Intelligent Environment Monitoring and Control System for Plant Growth

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Abstract. Indoor planting can purify the air, beautify the environment, satisfy people by closing to the nature and farming. However, the plants are easy to stop growing or even to die due to the lack of proper environment situations, such as lack of water or sunlight. This paper leverages the Internet of Things (IoT) and cloud computing technology to monitor the light intensity, air temperature and soil humidity of indoor plants. The plant growth condition and environment situation are also reflected to the user's smartphone and stored in the cloud. Outdoor users can also control the water pump to irrigate the plants and LED to add light supply via their smartphones. With our prototype, our system accurately monitors the environment and intelligently controls the plant growth.

Keywords: Plant growth · Environmental conditions · Internet of Things Cloud computing · Intelligent monitoring system

1 Introduction

With the rapid development of social economy and human life quality, the distance between people and natural environment are getting further and further. People's desire for green vegetation impel the tendency to indoor planting. Indoor plants not only relieve the visual fatigue caused by the computer, but also improve the air quality. Thus, indoor plant cultivation has become an indispensable element in our home and office environment. Nowadays, modern families can no longer be satisfied with simple flower planting, thus they start to plant a variety of plants and vegetables. However, due to the busy office work and long-time business travel, users are always absent from home and leaving the plants with water shortages. Additionally, due to inadequate indoor sun exposure, plant growth is also obstructed. Water, temperature and light are the major environment factors which have the most impacts on plant growth.

"Intelligent plant monitoring" refers to the application via IoT technology to monitor plant growth environment parameters (including light, temperature and soil moisture), and through the cloud computing technology, the growth situation is quickly reflected in users'

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smartphones and stored in the cloud. In addition, it should timely take corresponding measures and controls to ensure the normal growth of plants. In this paper, we develop a plant growth environment monitoring system, which consists of a low-power microcontroller as the main control system module, a LCD screen, and humidity, temperature, light sensors to simulate the natural environment of soil humidity. Those data are packaged to the smartphone via Bluetooth communication, and then transferred to the cloud.

The plant growth environment monitoring system is small and inexpensive to user, which is suitable for home and office area applications. Through a simple human-computer interface on smartphone, users set a variety of environmental parameters for each selected plants, e.g., the required light, temperature, and soil humility. When the measured values exceed or under the thresholds, our system will automatically upload the reminder message to the user's smartphone. As the whole process is intelligent and eco-friendly, users can easily plant as well as enjoy a "natural oxygen bar" at the same time.

2 Background on Environmental Conditions for Plants Growth

Environment refers to the space in which plants live and the various natural factors that directly or indirectly affect the plant life and development [1]. Plant growth and development are directly affected by some natural factors, such as temperature, light, soil humidity [2] and so on.

2.1 Light

Light is an important ecological factor that affects the survival, growth and distribution of plants and it is also the energy source for photosynthesis of plants [3].

The plant can be divided into 3 types, including light-demanding plant, shade-demanding plant and mid-demanding plant according to different requirements for the light. Light-demanding plants are those plants that grow better in a strong light conditions and grow poorly in a shaded and weak light conditions, such as *Rosa chinensis* Jacq., etc.; Shade-demanding plants are those plants prefer to live in the weaker light conditions compare with light-demanding plant, such as *Phalaenopsis aphrodite* Rchb. F. and *Monstera deliciosa*, etc.; Mid-demanding plants are those plants live in light condition between the two types of plants. These plants grow best under the full sunlight, and also can tolerate the shade condition, such as *Hemerocallis fulva* (L.) L., *Mirabilis jalapa* L. and so on.

According to the influence of the light time on the growth and development, the plants are divided into three types, including long-day plants, short-day plants and mid-day plants [4]. A long-day plants are those plants which length of sunlight exceeds its critical day length required for flowering, such as *Brassica chinensis* L., *Raphanus sativus* L. and so on. Short-day plants are those plants which length of sunlight is shorter than the critical day length required for flowering, such as *Viola philippica* and so on. The mid-day plants are those plants which their flowering is less affected by the length of the light. They can bloom under any sunshine lengths, as long as other conditions are suitable, such as *Taraxacum mongolicum* Hand.-Mazz.

