Fusion of environmental monitoring components and gardening modules for manipulating indoor air quality

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Abstract. People who live in a crowded jungle of metropolis are easy getting stressed and extremely need relaxing activities, e.g. gardening. The considerations about limited space, busy day and scarce experience will stop people to take action on gardening. They do need a device to help them taking care of plant, a smart device which is able to remotely control would be popular to the business of interior planting. This demand encouraged many designers to create the modules for interior planting. It also pushes researchers to study how interior planting is able to capture particles, to absorb VOC, to transform CO₂, to change temperature and moisture. However, planting module with smart control of indoor air quality is rare until now. So we created an environmental manipulator in which environmental monitoring sensors, planting modules, and remote relays are fused together. This study described the process how we get the optimal design of environmental manipulator under a series of interviews based on Evaluation Grid Method (EGM).

1. Introduction
Indoor air quality is really a matter of some concern while people spends 80–90% of their time staying indoors [1]. This concern induced us to think about the possibility of purifying indoor air quality by planting and attracted many researchers to study the functions of capturing particles, absorbing VOC, transforming CO₂, changing temperature and moisture by plants. Abhijith and Gokhale proposed medium-size trees with high porosity and low-stand density together with parallel and perpendicular car parking systems as the best passive controls in reduction of pedestrian exposure to the vehicle emission [2]. Tong, et al. proved the aerodynamics as more important than the deposition to impact the local concentration of airborne particulates [3]. So barriers should be high enough and porous enough to let the air through [4]. Jeanjean, et al. found that the aerodynamic dispersive effect of trees has a bigger effect on reducing PM2.5 concentrations than the deposition on trees and the deposition on grass [5]. Baldauf summarized how the height, thickness, coverage, porosity/density, and specie s of roadside vegetation affect air quality [6]. Yli-Pelkonen, et al. confirmed air particulate pollution can be reduced by urban vegetation [7]. Although those low-level hedges had some improvement of air quality in a street canyon environment, high-level trees led to a deterioration of air quality in such an environment. In the open road environments, wide, low porosity and tall vegetation could reduce the downwind pollutant but high porosity vegetation could even deteriorated air quality [8]. Obviously it would be no use in the reduction of air pollution if we adopt the wrong way to plant. Although gardening is one of the most popular activities in life, the considerations about limited space, busy day and scarce experience will stop people to take action on gardening. They do need a device to help them taking care of plant, a smart device which is able to remotely control would be popular to the business of interior planting. How to get an optimal design of interior planting modules? It is deeply
attractive to our attention for a long time. As more and more manufacturers are adopting a consumer-centric philosophy, it poses designers the challenge of developing differentiating products in a context of constant innovation and competitiveness [9]. Miryoku engineering is capable of evaluating the result of interaction between people and products. It does not only evaluate interactive methods, but also consider the human initiative emotions [10]. Evaluation grid method (EGM) is the core research method of Miryoku engineering [11]. Imai and Kawamura used the EGM to identify the model of a desirable bookstore from the point of view of users and successfully helped bookstores to improve their services [12]. Shen interviewed eleven experts by the EGM to determine the semantic structure of attractiveness from the interviews of experts and summarized the hierarchy of the relationship between the types of appeal or appeal factors, the reasons for users’ preferences, and specific characteristics of crossover car interior [13]. The above references convinced us the EGM as a useful way to the optimal design of object.

Right now service integrated with ICT technologies has become a trend, the smart greenhouse market was estimated to grow from USD 1.26 Billion in 2018 to 2.28 Billion by 2023 [14]. In Taiwan, the planting service for building and office has increased 17% during only five years from 2006 to 2011 and the whole planting industry reached the scale of 5075 companies in 2011. The above messages outline a trend on increasing expert service of interior planting. It gives the environmental industry a chance to promote its business model. Any firm who is able to extract valuable information from mega data collecting in environment will own a better chance of surviving in competition of business. J.S. is a ICT company with environmental monitoring service and ESCO service. A team including the experts of environmental monitoring, sensor, information technology and industrial design was organized to assist J.S. to extend their business into smart home. Under a three-years grant supported by MOST in Taiwan, we have been creating the environmental manipulator in which environmental monitoring sensors, planting modules, and remote relays are fused together. Based on EGM, we carried out a series of interviews to judge which parts of environmental manipulator should be reserved for the future design.

2. Optimal design of environmental manipulator

In order to meet the demands of remotely taking care of plant and purifying indoor air quality simultaneously, we create the environmental manipulator. Figure 1 introduces the procedure how we get the optimal design of environmental manipulator.

| Sketch out the application | Feedback and revision |
|----------------------------|-----------------------|
| To image which kind of gardening object we need. | To judge which parts be reserved for the next fusion |

| Preparation of elements | Interviews based on EGM | Fusion of elements |
|-------------------------|-------------------------|-------------------|
| User interface           | In-depth interview and summarize the participant’s requirements to the object | To create a gardening object by integrating elements in different way |
| Communication way        |                         |                   |
| Remote control           |                         |                   |
| Monitoring component     |                         |                   |
| Power supply             |                         |                   |
| Light                    |                         |                   |
| Watering device…         |                         |                   |

Figure 1. The flow of optimizing the design of environmental manipulator.

2.1. Sketch out the application

This study supposed that the gardening object will be placed in the living room. The VitalAir which fuses the concept of Feng Shui into air cleaner is a patent owned by J.S. company. The light of VitalAir not only supports the photosynthesis of plants but also brightens the room. It inspired us to sketch the
2.2. Preparation of elements
Any popular gardening activities must be easy to getting started. So we designed a web page to let the users remotely take care of plant via mobile device, e.g. smart phone. This web page was built by Microsoft C# and was linked with MSSQL service in cloud server. We also created a program to implement the order from remote control. The messages sent by different elements will be exchanged via the wireless communication. All the elements in this study were operated by power supply of 5-12V.

