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Smart Home 2.0: Innovative Smart Home System Powered by Botanical IoT and Emotion Detection

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Abstract Advances in human-centric technologies, such as artificial intelligence (AI), application-oriented sensing and smart home, along with recent developments in internet of things (IoT) and machine-to-machine (M2M) networks are enabling the design and development of a smarter home with cognitive intelligence. In this paper, we first investigate the integration of smart home and botanical IoT for creating a better living environment to increase people's quality of life. First, we point out that traditional smart home solution (Smart Home 1.0) only achieves the interaction between users and home appliances in indoor environment, while ignoring the relation between users and indoor greeneries. Then, we discuss the benefits of indoor greeneries for improving indoor living environment which leads a better physical health and mental health for home users. As greeneries are integrated into Smart Home 1.0, we propose an evolution from traditional smart home solution to Smart Home 2.0 to achieve the organic integration between users and greeneries. To verify our proposal, a prototype system of Smart Home 2.0 is designed and implemented. The experimental results show the smooth data flows from sensors deployed in smart green house to data center. A mobile cloud system is built to store, manage and visualize the data for the affective interaction between greeneries and home users. It is foreseeable that the emotion-aware capability of smart home 2.0 will bring more intelligent and interactive healthcare applications for urban residents in the future.

Keywords Smart home · Smart green house · Automatic plant cultivation · Smart switch

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1 Introduction

Urbanization improves people's quality of life in terms of convenience and material life, yet creates other problems due to limited space, high pressure and fast pace of life. Many people are in sub-health status and suffered from psychological problems, including depression and insomnia. Insomnia can cause unpleasant problems to people, such as poor working efficiency, extra traffic accident and unnecessary fiscal burden. Currently, the phenomenon of insomnia is common worldwide. Given US as an example, it is estimated that 23.6% of residents get insomnia already [1]. Meanwhile, insomnia is also the main cause for certain chronic diseases, particularly hypertension, cardiovascular disease, type 2 diabetes and psychiatric disorders. In summary, insomnia seriously affects the life quality of urban people [2].

As a human-centric IoT solution for indoor environment, smart home was proposed to improve people's quality of life when they stay at home [3]. The key of smart home technology is to interconnect home appliances and users via M2M communications [4]. Besides, cooperative communication protocols like [5] or MIMO transmission technologies like [6] can be employed to realize the energy-efficient M2M connections in human-centric IoT scenarios. By operating home appliances intelligently and remotely, energy saving is achieved. In this paper, we refer to the traditional smart home technology as first-generation smart home (Smart Home 1.0). At present, the focus of smart home 1.0 is still energy efficiency and life convenience at home. Very few work takes human's health status into account during their system design, not mentioning the further consideration of caring human's emotion in home environments.

Unfortunately, there is no work to introduce the greeneries into smart home 1.0 for improving human's health status both physically and psychologically [7]. To fill the void, we propose an evolution from Smart Home 1.0 to second-generation Smart Home (Smart Home 2.0), whose main distinctive feature is the introduction of the greeneries into home environments with the cognition of user's emotion. Without loss of generality, Smart Home 2.0 still possesses the following characteristics:

- Energy saving is achieved via the interaction between user and home appliances through M2M communications.
- IoT and sensing techniques are adopted for real-time monitoring and management of greenery cultivation.
- The evergrowing artificial intelligence (AI) technology can be applied to enhance the intelligence and affective interactions with user.

Figure 1 shows a typical scenario of Smart Home 2.0. The user is missing Spring, and hopes the technology of Smart Home 2.0 can help to "keep" Spring. Combining home appliances and environment with greeneries perfectly, Smart Home 2.0 provides users with more comfortable living conditions by adjusting the growth and flowering of the greeneries according to user's emotion and sleeping habit.

The left of this paper is organized as follows: Section 2 introduces the related work; Section 3 introduces the application scenario and system architecture of Smart Home 2.0; Section 4 introduces the deployment of Smart Home 2.0; in Section 5, a distinctive experiment based on Smart Home 2.0 is presented; finally, we give conclusion of this paper.

2 Related work

In the article [8], a big data centered intelligent system framework is proposed with the technology of IoE (i.e., Internet of Everything), big data and cloud computing [9]. The framework mainly consists of four parts: data collection, data processing, data management, and data interpretation. At last, a intelligent system exemplified by Smart City is illustrated. Paper [10] explores the composition of the three pillars of IoE, and illustrates the function of each pillar and its components, which provides valuable reference to the establishment of smart system. Sherry and his team investigate CARS (i.e., Cloud-Assisted Remote Sensing), which enables distributed sensing data collection, global resource sharing, remote real-time data access, and flexible resource scheduling. Compared with the mainstream commercial cloud platform, the main requirements and challenges CARS faced are discussed by author [11]. In paper [12], although the big data generated by IoE put forward higher demands on data analysis, system scalability and system performance, the combination of local clouds and remote clouds based on intelligent scheduling algorithm can solve these technical challenges [13]. By discussing the communication and networking of IoE, paper [14] provides a reference for the realization of intelligent system. Aalaa and his members design a Smart Agriculture System(i.e., AgriSys) to collect and analyze agricultural environmental information, furthermore, to try to maintain environmental suitability through governing devices; meanwhile, AgriSys also focuses on the design and implementation of various sensors related to environmental factors [15]. In paper [16], the author designs a architecture of Smart Farming System based on IoT technology, explores the detail of system implementation, finally, delivers a referral for the construction of intelligent system.

