply of minerals, fertilizers, and medicines is also equipotent as they make the plant healthy and productive. However, monitoring and maintaining these parameters pose certain challenges as discussed in the previous Section. To handle such challenges, these things need to be automated. For this purpose, we propose an IoT-based framework as a mechanism of greenhouse rose farming automation (see Figure 1). This IoT framework facilitates the rose plants a favorable growth environment by providing soil monitoring, auto-optimization of suitable environment, optimum irrigation, real-time problem diagnosis, reduced harvest failure, remote controlling and management, and cutting down in the operation cost.

The proposed IoT framework consists of following three parts:

1) Data acquisition system (DAS): A set of sensors for collecting real-time data from the greenhouse.
2) Central actuator manager (CAM): A set of equipment for performing different task of the greenhouse and is handled by a set of actuators.
3) Decision support system (DSS): A DSS is used to monitor and manage the resources.

Data Acquisition System (DAS)

The DAS (see Figure 2) records the data collected from various sensors, such as humidity, water level, the intensity of UV light, CO_2 level, pH and EC value, temperature, mist, and nutrient levels. These data are captured continuously from the sensors to monitor the environmental status of the greenhouse. After sensor data

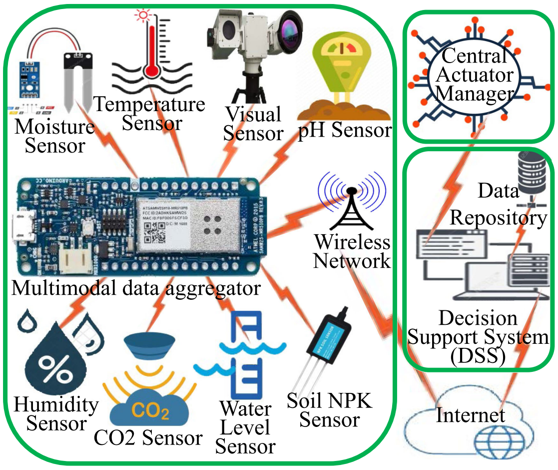

Figure 2. DAS for rose farming monitoring.

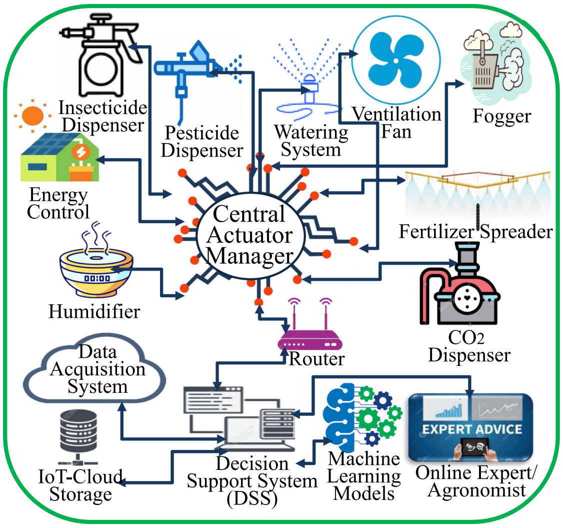

Figure 3. Actuator management system.

acquisition, the DAS sends it to the DSS. Furthermore, the DSS analyzes the data and takes appropriate action through an actuator management system (AMS).

Actuator Management System (AMS)

To control different parameters in greenhouse, separate actuators are used. All actuators are connected to a CAM (see Figure 3). The CAM takes instructions from the DSS and acts accordingly by activating/deactivating or controlling the actuators. The action is taken immediately if any irregularity in the greenhouse is detected. In the case of rule-based action, the CAM automatically activates/deactivates the actuator based on the rules decided by the DSS or by the agronomist *a priori*. For example, if the CO_2 level is above the upper limit (900 ppm), then it needs to open the air ventilators, and if the CO_2 level is below the lower limit (800 ppm), then it needs to switch ON the CO_2 cylinder. The machine learning (ML) model and expert advice actions are described in the next subsection.

Decision Support System (DSS)

The DSS acts as the main operating system of our proposed IoT-enabled greenhouse rose farming system (see Figure 4). Broadly, the DSS governs six major components namely: i) Rule-based designed engine (RBE), ii) CAM, iii) ML models, iv) experts or agronomist, v) greenhouse workers, and vi) data repository. The DSS not only acts as a resource allocator, but also as a resource optimizer.

Broadly, the ML models perform following four tasks: 1) Detecting common diseases using plant image classification. 2) Considering common environmental parameters; the ML module will predict the near future abnormalities that may happen and will recommend for preventive measure. 3) Recommending appropriate actions in case of any imbalance found in common environmental parameters. The tasks 2) and 3) of ML module use the previous actions recommended by the experts, which are stored in the data repository. 4) Identifying the growth of unwanted plants in the greenhouse. In tasks 1 and 4 of the

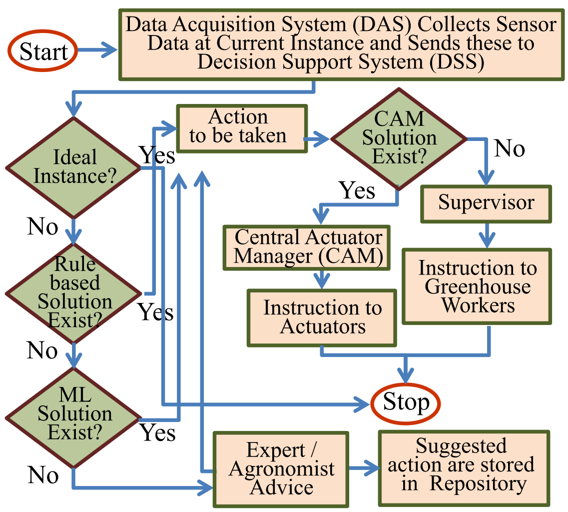

Figure 4. DSS working flowchart.

