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A Novel Automatic ICT System for Orchid Greenhouse Monitoring

Xiang-Yao Zheng[1], Yu-Kai Huang[1], Chi-Yang Lee[1], Chia-Pang Chen[1], Cheng-Long Chuang[2], Jyh-Cherng Shieh[1], and Joe-Air Jiang*[1]

1Department of Bio-Industrial Mechatronics Engineering, National Taiwan University, No. 1, Sec.4, Roosevelt Road, Taipei 106, Taiwan
2Intel-NTU Connected Context Computing Center, National Taiwan University, No. 1, Sec.4, Roosevelt Road, Taipei 106, Taiwan
*Corresponding Author, Tel: +886-2-3366-5341, Email: jajiang@ntu.edu.tw

ABSTRACT

This paper describes a novel monitoring system designed for orchid greenhouses. The proposed system provides important information on environment parameters related to orchid growth, such as temperature, humidity, and illumination. Based on wireless sensor networks (WSNs) the proposed system can monitor orchid greenhouses with high continuity and high frequency. With these benefits, the proposed system can discover the unbalance in temperature and humidity in a greenhouse. Through this system, orchid will grow in a well-controlled environment and the quality of orchid will increase. A dynamic routing and localization algorithm is also implemented in this system to manage a large amount of mobile sensor nodes to increase system robustness and scalability, and the lifetime of the proposed system is extended.

Keywords: Dynamic routing; Greenhouse monitoring; WSN

1. INTRODUCTION

Orchid is an important plant with high economic value in Taiwan. It has to be grown in a restricted environment where temperature, humidity, illumination are all under control. [1-2]. Improper control of these environmental conditions may lead to the decline of orchid production and huge economic loss. In the past, only a small amount of environmental sensors were generally used in greenhouse monitoring. The variation in environmental conditions may not be detected by traditional monitoring methods that employ a small number of sensors, causing the quality reduction of orchid when it grows. These monitoring methods are not suitable for large-scale greenhouse monitoring. Another challenge for large-scale greenhouse monitoring is that greenhouse benches are movable, so it is hard to monitor these benches. To overcome the problems mentioned above, this study proposed an automatic monitoring system based on the WSN for monitoring the growth environment of orchid. This paper deployed a WSN in greenhouse [3-7]. The WSN technology enabled space continuity, time continuity and high frequency monitoring [8-11]. With these benefits, orchid greenhouses can be more

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effectively monitored. Furthermore, a dynamic routing algorithm was designed to manage the WSN to increase system robustness and scalability. The proposed system also included a user-friendly interface that allowed users to visualize environmental information. The interface provided information about temperature, humidity, sensor localization and network topology. The remainder of this paper is organized as follows. Section II discusses the architecture of the ICT greenhouse monitoring system; this section focuses on the components of the proposed system. Section III introduces an algorithm designed for the proposed system in detail. The experimental methods and results that verify the effectives of the proposed monitoring system will discuss in section IV. The section V concludes this study, and future work is also provided at the end of this paper.

2. ARCHITECTURE OF AUTOMATIC ORCHID MONITORING SYSTEM

In this section, the architecture of the proposed monitoring system is introduced in detail. The overview of the proposed system is shown in Fig. 1. The system was divided into three layers, including the sensing layer, the data transmission layer, and the application layer. In the following, we will introduce the main characteristics of each layer.