2.3. Fusion of elements
Next we used 3D printer to shape up the parts of new gardening object. More than one hundred 3D parts of environmental manipulator were created in this study but only less than twenty of them were kept in the subsequent fusion. The fusion of elements includes the jobs of assembling, wiring and testing the remote control. Every object was equipped with power circuit, control circuit and communication circuit.

2.4. Interview based on EGM
Evaluation Grid Method (EGM) is a semi-structured interview method modified by the repertory grid method which was developed Kelly [15]. The interviewee in EGM will be asked the reasons of why an object is more preferable to others recurrently, and then together with leading questions, as a result each participant's requirements to the object are elicited structurally as an evaluation hierarchical map. Finally, we compiled the personal evaluation hierarchical maps of all the participants and calculated the number of overlapped evaluations to plot an integrated evaluation hierarchical map. Such a map does effectively systemize data obtained from in-depth interview and accurately reflects product’s attractiveness. Overall EGM is able to avoid the influence of subjectivity from few decision makers. The procedure of EGM was divided into the following steps:

1. Function description: At first we will make a short introduction and display how it work.
2. Identification of original evaluation: The participants will be asked to propose their perspectives of “satisfied/dissatisfied” or “most preferred/least preferred” about our design. These perspectives are the original conditions.
3. Extension of original evaluation: Meet every participant in a personal way. Then induce them to propose the abstract psychological perceptions and to describe the concrete features or reasons with respect to their original conditions identified in Step 2. Subsequently, the three hierarchical levels of each evaluation item can be identified: the abstract perceptions, the original conditions, and the concrete features or reasons.
4. Formation of a personal evaluation hierarchical map: Repeatedly conduct Steps 2 and 3 on all evaluation items provided by participants, and compile all the evaluation items into a three-layer hierarchy to form a personal evaluation hierarchical map.
5. Organization of an overall evaluation hierarchical map: Compile the personal evaluation hierarchical maps of all the participants and calculate the number of overlapped evaluations to plot an overall evaluation hierarchical map.

2.5. Feedback and revision
The messages extracted from evaluation hierarchical map will guide us to revise the original design. In this study, we did a major revise on the design of environmental manipulator.

3. Results and discussion

3.1. Evolution of the design
Through an evolution, the look and structure of gardening object has been adjusted as shown in Figure 2. The VitalAir gave us an original image of environmental manipulator and inspired us to design EM1 as the shape of a desk lamp for the application of interior planting, and finally EM2 became a combination of three modules in which every module was assigned a specific function. The way of
cleaning air in VitalAir is to spray water in a chamber, but the EM1 and EM2 catch air pollutants by forming a screen of waterfall. The upper part of EM1 is the area of air monitoring and its lower part is a water tank. In order to enhance the efficiency of air purifying in EM2, the spaces of air purifying area, planting area and water tank were enlarged and separated into different modules.

Figure 2. The steps of evolution in design.

3.2. Development of environmental monitoring components
We developed two ways of communication to monitoring the environmental quality. The temperature, humidity, CO2, pm 2.5 and VOC were continuously measured and recorded in the cloud server. Figure 3 displays the procedure of measuring indoor air quality by AirBox, transferring the monitoring signals as the protocol of Modbus/TCP by a Signal Conditioning Module and uploading the monitoring data to the cloud server by Zigbee communication. We adopted the induSoft Web Studio® to create the HMI platform capable of allowing user to control environmental manipulator by the mobile device. This communication way is able to handle multiple components in a long distance but is not able to fuse all the components into one object because the size and shape of component is fixed. So we developed another communication way as shown in Figure 4. All the monitoring components were combined with Arduino. Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino sensed the environment by receiving inputs from different sensor and adjusted the operating state of EM2 via Bluetooth communication.

Figure 3. The monitoring system with Zigbee communication.
3.3. Evaluation by EGM

We received many responses through a series of interviews and organized them into three-layer hierarchical diagram as figure 5. Four original conditions were extracted and connected with the abstract perceptions, the concrete features and the concrete reasons answered by the respondents. At the layer of perceptions, the shape of object is the original condition of greatest concern. That means the design of shape is of critical to catch the buyer’s attention. At the layer of concrete features and reasons, the function of object replaces the shape to be the top concern. That means the buyer might not take action until he or she satisfy the design of function. Many negative reasons happened in the item of efficiency because the environmental manipulator we created was still in the development. There are not enough messages to verify its efficiency of purifying indoor air quality. This problem will be omitted once we finish all the experiments of purifying indoor air quality. We also found that the cost of object was not the major concern in these interviews. That means only a few buyers are not afforded to buy our environmental manipulator. This finding encourage us to pursue a good design on the shape, the function and the efficiency of environmental manipulator.

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**Figure 4.** The fusion of air monitoring components and gardening module.

**Figure 5.** Three-layer hierarchical diagram based on in-depth interview of EGM.
4. Conclusion
Based on the interviews of EGM, we are able to judge which parts of environmental manipulator should be reserved for the future design. The design of shape is of critical to catch the buyer’s attention. But the buyer might not take action until he or she satisfy the design of function. We also found that the cost of object was not the major concern in these interviews. That means only a few buyers are not afforded to buy our environmental manipulator. This finding encourage us to pursue a good design on the shape, the function and the efficiency of environmental manipulator. In order to enhance the efficiency of air purifying, the spaces of air purifying area, planting area and water tank were enlarged and separated into different modules as EM2.

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