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Design and development of an intelligent irrigation system for Thailand: a Kansei Engineering based approach

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Abstract

Recent advancements of the Thailand 4.0 model use a knowledge-based economy for sustainable development with high importance given to proper water management. The application of Kansei Engineering on the design and development of an irrigation system will provide an innovative solution to improving the model. This research study focuses on the design and development of an intelligent irrigation system to satisfy customer requirements using Kansei Engineering. Kansei Engineering is used to capture and translate consumer perceptions to be elements of the design. This research classifies Kansei words using statistical analysis and the influential Kansei words are considered as the basic layout to design and develop an intelligent irrigation system. The developed intelligent system incorporates a control module using a microcontroller with different sensors to monitor environmental parameters as well as a ring-shaped emitter to directly provide water to plant roots. The results ensure that the influential factors of consumer needs include physical appearance, feasibility and operational performance factors. The developed system provides an opportunity for urban residents to create green areas in their limited living space as the implemented system in Thailand recorded and displayed productive results in diverse environmental conditions. Further, this research study can be used to minimize the additional cost of water wastage from natural sources and storage tanks and thus, develop an effective water management system.

Keywords: Intelligent irrigation system, Customer preference, Kansei Engineering, Automation.

1. Introduction

Initiating the development of a successful product requires understanding of user demands, preferences and inclination rates towards the product. Brilhuis-Meijer et al. [1] and Racela et al. [2] discuss the influence of the product development process (PDD) on products in terms of new technologies in their research study. The characteristics and specifications of product designs are generally developed with consideration to the needs of the customers while the finished product necessitates the ability to work with a minimum workload. Figure 1 shows the concept of design and development of a product cycle.

A recent study on water management [3] in Thailand indicates that at present, Thailand consumes 90.4% of its fresh water for agricultural activities, while upper-middle- and high-income countries consume only 67.8% and 40.8% respectively. According to Foster et al. [4] efficient water management plays a main role in the irrigated agricultural cropping systems. Thus, it is important to improve the existing irrigation system in Thailand. Most of the problems facing irrigation practices were solved by adopting intelligent irrigation controllers [5-6]. Further, Kponyo et al. [7] focuses on reading the moisture content of the soil. These research studies focus only on the technical aspects and not the preference, needs and requirements of the customers in the designs during product development. Nevertheless, it is important to consider the requirements from the users for an effective implementation of any product.

Nagamachi [8] describes Kansei Engineering as an effective methodology to study the cause-and-effect relationship between product features and the affective responses of users. The application of Kansei Engineering quickly and accurately translates the perceptions of the users towards a product into tangible requirements of the design element. Kansei Engineering is a valuable method of connecting the affective responses of customers to the design process of products. In addition, Nagamachi [9] presents the ability of the method to translate the impressions of customers for a certain product into product specifications.

Vieira et al. [10] presents five types of Kansei Engineering procedures, such as Type I, II, III, Hybrid and virtual while Schutte et al. [11] adapted Type I procedures in his study on category classification. This is the simplest and fastest way to analyze the targeted concept of new products to subjective Kansei words. Various researches [12-14] use Kansei Engineering in their research study to translate the psychological feelings of customers into the domain of product design by identifying engineering parameters on the proposed product to design solutions using the sematic differential technique.

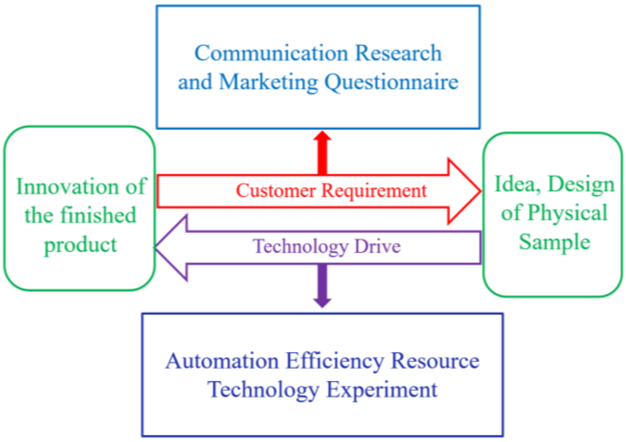

Figure 1 Concept of design and development of the product cycle.

The Kansei words are given in two antonyms for proposing the mind image of a product. (i.e., good-bad or cheap-expensive) The number of choices between the two words is flexible in Kansei Engineering, and can be presented in a Likert-scale style [15]. In general, the step span of the semantic differences is used in the initialization of desiring a domain [16]. Secondly, the number of words is reduced to an acceptable level using various product development tools and the data is compiled to facilitate the synthesis phase.