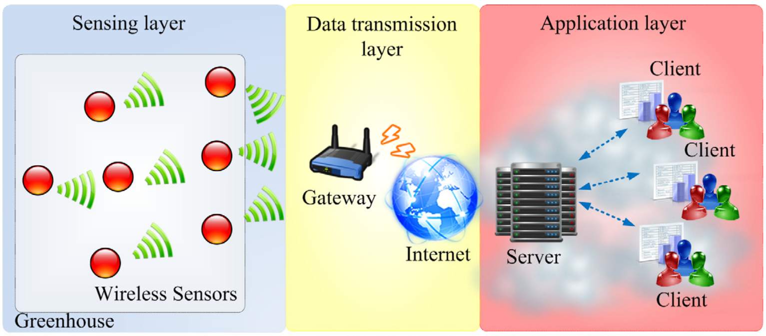
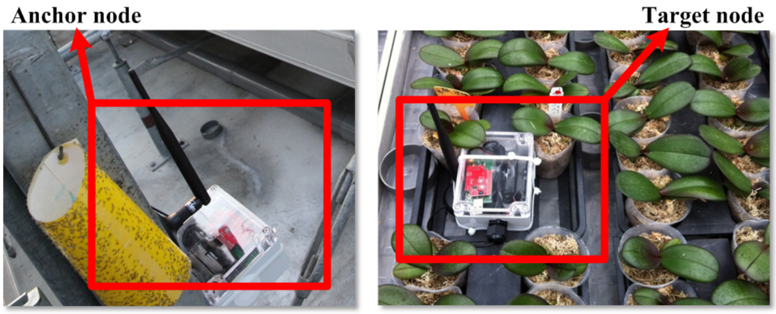


Figure 1. The architecture of automatic orchid monitoring system

2.1 Sensing layer

According to Fig. 1, the sensing layer is the frontend side of the automatic orchid monitoring system. It consisted of a large number of wireless sensor nodes, and each sensor node had sensing and communication abilities. The sensor nodes used in this study was the Octopus II developed by National Tsing Hua University. The MCU of the octopus II was MSP 430 made by the TI company. It allowed the Octopus II to have great computing capability for dealing with data. In this study, two kinds of sensor nodes were designed, including anchor nodes and target nodes. The configuration of these nodes is shown in Fig. 2. Anchor nodes provided not only environmental data but also localization information of target nodes. Anchor nodes were immovable, because they were placed on greenhouse beams in a real environment. Target nodes were placed on movable benches to monitor the growth environment of orchid more precisely.



(a) (b)

Figure 2. (a) Anchor nodes were placed on the greenhouse beams; (b) Target nodes were placed on the movable benches

2.2 Data transmission layer

As shown in the middle part of the architecture of the entire monitoring system in Fig. 1, the data transmission layer was used to transmit all sensing data to a backend server. The Gateway, a data aggregation device, was the core in controlling sensor nodes and collecting the sensing data. The sensing data included environmental information, such as temperature, relative humidity, and illumination. All of the collected data was sent to the backend server. Furthermore, the Beagleboard-xM embedded board designed by the Beagleboard company [12] was adopted in this study. Due to its energy-efficient feature, the ARM-based embedded system was widely utilized to develop many tiny devices such as mobile phones, printers, and watches. The CPU of the Beagleboard-xM had 1GHz process ability, enough for the gateway to conduct greenhouse monitoring. The Beagleboard-xM had a voltage protection mechanism; this mechanism could prevent the embedded system from overvoltage. In addition, the BeagleBorad-xM had a number of I/O interfaces, including high-speed universal serial bus (USB) ports and an on-board four-port USB hub with 10/100 Mbps Ethernet. With these advantages, the Beagleboard-xM was suitable for long-term environmental monitoring.

2.3 Application layer

As shown in Fig. 1, the application layer is the top part of the entire monitoring system. This layer provided different applications for users. Website applications, for example, offered a Graphical User Interface (GUI) for users to access to the monitoring data collected from the orchid greenhouse, as shown in Fig. 3. The GUI had two functions; one was real-time data query and the other was long-term statistics. The function of real-time data query allowed users to inquire most up-dated monitoring data. Long-term statistics function provided visualized history data, and users could take proper action based on the results of statistics.