ML module, DSS activates the ML model by providing images from visual sensors. The ML model classifies the images to any one of these 12 classes, namely: *normal, the 10 common diseases (aphids, black spot on roses, Cercospora leaf spot on roses, crown gall on roses, Japanese beetles on roses, rose mosaic virus, powdery mildew on roses, rose curculios, rose and pear slugs, thrips on roses), and other disease*. A support vector machine (SVM) based classifier is used for classifying the images. A sample size of 40 from each class is used for training purpose and 10 samples from each class are used for testing the model. Overall classification accuracy of 91% is obtained on training data and 85% classification accuracy on test data.

An RBE is created by taking help of the experts/agronomist/greenhouse supervisor to manage everyday activities, deciding appropriate proportion of the nutrients, time interval of supplying water, amount of nutrients and pesticides to apply, for different climatic condition, soil parameters, temperature, humidity, and plant disease. In case of any disease found by the rule-based system or ML module or expert/agronomist the CAM is asked to apply any/some of these remedies such as strong blast of water and insecticidal soap at the appropriate time, good air circulation, and spraying them with Bordeaux mix or neem, applying baking soda or milk, cleaning the pruners between cuts with a dilute bleach solution and applying appropriate pesticides. These remedies are performed by the CAM under the instruction and supervision of the DSS. Data acquired from the DAS is given to RBE and the RBE prescribes the appropriate action to be performed by the CAM. For some situations, if no action is stored in the RBE, it seeks help from the expert/agronomist. The actions recommended by the expert/agronomist are stored in RBE for future use. For better and optimized action, the CAM is recommended by the DSS to perform the recommended actions in 1-m radial distance of the instructed location of the greenhouse. The DSS also provides an interface for communication and interaction with human actors, such as greenhouse workers, supervisors, and experts through mobile application and text message as and when required. The supervisor also monitors the status of greenhouse

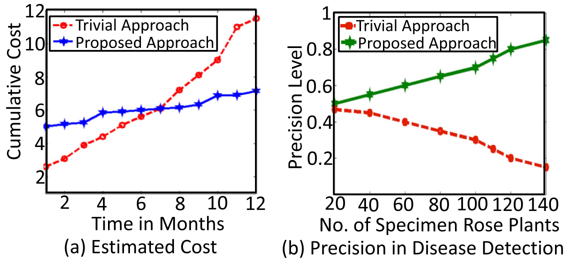

Figure 5. Experimental results. (a) Estimated cost. (b) Precision in disease detection.

remotely through a user interface and can instruct the CAM to perform some task through DSS. Even if automation is there, some jobs need to be done manually and periodically and some are event based. The jobs of the greenhouse workers are controlled, scheduled, and actively monitored by the DSS.

CASE STUDY VALIDATION OF MyGreen

For validation purpose, a prototype of MyGreen was implemented in a subpart of 1000-sq-ft area of an original greenhouse of 2.5 acre. Over a year, the cost incurred in both MyGreen implemented area and other area of the greenhouse was estimated. The monthly cumulative cost incurred in both the approaches is estimated per 1000 sqft and plotted in a graph [see Figure 5(a)]. It can be observed from the graph that, at the end of the year, the cost incurred in MyGreen approach is significantly low as compared to the traditional approach. Although, MyGreen approach require an extra initial investment due to the IoT infrastructure, but afterward, it requires less involvement of human resources and results in optimum use of the resources. Thus, in initial phase MyGreen incurs greater investment. However, after several months, the cumulative cost of the traditional approach crosses the MyGreen approach.

Similar observations can be seen while considering the precision of accuracy in detecting the diseases in rose plants [See Figure 5(b)]. Although the precision is almost the same for a smaller number of rose plants like 20, but with an increase in the number of rose plants, the accuracy level decreases in trivial farming methods. On contrary, the proposed IoT framework gives better accuracy with an increase in the number of samples. This is because with the increase in samples, the dataset becomes rich and the learning rate increases, yielding better accuracy and prediction for detecting diseases in rose plants.

Along with the cost and level of precision, the death rate of plants declines significantly because of early detection of diseases in the plants and taking necessary action for the same in time. Effective use of fertilizers, minerals, insecticides, and pesticides is another major advantage as the exact amount of doses is applied to the infected and nearby infected plants only (not the entire greenhouse) in an IoT-based approach. This prevents plant's death from overdose of medicines or fertilizers.

CONCLUSIONS

The IoT-enabled automated system MyGreen can increase productivity while reducing cost. The investment needed in the IoT-devices is low as compared to the expenditure involved in the manual process. The IoT-enabled process not only gives accurate pieces of information but also lowers the burden of manual work by automation. It mitigates the traditional load of data gathering, refining, and determining the accuracy percentage. With technology in hand, the new methods of making greenhouse sustainable is higher with more accessibility. MyGreen can be integrated with other sustainable IoT solutions to build stronger backbone for smart cities and smart villages.[6]

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