Campbell et al. [17] in his study presents self-administered questionnaires by presenting the specifications of the desired product as easily answerable questions with simple words. Users who live in and around the metropolitan area of Thailand including Pathumthani, Nothanburi, Bangkok and Ayutthaya provinces are selected as target groups and questionnaires focusing on the perceptions of the users regarding the irrigation of plants are distributed. An innovative design is developed as a solution based on the responses from users using existing tools of product design and development.

Kulatunga et al. [18] apply various strategies to analyze new designs in terms of existing systems. Nevertheless, in addition to the requirements from the customers, it is crucial to examine unpredictable conditions of the environment including water scarcity and the nature of the soil before and after planting certain crops. Thus, an intelligent irrigation system with efficient water distribution and good performance is required in developing countries. This research study focuses on the application of Kansei Engineering as a tool to design and develop an effective irrigation system. The novelty of this research study relies on revealing and capturing the preferences of the customer on ring irrigation systems to incorporate into an intelligent irrigation system. It also considers various environmental parameters for water management and plant growth at an affordable price.

2. Materials and methods

The research is divided into major steps including collecting data using questionnaires from people with relevant experiences, applying Kansei Engineering to obtain the product adjectives and functions, applying factor analysis to investigate the proposed Kansei words and finally by specifying the most important factors as the original model to create a system which provides customer satisfaction. Based on the responses from Kansei words, an intelligent irrigation system is designed and developed. The implemented system is tested for performance and the satisfaction rates of the customers are recorded as the final step of the research study.

2.1 Application of Kansei Engineering

The method used in Kansei Engineering type I is as follows:

a. Collected data from respondents: The respondents are the potential customers who agreed on the understanding of Kansei words.
b. Feasibility testing of questionnaire: The collected data is analyzed using the reliability and validity tests.
c. Factor analysis for Kansei words: Using statistical analysis techniques, the collected data is processed with factor analysis and SPSS 24.0 software to determine the relationship between words and combinations of Kansei words with the design elements.

Kansei Engineering Type I using Kansei words is applied to determine consumer preferences for the product design elements and Figure 2 presents a flowchart of the proposed approach.

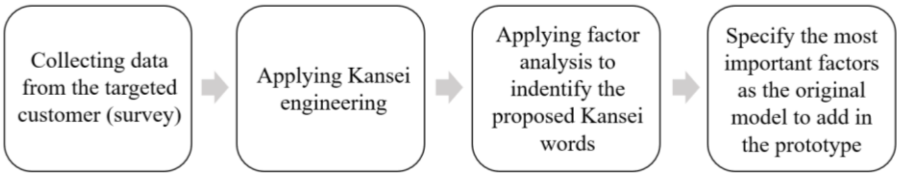

Figure 2 Flow chart of the proposed approach.

Kansei words from 54 respondents who have enough experience of designed functions and planting are identified using the questionnaire with Kansei words to understand the requirements of the physical design specifications of the product. The list of selected Kansei words and their definitions are tabulated in Table 1.

Table 1 List of selected Kansei words and definitions.

Kansei words	Description
Small	Having a comparatively small size (Dimension 20x10x8 cm)
Big	Having a large size (Dimension 50x25x15 cm)
Specific	Restricted to a particular and small area (Pot plant or home gardening)
Various	Inclined assorted and big area (Estate and farming field)
Powerless	Having a slow power of water flow (Small pump for feeding water)
Powerful	Having a great power of water flow (Big pump for feeding water)
Manual	Requiring physical skill and energy
Automatic	Having a self-acting mechanism
Uninformative	No information about the device
Informative	Imparting knowledge about the device
Unthrifty water	Extravagant water
Thrifty water	Optimizing water
Plain	Coloured housing
Patterned	Multicolored housing
Affordable	Having a cost that is not too high (cheap)*
Expensive	Involving high cost or expense
Scattered	Irregular distribution of cable and components
Tidy	Neat and orderly in appearance
Simple	Readily understood, performed or operated; easy-to-access
Complex	Made up of expanded or interrelated parts for operation
Manual mode	Applying manual emergency stop switch
Automatic mode	Self-acting mechanism to prevent inadvertent or hazardous operation
Connected	The supported component is connected directly to the machine
Arrangeable	Easy to plug in/off the supported component with the machine
Embedded	Device immoveable after assembly
Portable	Device is movable
Easy-to-access	Not requiring a key lock in the device for simplicity
Highly secured	Requiring a key lock to open the device

*Thailand average monthly wages 2017 is 13,620 THB (Trading economic, 2017). Cheap is the price of the product, if it is not more than 10% of the average wage or not more than 3,000 THB, otherwise is expensive.