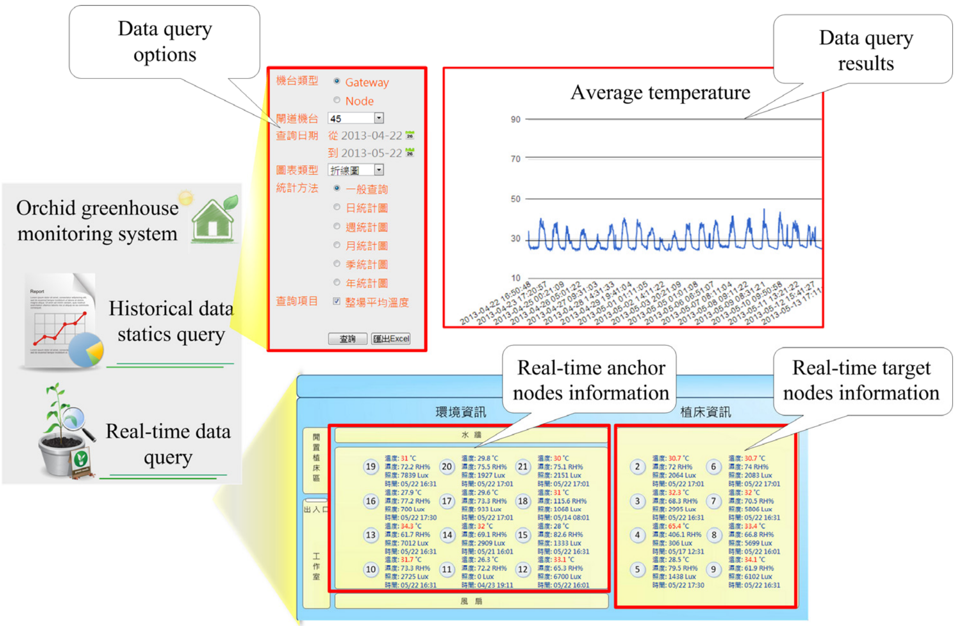


Figure 3. Website applications: different GUIs provided by the monitoring system

3. SOFTWARE DESIGN OF THE PROPOSED SYSTEM

3.1 Dynamic routing and localization algorithms

A dynamic routing and localization algorithm and an intelligent Machine-to-Machine (M2M) mechanism were designed for each sensor node in this study. The distributed routing and localization algorithms were used to improve the robustness and scalability for the dynamically formed WSN in greenhouse monitoring. The flowchart of the two algorithms is shown in Fig. 4. Beginning with the dynamic routing plan phase, every node got its own hop number through a flooding technique. Each node was aware of a relative distance between itself and the gateway. Then each node would collect the environmental data and enter the localization phase. In the localization phase, the target node completed a localization task based on the value of received signal strength indication (RSSI). After the localization phase ended, the phase of flexible time-slot planning began. Time slot allocation is crucial for WSN-based systems to arrange work schedules for all sensor nodes.

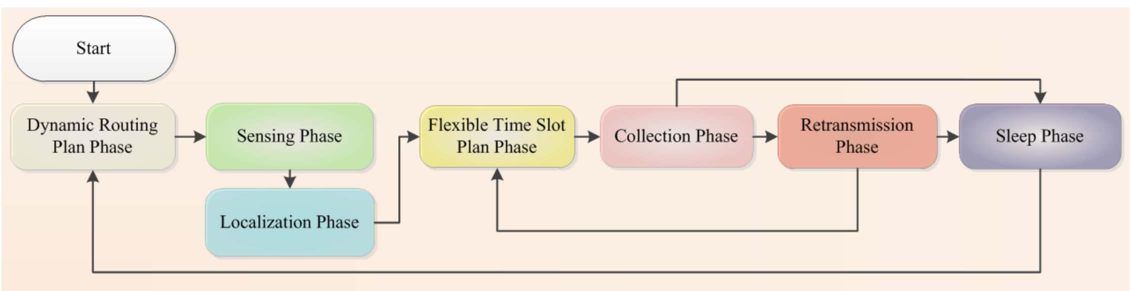


Figure 4. Flowchart of the dynamic routing and localization algorithm

3.2 The intelligent M2M mechanism

The intelligent M2M mechanism allowed each node on a movable bench to communicate with actuators. Table.1 shows every type of command packages between the node and the actuators. In this paper, four actuators were designed for automatically controlling the growth environment of orchid including a lighting system, an irrigating system, a camera module, and a rotatable fan module. The Lighting system was activated when the node on the movable benches detected insufficient illumination. The irrigator system was triggered if the relative humidity was lower than a predefined threshold. The camera module was triggered to take pictures of orchid when users would like to know the orchid growth status immediately. The rotatable fan module was designed for cooling down the temperature in the greenhouse when the temperature was too high. The rotatable fan module could track a heat source. When a hot spot was detected, the nearby rotatable fan module was responsible for cooling down the temperature.