Figure 1 shows *Brassica chinensis* L., an example of long-day plants, with suitable environment by 25–30° C temperature and 75% Relative Humidity [5].

Fig. 1. *Brassica chinensis* L.

2.2 Water

Water is an important factor for plant survival. The physiological activity of plants can be carried out normally only with the proper water. Most plants absorb moisture from the soil rely on their roots [6]. Therefore, this paper measure the soil humidity as a key parameter to determine whether the plants are dehydrated.

According to the water requirement, the plants can be divided into xerophytes, aquatic plants, wet plants and mesophytes. The xerophytes grow in arid environment. They can maintain the balance of water themselves and keep growing under drought condition for a long time, such as *Opuntia stricta* and so on. Wet plants grow in humid environments. They cannot survive under water shortage condition for a long time. They are the least drought-tolerant terrestrial plantsa, such as *Begonia grandis* Dry and so on. Mesophytes are land plants that grow in moderation humidity conditions. Most plants fall into this category. Aquatic plants are plants that live in the water, such as *Nelumbo nucifera* and so on.

2.3 Temperature

Similar with the light, temperature is also a key factor that it influences the various physiological and biochemical activities of plant. Only if the plant lives in a certain temperature conditions can they grow. It is harmful for plant survival if the temperature is too high or too low.

3 Measurement Principle on Soil Humidity

The soil resistance value is related to humidity. For example, the resistance is small in humidity soil and the resistance is large in dry soil, thus the humidity size can be measured based on the soil resistance value. However, if we use the normal measurement method as-is, we cannot obtain the stable resistance measurement values. The reason is that the moisture in soil can be regarded as electrolyte, it will be polarized under the action of DC voltage, resulting in the separation and accumulation of anions and cations, so that the soil resistance cannot reflect the soil moisture.

This paper adopts a new measurement method. As shown in Fig. 2, the soil resistance constructs an electronic circle with two capacitances, and constructs an oscillating circuit with NE555. At the meantime, the output of NE555 is digital signals, thus can be connected with the digital control system to measure the circuit oscillation frequency. At last, we transform the circuit oscillation frequency into soil humility via numerical fitting of Eq. 1.

$$\mathrm{f} = \frac{1}{0.00003 + 8.109E - 9R} \tag{1}$$

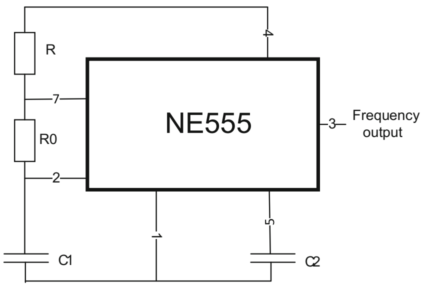

Fig. 2. Electric schematic diagram.

In order to evaluate the accuracy of our novel soil humility measurement method, we use the readings from a professional hygrometer as the ground truth, and Fig. 3 shows the CDF of our measurement errors. We measure the humility of a sample soil every

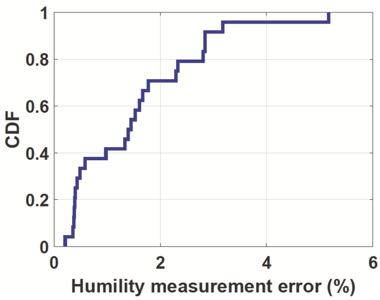

Fig. 3. CDF of soil humility measurement errors.

hour in a day. We observe that the 90-percentile measurement errors are around 3%, which shows the effectiveness of our method.

4 System Architecture

Based on the above soil humidity method, we propose an intelligent plant monitoring system, as Fig. 4 shows. It is comprised of the frontend, home smartphone, and the cloud. We also develop the Bluetooth communication for sensory data transmission between the frontend and the smartphone, and the WAN transmission between the smartphone in home and the cloud. In our system, the smartphone serves as the home control center, which transfers original data, and provide kind user interface for monitoring and control.

Below we introduce our plant monitoring system in details.