At the stage of Kansei words collection, 16 words which consist of product functions specification and customer feelings on product design are chosen. The possible adjective words related to ring irrigation systems are collected and with the scale of preference of a 7-point sematic differential as shown in Figure 3, the words are evaluated. Each Kansei word is evaluated to achieve a function. Factor analysis is used to determine the number of words where customer's needs are applied as the main criteria for creating the correlation between proposed design and customer requirements. The data obtained from the questionnaires which use the 7-point sematic scale are tested using factor analysis by using Kaiser Meyer Olkin (KMO) and Bartlett's test. The average number of times 54 participants used the selected Kansei words are analyzed using factor analysis and the results are used as design factors in selecting the components and developing the irrigation system.

2.2 Intelligent irrigation system

The major part of the developed irrigation system design is the automatic irrigation module which includes a micro irrigation system of a ring which is placed at the subsurface of the soil to directly water the plant. A schematic flowchart of variable rate irrigation is shown in Figure 4.

Like More				**Neutral**				**Like More**
Small	3	2	1	0	1	2	3	Big
Specific	3	2	1	0	1	2	3	Various
Powerless	3	2	1	0	1	2	3	Powerful
Manual	3	2	1	0	1	2	3	automatic
Uninformative	3	2	1	0	1	2	3	informative
Unthrifty water	3	2	1	0	1	2	3	Thrifty water
Plain	3	2	1	0	1	2	3	Patterned
Expensive	3	2	1	0	1	2	3	Affordable
Scattered	3	2	1	0	1	2	3	Tidy
Simple	3	2	1	0	1	2	3	Complex
Manual safety device	3	2	1	0	1	2	3	Automatic safety device
Connected	3	2	1	0	1	2	3	Arrangeable
Embedded	3	2	1	0	1	2	3	Portable
Easy-to-access	3	2	1	0	1	2	3	Highly secured

Figure 3 7-point sematic differential scale of Kansei words.

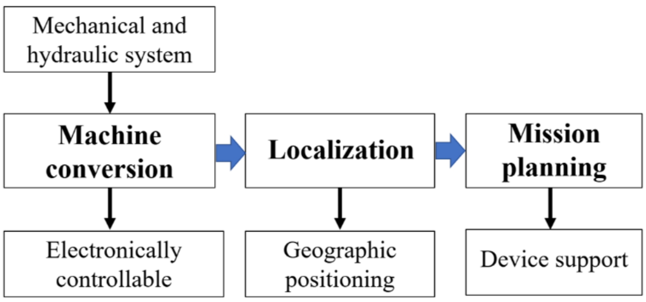

Figure 4 Schematic flowchart variable-rate irrigation of the developed system.

The schematic flowchart consists of the machine conversion, localization in terms of geographic positioning and mission planning. The irrigation systems of developing countries are in general mechanical and hydraulic systems. The existing system is changed into an electronic system since controllable conditions are required for the developed individual ring-shaped emitter controllers to perform effectively. The irrigation system is developed as an intelligent system with accessible and controllable geographical positioning in addition, to an automatic identification and recording system of soil condition, temperature parameters and the intensity of light.

The system uses an Arduino Uno microcontroller as a controller for the system with 12V switching supply, a 12V water pump and a relay module for operation. In addition, the system is inbuilt with a soil moisture sensor (LM393), Negative Temperature Coefficient (NTC) thermistor temperature module, Light Dependent Resistor (LDR) photo resistor sensor module, real time clock and a Liquid Crystal Display (LCD) to display information. The system has a plastic casing. The overall cost of the developed hardware system is $75. Mission planning includes the time duration of water flow with respect to the condition of the soil. Furthermore, the system updates the instructions for watering procedures with monitoring of environmental parameters using the sensors distributed across the field.

The developed system device is utilized with the ring-shaped emitter to support water optimization. The proposed ring-shaped emitter employs principles of the permeation systems from the porous material covering the ring-shaped emitter. Conventionally, the subsurface irrigation uses long pipe without considering the porous material. In the existing systems, most of the required water either drops down directly or permeates in a wider area. The ring-shaped emitter version supported with the porous material is buried in the subsurface and root zone area for minimizing evaporation with the effective transfer of water using the permeation system.

In this research, the emitter design has the ring shape that can be placed under the soil to support the utilization of dry land. The proposed ring emitter is developed by using the integration concepts in micro irrigation, subsurface irrigation and watering potted plants where the water is emitted in the ring-like spraying subsurface direction. The soil condition is identified by the sensors as an initial step for proper preparation for cultivation. Water is discharged from the circle-shaped emitter and passes through the semi permeable membrane or material with the small discharge; only a certain amount of water is sprayed to maintain the humidity in the soil.

The performance of the emitter in this research is the ability of the emitter to provide water according to the soil type and semi permeable material which covers the ring-shaped emitter. The analyzing of water permeability in the soil is provided using the constant head test and falling head test for semi permeable material. This innovation is derived for addressing in the potted plants to substantiate the sustenance of agricultural practiced by a small and marginal farmer.