Table 1. Command types of the M2M communication mechanism

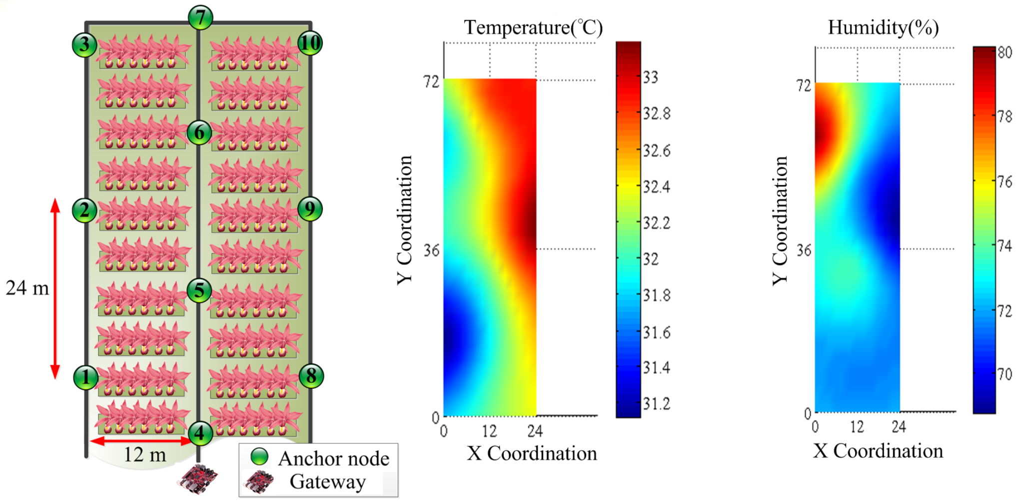
Command type	Function
0x70	Go to the light deficit area and turn the light on
0x60	Leave the light deficit area and turn the light off
0x71	Go to the irrigation area and turn the irrigator on
0x61	Leave the irrigation area and turn the irrigator off
0x72	Go to the camera area
0x62	Leave the camera area
0x87	Taking an picture immediately

4. SYSTEM VERIFICATION

To verify the proposed system, the proposed system was deployed in at real automated greenhouse. The temperature and humidity distributions in the greenhouse were reconstructed. To verify the effectiveness of the dynamic routing algorithm and the intelligent M2M mechanism used to connect the nodes on the movable benches and actuators, a series of simulations and experiments done in a real greenhouse were conducted.

4.1 Temperature and humidity distribution reconstruction

The proposed monitoring system was deployed in an automated orchid greenhouse in Chia-Yi city located at the southern Taiwan. The greenhouse occupied an area of 24 m × 72 m × 10 m. The system consisted of 25 sensor nodes; 10 were anchor nodes and 15 were target nodes. The anchor nodes were scattered to cover the whole greenhouse. The layout of the experimental environment is shown in Fig. 5(a). Every sensor node collected sensing data every 10 minutes. Fig. 5(b) shows a sample of temperature and humidity distribution in the greenhouse. Users can easily find out the variations in temperature and humidity.