With the development of pervasive computing, Smart Home solution can allocate services that are no longer confined to the home space [17], on the basis of which, paper [18] proposes a service model with family calendar to implement ambient intelligence in Smart Home. In paper [19] and [20], the authors put forward a possible Smart Home architecture based on the technology of Resource Name Service(i.e., RNS) and cloud technology. Paper [21–23] and [24] explore the energy efficiency of Smart Home. Based on the wireless sensor network and power line communication technology, the author investigates the design and implementation of the Smart Home Control System and analyzes the improvement of these technologies on energy saving [25]. The paper [26] discusses how to apply the Web of Things technology to construct Smart Home System so that the complexity of heterogeneous device access to system can be shielded, and it also explores how to utilize flexible

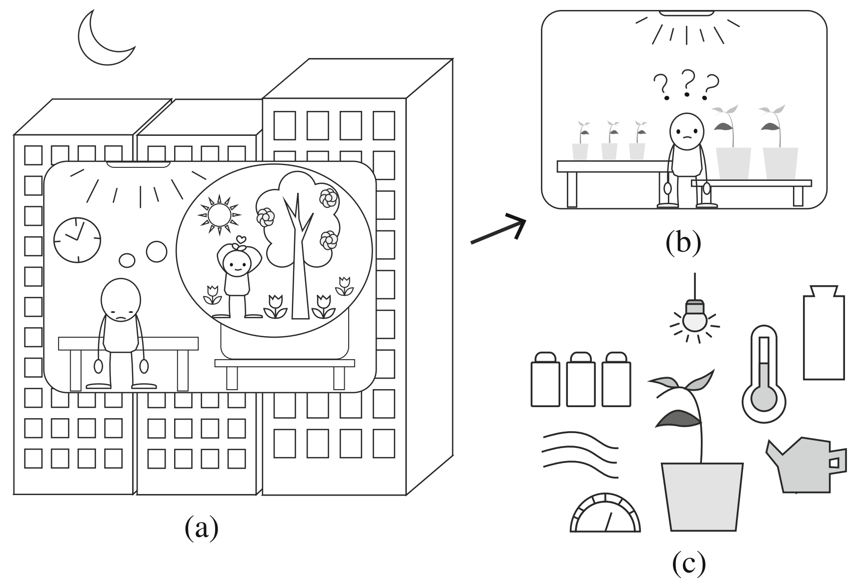


Fig. 1 Application scenarios for Smart Home 2.0: **a** the current status and vision of users; **b** the dilemma faced by users; **c** the important environmental indicators affecting the growth of plant

solutions to break the challenge of high energy consumption. Paper [27] and [28] involves the subject how smart appliances have access to Smart Home.

3 Application scenario and system architecture

As shown in the Fig. 1a, a special application scenario of Smart Home 2.0 is introduced to focus on the users with personalized lifestyle. For example, a user feels exhausted after heavy workload in daytime. When at home, greeneries exhibiting beautiful status (e.g., flowering, prosperous growth, etc.) help the user to relax. To accomplish the consequence, as shown in the Fig. 1b, it is necessary to be in charge of the crucial environmental factors for greenery cultivation, such as ambient temperature, humidity, illumination, etc. Obviously, with the intelligence supported by intelligent hardware and cloud, Smart Home 2.0 should be the appropriate option for users to govern the life cycle of greeneries automatically. However, data is the essential material for intelligence, as shown in Fig. 1c, Smart Home 2.0 utilizes sensing equipments to collect data including ambient temperature, humidity, soil humidity, illumination intensity, CO2, O3, O2, NO2, etc. By mining these data, Smart Home 2.0 implements the intelligent monitoring and automatic cultivation of greeneries, furthermore, achieves automatic greenery cultivation on the basis of mood and status of users to improve users' quality of life. In indoor environment, users thoroughly enjoy the great experience in aspects of physiology and psychology brought by Smart Home 2.0, meanwhile avoid the cumbersome caused by necessary maintenance of home environment.

With the convenience of Smart Home 2.0, users can manage indoor environment, home appliances and greeneries even if they are outdoor. As Fig. 2 shows, the system architecture of Smart Home 2.0 consists of the following three parts: Smart Home 2.0 infrastructure, cloud platform and users. Smart Home 2.0 infrastructure means that to establish complete application in indoor environment and to realize a series of functions for home appliances and greeneries, including appliance monitoring, environmental monitoring, greenery monitoring, automatic greenery cultivation, etc. Cloud platform offers various services, including equipment registration, users management, authority management, equipment configuration, configuration of greenery cultivating strategy and so on. With mobile terminals or web terminals, users have access to cloud to fulfil their requirements.

4 Deployment of smart home 2.0

As shown in Fig. 3, the deployment of Smart Home 2.0 consists of three parts:

- The construction of green house;
- The installation of botanical sensor networks;
- The building of supporting cloud platform.

In cloud platform, there are two kind of users: administrator and resident of smart home. To deploy a Smart Home 2.0 system, there are six steps, including equipment deployment, equipment registration, user registration, authority allocation, equipment configuration as well as configuration of automatic cultivating strategy.