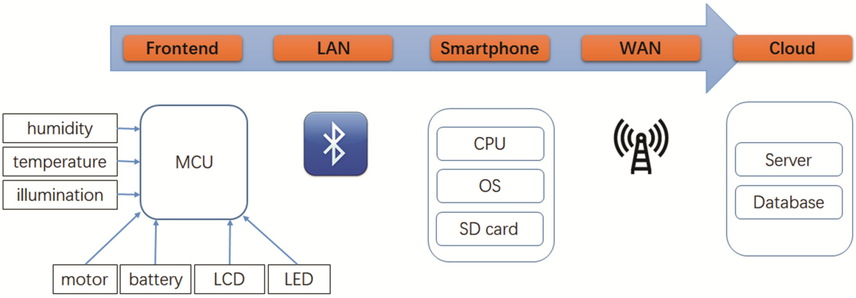

Fig. 4. The architecture of plant monitoring system

4.1 Frontend Sensery System

In the frontend sensory system, we aim to measure the soil humility, the air temperature and the illumination period. As Fig. 4 shows, we build the humility sensor based on our own observations, and these three sensors are all attached to the MCU. We also attach a LCD for display, a LED for light supply, and a battery for energy supply.

In order to irrigate the plants when users are absent, our MCU also controls a motor as a water pump. Thus users can send the irrigation order with their smartphone even when they are out, and our system irrigate the amount of water just as the plant needs.

Finally, the MCU packages the data every second, and sends the data to the control center in home via Bluetooth communication, which is an energy efficient data transmission protocol and widely equipped on smartphones.

4.2 Home Control Center: Smartphone

The home control center receives the sensory data from frontend sensors, and store the data in local database. It also keeps a database for the environment requirements on the selected plants, thus can determine whether the environment is satisfied. In case the plant lacks of water, the control center will send an alert to the user via WAN, and send the irrigation request back to the frontend system when necessary.

4.3 Cloud Server and Database

We build the cloud on a tomcat server with fixed IP address, and use the JDBC to store the data in a MySQL database. In future we will transplant the server to a cloud server, e.g., on the Aliyun platform, thus providing the service to the public.

5 Frontend Sensery System

The working principle of our frontend sensory system is as follows: we combine the humidity, temperature and light intensity sensors to collect the humidity, temperature and light intensity information of the environment, and perform the A/D conversion to collect such signals via a single chip microcomputer for data processing. The system does not irrigate when the humility value is larger than the bound; it automatically turns on the watering pump when the humidity value is lower than the bound and the temperature value is lower than the set value. In case the humidity value is lower than the bound but the temperature value is higher than its set value, then only when the light intensity is lower than the set value, our system will automatically start the irrigation facilities. Users can also set different conditions to stop watering conditions in the above methods: e.g., humidity is higher than the set value, or watering time exceeds the set period. We employ a LCD screen to help users set the system in a menu way. We also leverage a solar powered battery for sustainable operation without additional power supply (Fig. 5).

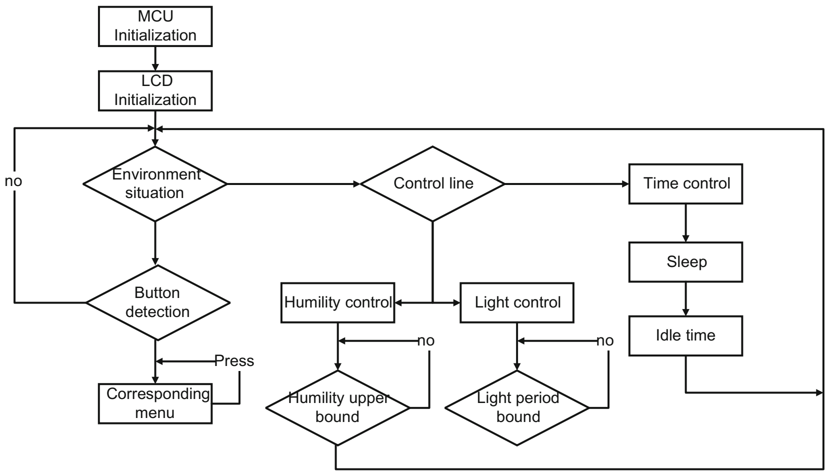

Fig. 5. Software work flow.

Our system waters the plants only at night during the summer, which prevents plants from being sunburn wounds while minimizing water loss due to evaporation. Watering the plants in the daytime in winter reduces the risk of frost damage.