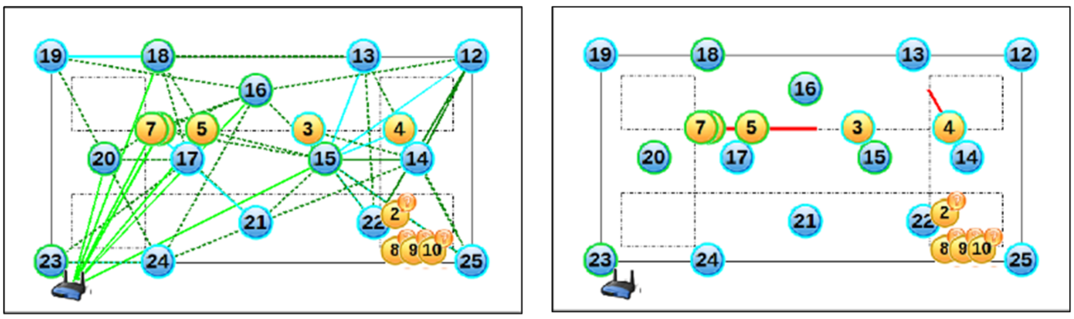


(a) **(b)** **(c)**

Figure 5. (a) The layout of the deployed sensor nodes and gateway; (b) a sample of temperature distribution and (c) a sample of humidity distribution

4.2 Dynamic routing and real-time localization algorithms

A number of mobile cars equipped with sensor nodes were used for simulating movable benches in a real greenhouse. The layout of the mobile cars, the actuators, and the experimental site is shown in Fig. 6. Moreover, a GUI was designed to display the topology of the dynamic routing and real-time localization every 6 seconds, as shown in Fig. 6. The blue dots in the figure represent the locations of the anchor nodes, and the yellow dots represent the estimated locations of the mobile cars along the rail (grey dashed line).



(a) (b)

Figure 6. A simulation of the movement of practical benches in an orchid greenhouse, (a) overall topology; (b) the estimated locations of the mobile cars

4.3 The intelligence M2M communication mechanism

A GUI was designed for showing the interaction between the mobile cars. The layout of the M2M interaction interface is shown in Fig. 7, the left side of the GUI is an instant photograph taken by camera modules when a mobile car receives the command. The photographs were saved into a database to record the trend of orchid growth. The right side of the GUI is the M2M interaction view. When a mobile car detected any deficit in lighting or humidity, it would trigger the corresponding actuator to compensate the deficit (e.g. a mobile car would trigger the irrigator when the humidity was too low). The interaction between mobile cars and actuators would be shown on the M2M view.

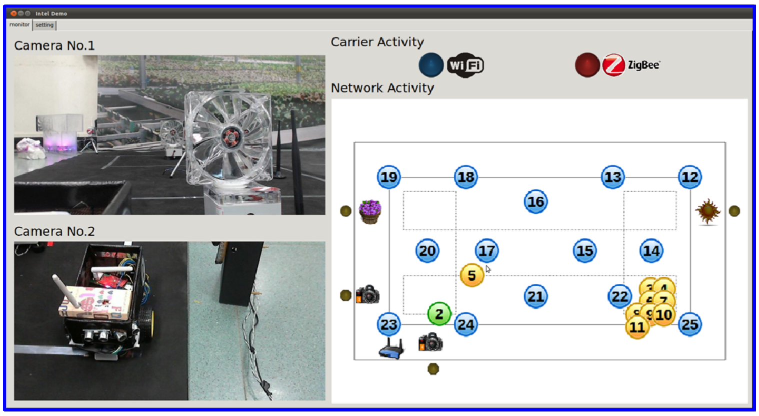


Figure 7. An example of instant photographs and the M2M interaction interface

5. CONCLUSION

This paper proposed a novel automatic monitoring system based on the WSN technology for orchid greenhouse monitoring. Through this system, orchid grew in a well-controlled environment. A dynamic routing and localization algorithm was also implemented in this system to manage a large amount of mobile sensor nodes to increase system robustness and scalability, so the lifetime of the proposed system could be extended. Furthermore, an intelligence M2M communication mechanism was designed and implemented in an experiment field. Through the proposed mechanism, mobile sensor nodes could communicate with each other more efficiently, and the mobile sensor nodes could communicate with surrounding actuators when needed.

6. ACKNOWLEDGMENT

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