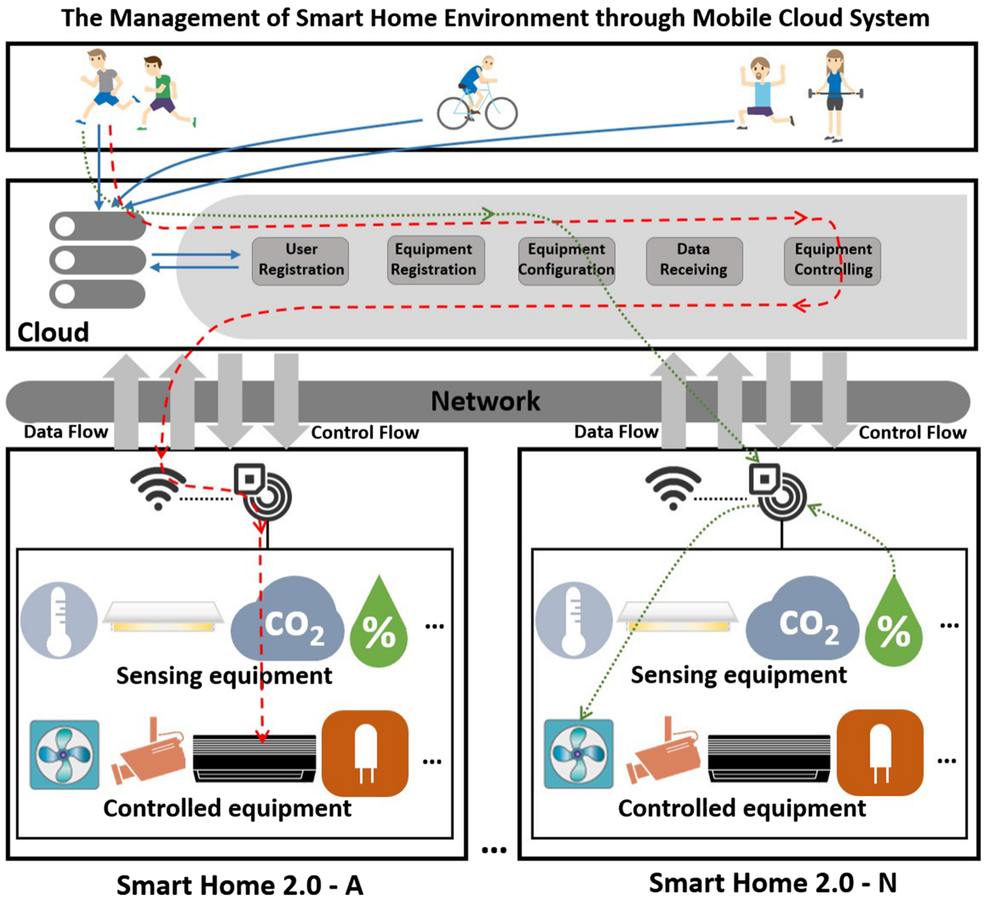


Fig. 2 System Architecture

4.1 Equipment deployment in indoor environment

This section introduces how to deploy equipments in home environment and describes how to establish the connection between home and cloud. The deployment architecture of Smart Home 2.0 in indoor environment is shown in the Fig. 4, traditional home appliances and homologous equipments are introduced into Smart Home 2.0 via smart switches, while smart switches access to Micro-Processor. Sensing equipments are deployed to collect environmental data, which are transmitted from sensors to Micro-Processor in wired way. With the help of Wi-Fi, Micro-Processor is mainly responsible for interaction with cloud.

4.2 Equipment registration in cloud

Once communicated obstacle between Micro-Processor and cloud is eliminated, a package, contained all information of Micro-Processor and equipments, is packed and sent to cloud for equipment registration. When equipment registration is done, an new object of Smart Home 2.0 is established in cloud and all information of equipments are stored in cloud, furthermore, equipments are assigned to the corresponding object of Smart Home 2.0, which is identified by ID of Micro-Processor.

4.3 User registration in cloud

Before enjoying services offered by Smart Home 2.0, user registration is necessary. User submits personal information such as user name and password into cloud to achieve registration. Then it is ready to assign corresponding objects of Smart Home 2.0 to user.

4.4 Authority allocation for user

In cloud platform, equipment registration and user registration will be conducted first. Later, administrator will assign the privileges for various users. That is, different user will get the privileges of controlling and managing a set of registered objects at Smart Home 2.0. An object can be an equipment or an appliance.

4.5 Equipment configuration

User can further configure equipments affiliated to himself, all of which are still in the status of un-initialization and not work properly though equipment registration is finished. There should be extra information, including equipment name, equipment type, working mode and so on, to be configured into cloud with regard to equipments. Then