Our frontend sensory system uses a MEGA8 high-end microcontroller as the processing unit for the frontend system. It has an 8 K flash program memory, 1 K RAM, 512 Bit EEPROM, four 10-bit AD conversion circuits with two 8-bit AD conversion circuits. It also has an independent built-in watchdog circuit, which is extremely simple and reliable. We also use a 48 × 84 pixel PCD 8544 LCD screen, which is of low price and easy to buy. The LCD display is connected to the microcontroller via the SPI synchronous serial interface.

Humidity detection. The soil resistance value is related to its humidity. When the humidity is low, the resistance value is small, and the resistance value is high when drying. Therefore, the soil resistance can be used to measure the soil humidity. However, direct measurement method by the conventional DC method cannot measure a stable resistance value. The reason is that: since the water in the soil can be regarded as the electrolyte, it will polarize under the action of the DC voltage, resulting in the separation and aggregation of the anions and cations, thus the soil resistance cannot reflect the soil moisture. Our system develops the original R-F conversion detection circuit to measure the soil humility: the NE555 oscillator circuit adds the AC to the two electrodes, transforms the soil resistance into a pulse signal to facilitate single-chip processing. The actual use of our method is reliable and practical.

We use an 8-bit A/D converter built-in microcontroller to sample and transform the temperature and light intensity information. Temperature probe is an ordinary thermistor, and the microcontroller only conducts a simple conversion for the results instead of using a look-up table. Although the accuracy is not very high, it works well and meets the system requirements. Light intensity are measured using a small photoelectric sensor, and the A/D built in the microcontroller directly samples and transforms the results of the sensor output voltages.

When the watering conditions are met, our system outputs a 12 V voltage at the output port, driving the water pump to start watering. In order to control the amount of water poured, we connect the pump outlet with the water control valve, thus control the amount of water well. In cloudy days, our system controls the LED to make up the light supply, thus keep the suitable environment for any plant.

The system uses the solar-powered battery, without additional power supplies. Although solar cells can also be used directly to power the system, such designs require larger and expensive solar cells. Regarding that our system requires high-current work for only a few minutes in one day, the average power consumption is relatively small, thus our system uses a small solar battery to charge the lithium battery pack, and pack the lithium battery for high-current work at night. The system uses lithium battery pack for its smart charge and discharge protection circuit, and convenient and reliable usage.

6 Control Interface on Smartphone

Humidity settings. Users can set the soil humidity according to the plant species and soil types, with the upper and lower bound. When the soil humidity value is larger than the humidity upper bound, regardless of temperature, light intensity, the system stops watering (at this time the soil humidity has been saturated). When the soil moisture value is smaller than the humidity lower bound (when the soil is dry, water the plant), the system then set the temperature and light intensity to decide whether to irrigate (Fig. 6).

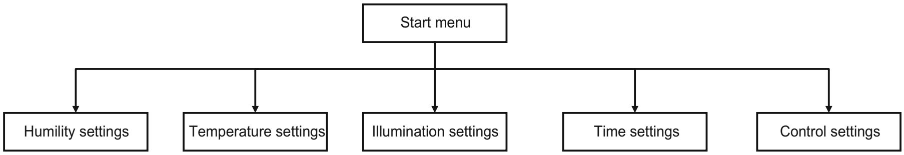

Fig. 6. Initialization process.

Temperature and illumination settings. When the soil humidity is smaller than the humidity lower bound (humidity meets the water conditions), if the soil temperature is lower than the temperature lower bound, the system starts watering the plant. For example, in summer, the soil temperature is too high (temperature is larger than the temperature upper bound), we implement the irrigation equipment with a water pump which is easy to burn plants, thus the system set the light intensity according to the decision whether to irrigate, when the light intensity is larger than the light intensity lower limit (such as during the day), the system does not water the plant. When the light

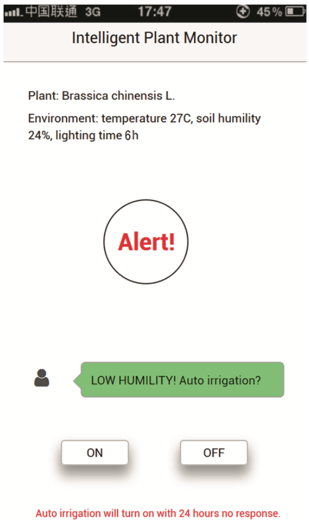

Fig. 7. Smartphone control interface.

intensity is smaller than the light intensity lower bound (such as night), our system starts the pump to water the plant (Fig. 7).