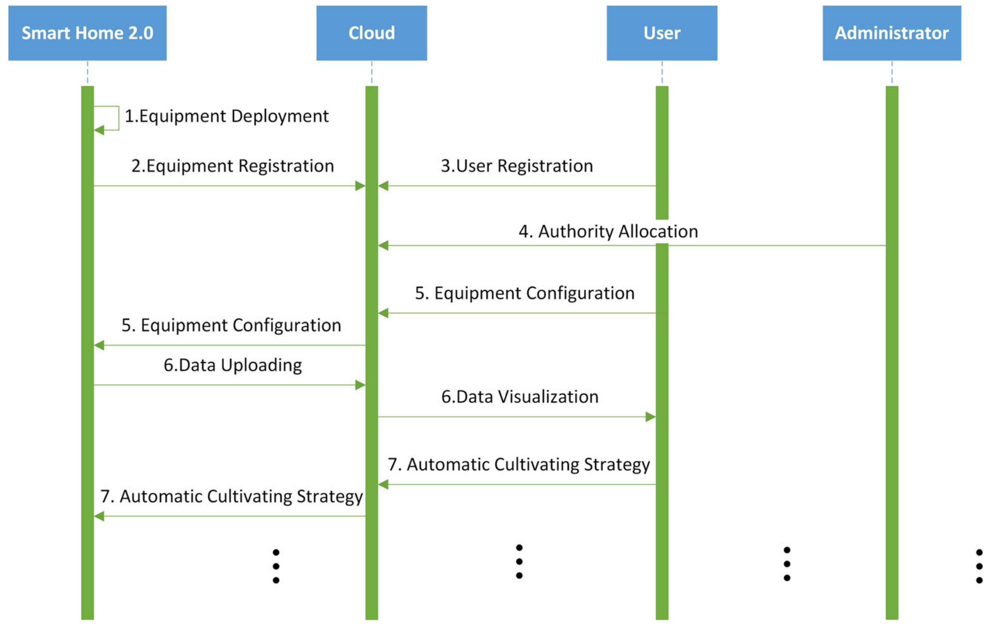


Fig. 3 Deployment procedure of smart home 2.0

equipments work smoothly and are marked as 'Normal' status in cloud.

As shown in Table 1, equipments are classified into two types: sensing equipment and controlled equipment. Sensing equipment perceive environment and collect environmental data; controlled equipment activate themselves to regulate environment. Take illumination as an example, as the sensing equipment, the illumination sensor can detect the intensity of indoor light, and as the controlled equipment, the LED can adjust intensity of indoor light. Also taking LED as an example to present working mode of equipment, LED embedded with Smart Switch can work automatically if a working mode for LED has been arranged, such as terminating LED at 07:00 AM as well as activating it at 06:00 PM. Obviously LED will work accordingly on the basis of corresponding working mode.

The 'Normal' status of equipment represents that fundamental configuration of equipment is succeeded, which means Micro-Processor in indoor environment can collect environmental data from sensing equipments and transfer them to cloud. The interval of data collection and data transferring can be set up by users optionally. By utilizing environmental data stored in cloud, cloud can manage home appliances and environment intelligently.

Equipments can further be set up to map with each other by users. Users configure mapping-control strategy between sensing equipment and controlled equipment into cloud, then strategy can be issued to Micro-Processor for execution. Typical mapping-control strategies are shown in Table 2. For the strategy(e.g., temperature and air conditioner), the expectation of indoor temperature is set up to 22 °C, Micro-Processor collects indoor temperature from temperature sensor at intervals to decide whether it needs to issue a instruction to operate the corresponding air conditioner in order to maintain the stability of indoor temperature. For the strategy(e.g., illumination and LED lamp), LED lamp is operated to provide suitable illumination for greenery cultivation in indoor environment when Micro-Processor detects illumination intensity from illumination sensor and finds out that illumination intensity is not adequate. As for the strategy(e.g., soil humidity and hose nozzle), hose nozzle irrigates greenery to regulate soil humidity, the irrigation only sustains 5 seconds at a time and whether it should be performed or not depends on status of soil humidity detected by corresponding sensor. As shown in the fifth column of Table 2, a specific effective time is assigned to each operation to avoid poor user experience and equipments' damages caused by frequent equipment switching.

4.6 Automatic cultivating strategy for greenery

The equipments, listed in the Table 1, are utilized to assemble automatic cultivating strategy for greenery in Smart Home 2.0. For people who do not have cultivation experience and spare time, Smart Home 2.0 supports automatic cultivating strategy of greeneries to achieve the flourishing growth in indoor environment. By assembling mapping-control strategies organically, users can design a automatic cultivating strategy conveniently. As shown in Fig. 5, by configuring multiple mapping-control strategies related to multiple environmental factors, i.e., soil humidity, illumination as well as temperature, a automatic cultivating strategy could be accomplished. Automatic cultivating strategy should be activated by users if there are corresponding greeneries being cultivated in indoor environment.

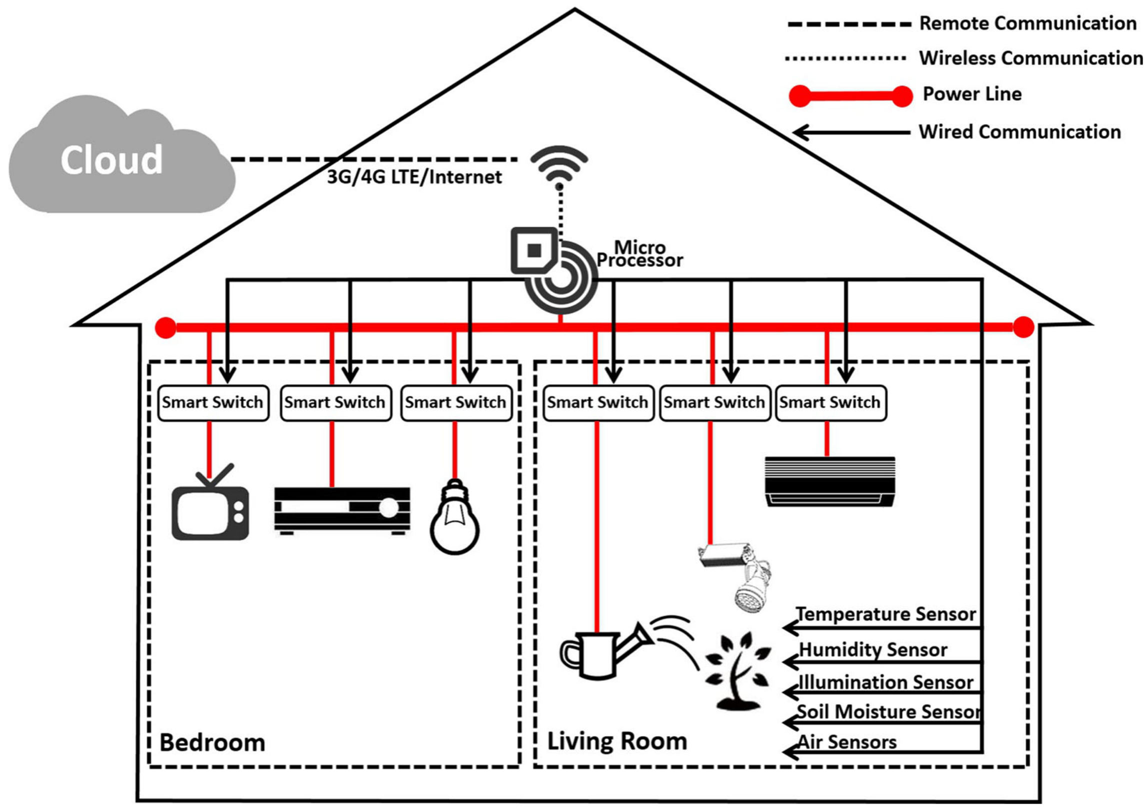


Fig. 4 Equipment deployment in indoor environment

As appropriate environmental factors for greeneries varies according to different growth stages of greeneries, automatic strategies are configured diversely in terms of days. It's worth noting that one strategy is appropriate for one greenery species and can be applied to innumerable objects of Smart Home 2.0 for cultivating corresponding greenery.

4.7 Illustration for equipment control

With the help of smart terminal, users can issue instructions to manage controlled equipments flexibly. Currently equipment control is divided into manual control and automatic control. Manual control issued by users through android terminal or web terminal possesses the highest priority, which is represented as Level 1. Automatic control, produced by cloud automatically according to mapping-control strategy, possesses lower priority, which is marked as Level 2. Taking LED as an example, Fig. 6 illustrates the control flow of LED with 2 different controlling instructions. Furthermore, in order to avoid frequent equipment switching, each instruction works uninterruptedly during effective period, which means that a new instruction with lower priority arriving in effective period will be neglected automatically by equipment.

Table 1 List of deployed equipments

Equipment type		Equipment name	
Sensing equipment		Temperature sensor	O2 Sensor
		Humidity sensor	CO2 Sensor
		Illumination sensor	Soil moisture sensor
Controlled equipment	Greenery adjusting equipment	LED	Ventilator
		Hose nozzle	
	Home appliances	TV	Kettle
		Air conditioner	Sound
		Bulb	Electric cooker
		Refrigerator	Smart switch

Table 2 Mapping-control strategies for equipment

Mapping name	Sensing equipment	Controlled equipment	Control strategy	Effective time

Temperature
–
Air conditioner
	Temperature sensor	Smart switch(Air conditioner)	Initial temperature on air conditioner to 22 °C.
			if(temperature>28 °C OR temperature<16 °C)
			Air conditioner turn on;
			if(temperature between 20 °C AND 24 °C)
			Air conditioner turn off;
				30 Mins

Illumination – LED	Illumination sensor	Smart switch(LED)	Daytime(06:00-19:00) illumination<40Lux: LED turn on; illumination>65Lux: LED turn off; Night(19:00-06:00) LED always turn off;	5 Mins
Illumination – Bulb	Illumination sensor	Smart switch(Bulb)	Daytime(06:00-18:00) Bulb always turn off; Night(18:00-23:00) illumination<150Lux: Bulb turn on; illumination>300Lux: Bulb turn off; Night(23:00-06:00) Bulb always turn off;	5 Mins
Soil humidity – Hose nozzle	Soil humidity sensor	Smart switch(Hose nozzle)	if(Soil humidity<40%) Hose nozzle turn on;	5 S

5 Experiment

An experiment based on Smart Home 2.0 is designed and implemented to explore the growth of greeneries in indoor environment, the greenery this experiment choose is KoreanGinseng. In order to accelerate the growth of KoreanGinseng to attain rapid maturity, we design the corresponding intelligent cultivating strategy in this experiment, which manages the growth of KoreanGinseng by regulating critical environmental factors, such as illumination, temperature, humidity, air, soil moisture, soil ph, etc. And the consequence of experiment meets our expectation.