Time and control settings. In order to allow the soil to have a gradual process for absorbing water, users can set the watering time period. In this case, users set the watering mode to stop the system from watering based on the upper humidity bound or set to stop watering based on the length of time.

7 Conclusion

In this paper, we use the method of resistance-frequency (RF) conversion circuit to measure the soil humility, and develop an intelligent environment monitoring system for plant grows. In addition, the system can control the water pump to irrigate home plants when necessary, report the environment situation to users via smartphones, and store the sensory data in the cloud. From evaluation and our prototype, the method proposed in this paper costs low and is worth to be popularized. Our system can be connected with other indoor localization techniques [7–14] to help improve our daily life.

References

1. Deqin, L., Yunxia, D., Shuwen, Z., Xiaohang, W.: Quantifying parameter sensitivity and calibration in simulating soil temperature and moisture. Chin. J. Atmos. **39**(5), 991–1010 (2015)
2. Qiaosheng, G.: Environmental requirements for medicinal plant growth and development, China News of Traditional Chinese Medicine, 19 June 2002
3. Xiangzeng, X., Jinyan, Z., Guanghui, Z., Guangqiang, L.: Effects of light intensity on photosynthetic capacity and light energy allocation in Panax notoginseng. Chin. J. Appl. Ecol. 1–14 (2017)
4. Cong, L., Tian, T., Shan, L., Liang, Yu.: Growth response of Chineses woody plant seedlings to different lighy intensities. Acta Ecol. Sin. **38**(2), 1–8 (2018)
5. Beibei, G.: Study of crop growth environment simulation system, Tianjin University of Technology and Education (2013)
6. Juan, X., Yi, C., Fei, T., Chuntao, L.: The influence of environmental factors on flower growth and family flower - growing techniques. J. Anhui Agric. Sci. **31**(4), 656–658 (2003)
7. Gao, R., Zhao, M., Ye, T., Ye, F., Luo, G., Wang, Y., Bian, K., Wang, T., Li, X.: Multi-story Indoor floor plan reconstruction via mobile crowdsensing. IEEE Trans. Mob. Comput. **15**(6), 1427–1442 (2016)
8. Gao, R., Tian, Y., Ye, F., Luo, G., Bian, K., Wang, Y., Wang, T., Li, X.: Sextant: towards ubiquitous indoor localization service by photo-taking of the environment. IEEE Trans. Mob. Comput. **15**(2), 460–474 (2016)
9. Gao, R., Zhao, M., Ye, T., Ye, F., Wang, Y., Luo, G.: Smartphone-based real time vehicle tracking in indoor parking structures. IEEE Trans. Mob. Comput. **16**(7), 2023–2036 (2017)
10. Gao, R., Zhou, B., Ye, F., Wang, Y.: Knitter: fast, resilient single-user indoor floor plan construction. In: Proceedings of IEEE INFOCOM (2017)
11. Gao, R., Zhao, M., Ye, T., Ye, F., Wang, Y., Bian, K., Wang, T., Li, X.: Jigsaw: indoor floor plan reconstruction via mobile crowdsensing. In: Proceedings of ACM MobiCom (2014)

12. Zhou, B., Chen, X., Hu, X., Ren, R., Tan, X., Fang, X., Xia, S.: A Bluetooth low energy approach for monitoring electrocardiography and respiration. In: Proceedings of IEEE Healthcom (2013)
13. Zhou, B., Elbadry, M., Gao, R., Ye, F.: BatMapper: acoustic sensing based indoor floor plan construction using smartphones. In: Proceedings of ACM MobiSys (2017)
14. Zhou, B., Elbadry, M., Gao, R., Ye, F.: BatTracker: high precision infrastructure-free mobile device tracking in indoor environments. In: Proceedings of ACM SenSys (2017)