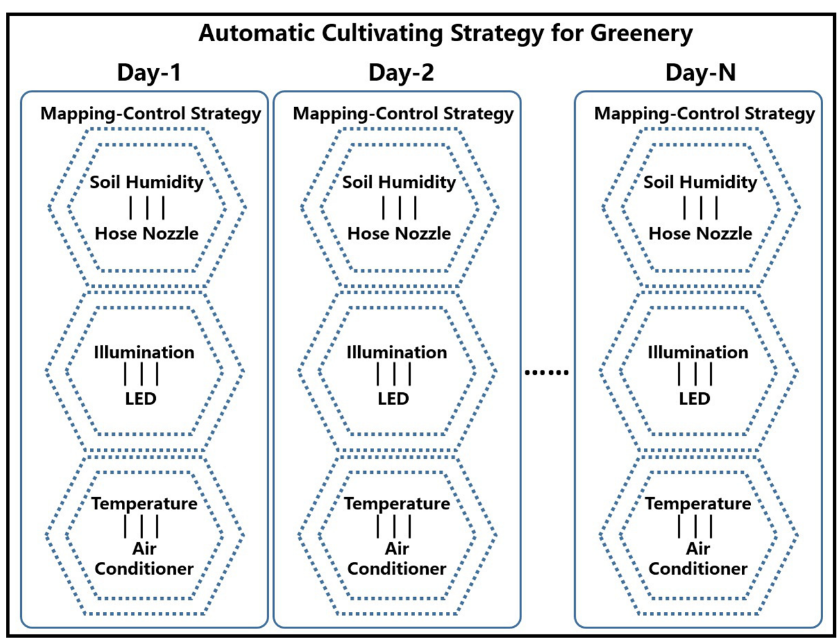


Fig. 5 Automatic cultivating strategy

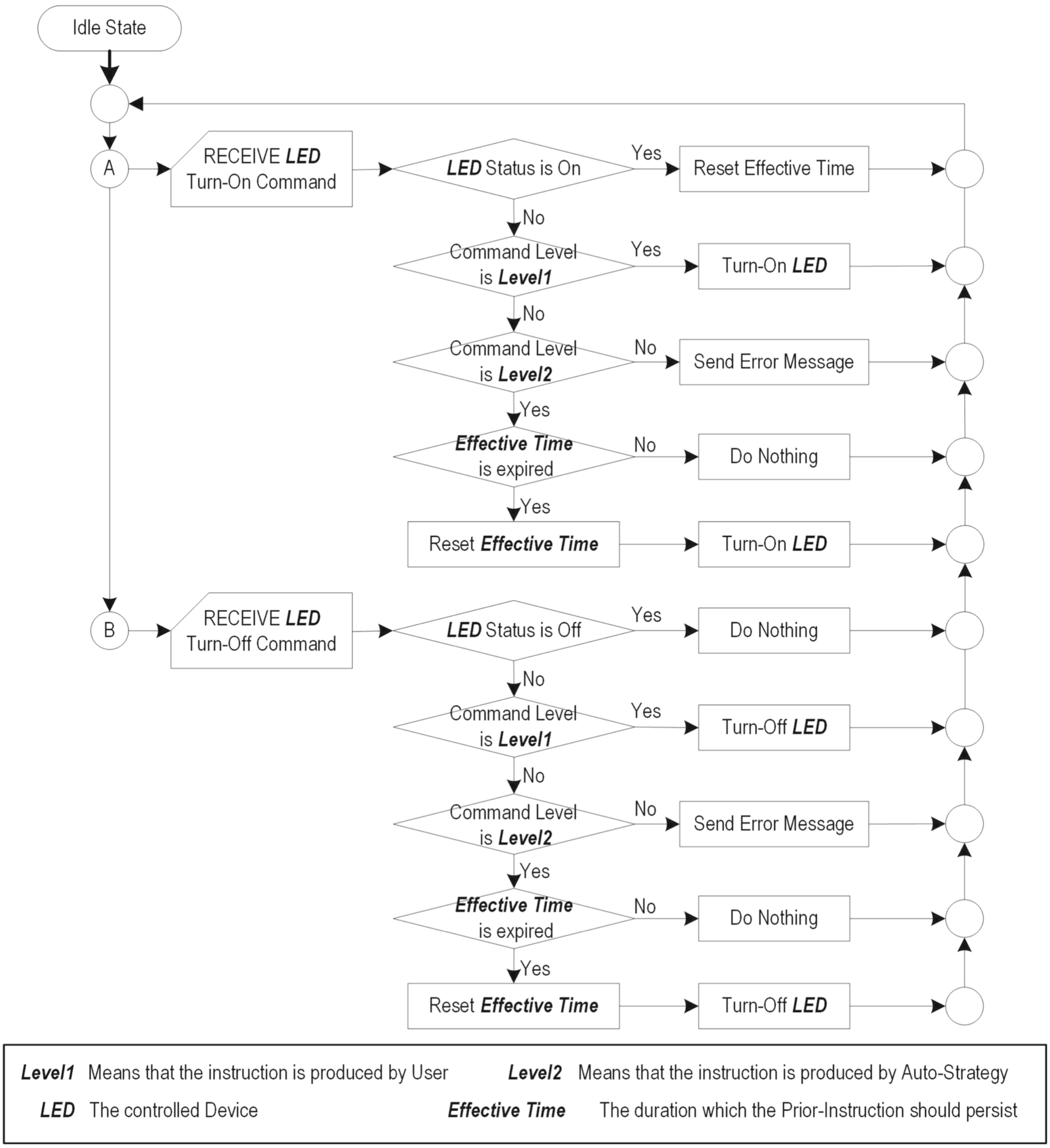


Fig. 6 The controlling flowchart of LED

Table 3 shows the information of cultivating strategy, cultivation soil and fertilizers we have adopted also are presented. To the best of our knowledge, coldness and shadiness are suitable for cultivating KoreanGinseng, meanwhile, cultivation soil for KoreanGinseng must fulfil certain restrictions, i.e., high humus, high swelling, great ventilation and easy drainage. At last, coconut-shell-powder is adopted as the soil for KoreanGinseng cultivation because of its excellent qualification in all demands described above. As for fertilizer, we have adopted organic fertilizer, phosphorus, potassium, nitrogen and so on, which are all necessary for growth of KoreanGinseng. Fertilizer is mixed into coconut-shell-powder in accordance with a specific proportion.

Some essential factors related to growth of KoreanGinseng are recorded throughout the life cycle of KoreanGinseng. Fro the beginning (February 25) to end (June 22), four factors, i.e., temperature , illumination, height of KoreanGinseng as well as growth rate of KoreanGinseng, are recorded consistently. Detail information are illustrated in Fig. 7, which shows 4 curves varied with time at intervals of 4-day. Figure 7a demonstrates how temperature varies with time, and it almost fluctuates between 15 °C and 19 °C. Meanwhile, as time goes by, there is a slight uptrend of

Table 3 Strategy of Cultivation

Greenery	KoreanGinseng		
Cultivation materials	Cultivation soil	Powder of coconut shell	
	Fertilizer	Organic fertilizer, phosphorus, potassium, nitrogen, etc	
Cultivation strategy	Humidity	40%–45%	
	Soil humidity	40%–60%	
	Soil PH	5.0–6.5	
	Illumination	0–2Week	1LX-5LX
		2Week–2Month	Daytime(07:00–23:00):35LX-50LX; Nighttime(23:00–07:00):1LX-5LX
		2Month–4Month	Daytime(07:00–23:00):55LX-60LX; Nighttime(23:00–07:00):1LX-5LX
	Temperature	0–2Week	Daytime(07:00–23:00):15 °C–17 °C; Nighttime(23:00–07:00):14 °C–15 °C
		2Week–4Month	Daytime(07:00–23:00):16 °C–19 °C; Nighttime(23:00–07:00):15 °C–16 °C

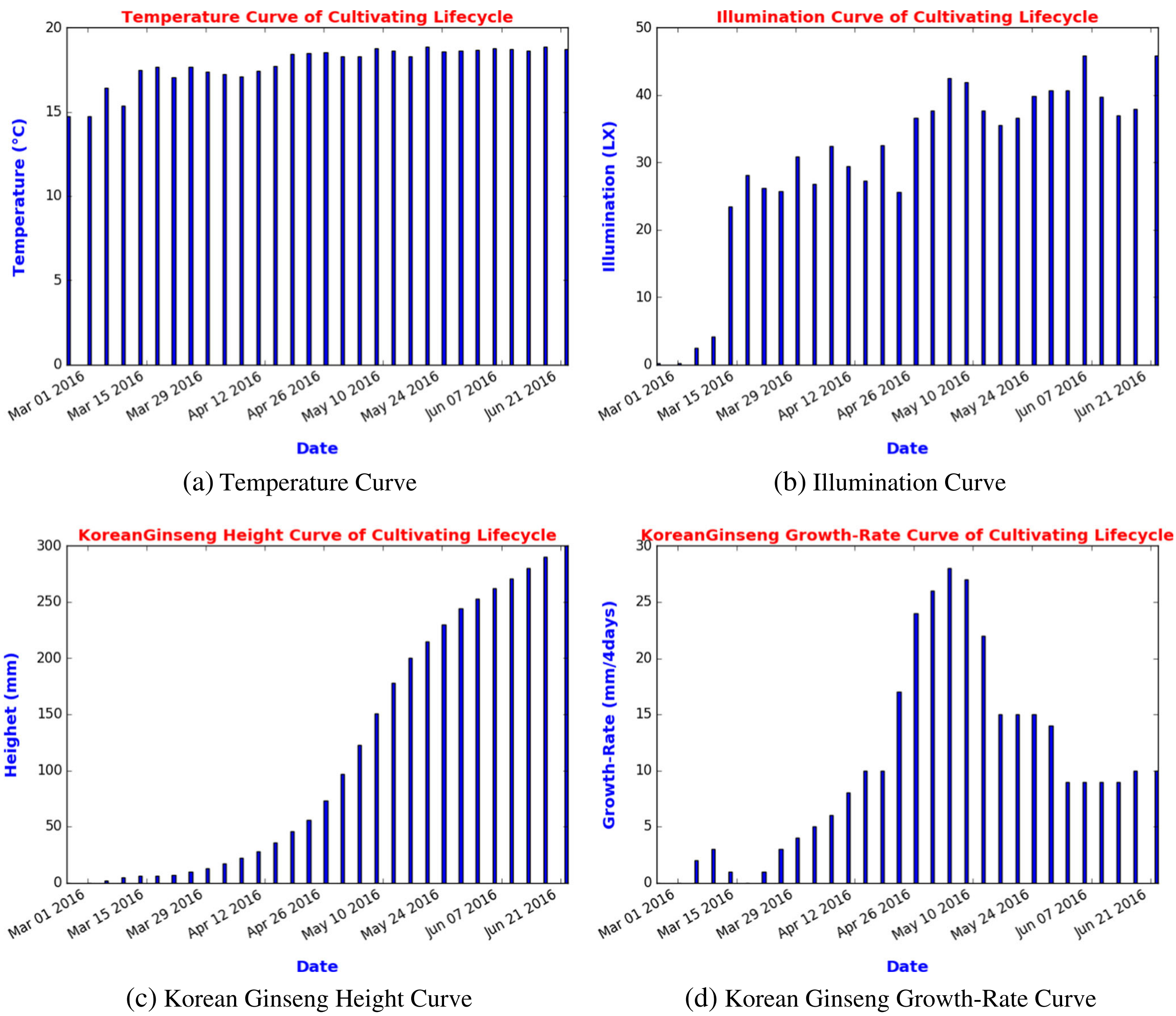
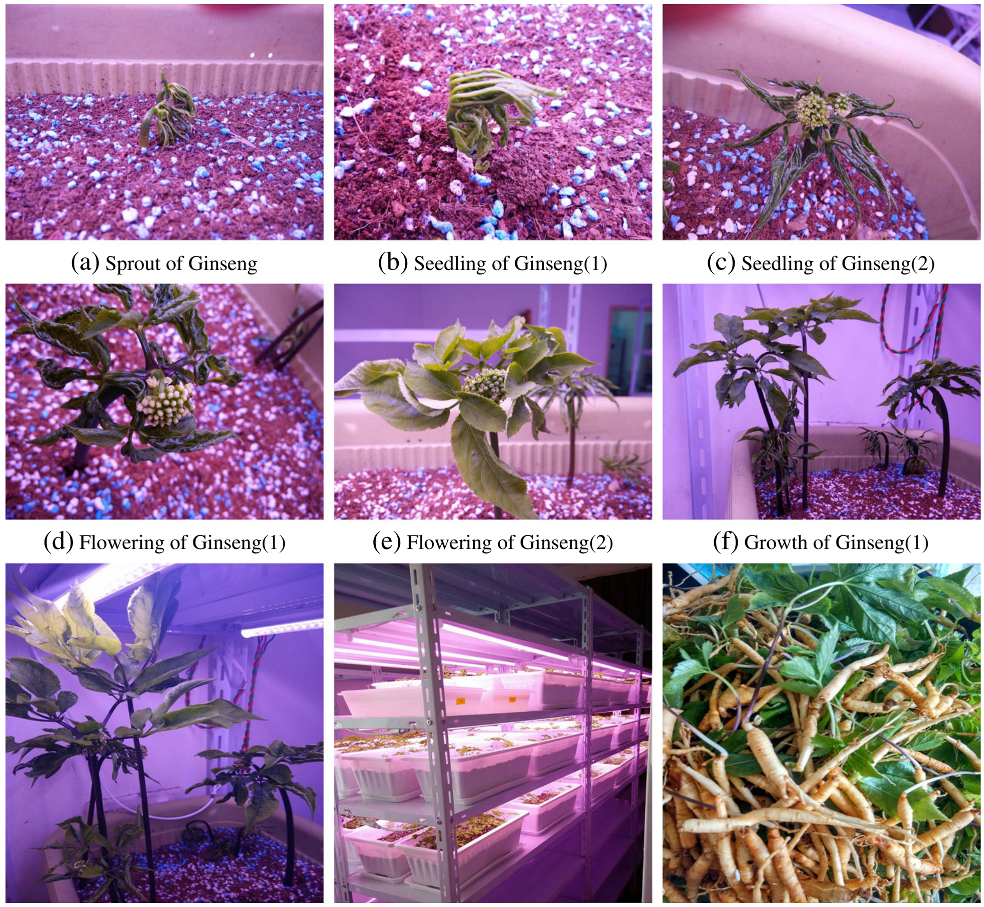


Fig. 7 Statistic data of KoreanGinseng cultivation

Fig. 8 Display of KoreanGinseng cultivation



(a) Sprout of Ginseng (b) Seedling of Ginseng(1) (c) Seedling of Ginseng(2) (d) Flowering of Ginseng(1) (e) Flowering of Ginseng(2) (f) Growth of Ginseng(1) (g) Growth of Ginseng(2) (h) Large Scale Cultivation for Baby Ginseng (i) Harvesting the Baby Ginseng

temperature. Figure 7b displays how illumination changes with time, obviously KoreanGinseng experiences non illumination at the first two weeks and is exposed to feeble illumination in previous weeks. Along with the growth of KoreanGinseng, the illumination intensity is gradually strengthened and finally stabilized within a certain range. Figure 7c reveals the height of KoreanGinseng throughout its life cycle, at first KoreanGinseng grows slowly, then gets into the rapid growing stage after more than one and a half months. Figure 7d presents the growth rate of Korean Ginseng, the increment of its height is recorded at intervals of 4-day, we find that the growth rate of KoreanGinseng gradually accelerated from the beginning, peaked in the time of two and a half months, then gradually decreased.

The growth cycle of KoreanGinseng in this experiment is shown in Fig. 8. KoreanGinseng only takes 4 months to mature in experimental environment compared with 2 years in nature environment due to strict control of environmental factors in indoor environment. Figure 8a shows the growth status of KoreanGinseng in two weeks; Fig. 8b and c show the growth status in 1 month, at this time, KoreanGinseng is in seedling status and has gradually grown out 5 or 6 leaves; Fig. 8d and e show the status in 2 months, then KoreanGinseng is in flowering stage; as shown in Fig. 8f and g, KoreanGinseng strides forward into growth stage, both roots and stems are growing fast; at last KoreanGinseng enters the mature stage in 4 month, meanwhile the root of KoreanGinseng has become ginseng-like. Figure 8h shows the large scale cultivation for Baby Ginsengs in our experiment, while Fig. 8i shows the harvesting of those Baby Ginsengs displayed in Fig. 8h after cultivating another 3 months.

6 Conclusion

In this paper, we propose a novel solution (Smart Home 2.0), in which users interconnect with home appliances and greeneries harmoniously. Users can enjoy wonderful life living with greeneries and smart appliances in indoor environment. As for construction of Smart Home 2.0, we emphatically discuss equipment deployment in indoor environment, explain the control strategies of equipments, and present how to build a automatic cultivating strategy for greenery. Then, we experimented with the cultivation of

Korean Ginseng in indoor environment to explore the feasible scheme of harmonious sharing indoor space between human and greeneries, which should be a precious reference for the establishment of Smart Home 2.0. However, the privacy and security of Smart Home 2.0 are not involved in this paper, there should be further work to achieve completeness of the solution. Furthermore, we need to design a advanced means to evaluate the improvement brought by Smart Home 2.0 in terms of users' quality of life.

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