Conventional irrigation machines require conversion to adjust to field-based irrigation control variables. From the developed design, the results including temperature, soil moisture and water pump output volume can be interpreted. The relationship between temperature (T) and generated voltage (V) is shown in Eq. (1) with which minimum and maximum values are considered as in Eq. (2) and Eq. (3) respectively where m is transfer function and c is intercept.

$$T = (V \times m) + c \tag{1}$$
$$Low\ state\ of\ 50 = (0.25 \times m) + c \tag{2}$$
$$High\ state\ of\ 150 = (4.75 \times m) + c \tag{3}$$

The generalized linear equation for temperature is thus given in Eq. (4). Similarly considering the low state and high state values, the generalized equation for water output is given in Eq. (5).

$$T = (V \times 22.2) + 44.4 \tag{4}$$
$$Water\ Output = (V \times 128.57) + 857.14 \tag{5}$$

The water output is adjustable for the purpose of increasing and decreasing the amount by changing the voltage value. Since initial conditions are not always easy to interpret, the temperature sensor is compared with the allied tools including the infrared and mercurial thermometers.

Considering the objects of interest for measuring as cold and warm water, the precision of the thermometer sensor is checked with simultaneous sensor recording with the infrared and mercurial thermometers and the generated results using various thermometers are shown in Table 2.

Table 2 Temperature measurements using various thermometers.

Measuring tools	Cool water (˚C)	Warm water (˚C)
Thermometer sensor	18.40 – 19.75	49.2 – 51.0
Infrared thermometer	18.0 – 21.9	49.8 – 52.4
Mercurial thermometer	17.2 – 17.9	51.0 – 51.1

3. Results

The research study indicates 3-factor axes of importance as physical factors, information factors and performance factors for the development of the product based on consumer requirements. Table 3 shows the most highly preferred Kansei words related to the considered factors. Accordingly, a system is developed with restriction to a maximum size of 20x10x8 cm with a small pump of a maximum capacity of 2.4 l/min to support potted plants as requested by the words ‘small’, ‘specific’ and ‘powerless’ by the users. Additionally, the physical appearance of the system is compact and with secure protection due to the selection of words such as ‘tidy’ and ‘highly secured’ by the users. These words are considered as physical factors for the system.

Table 3 Preferred Kansei words and corresponding major factors.

Major factors	Preferred Kansei words	
Physical factors	Small	Powerless
	Specific	Tidy
	Arrange-able	Highly secured
Feasibility factors	Informative	Affordable
	Complex	Portable
Operational factors	Automatic	Thrifty water

Words including ‘Informative’, ‘Affordable’, ‘Complex’ and ‘Portable’ are described as feasibility factors even though the way they are developed are influenced by designing of the physical systems. The design thus, incorporates a digital LCD screen for quick and easy access of sensor performance with informative details as shown in Figure 5. The intelligent irrigation system is controlled by an Arduino Uno microcontroller with a ring shaped emitter for optimized water supply as an affordable and portable solution. Initial environmental conditions are recorded and a greenhouse environment is developed with plastic plate on an iron pipe frame as an inexpensive form of environmental control and the system is designed to incorporate interrelated controller and operation sensors that measure environmental parameters including moisture and temperature. The system is designed as an autonomous solution which optimizes water flow with the users prioritizing the words ‘Automatic and ‘Thrifty Water’.

Choy Sum (Brassica rapa subsp. parachinensis) aged 12-14 d after sprouting from the seed in the seedling media is used in irrigation system analysis. Field conditions including the type of soil, humidity of the soil, light intensity and temperature around the planting area are recorded in real time conditions.

The ring-shaped emitter is designed as in Figure 6 for effective water flow rate around the root zones with an internal diameter of 16mm and inlet and outlet holes of 5 mm. A fabric material is installed as coating for the tube to control the flow of water out of the container to the wall of the emitter and soil. The emitter delivers only a few quarts of water per hour. The area which is covered by the emitter depends on the amount of flow, soil type, soil moisture, and vertical and horizontal soil permeability.

The ring emitter provides water by discharging water through the wall of the emitter developed with porous material. Thus, according to the equilibrium conditions of water in the soil and in the porous material, the water will drain. The water inside the emitter is circulated in a circle around the roots of the plant to obtain optimal wetting results so that water can reach the root area quickly and uniformly increasing the efficiency of the performance.

The developed intelligent irrigation system using Kansei Engineering is shown in Figure 7. The irrigation activities are initiated by the sensing of a required level of dryness based on the data from the soil moisture sensor. Once the soil is in dry state, water is released from the tank directly to the root via the ring-shaped emitter.

The field experiment results from the soil moisture sensor and the light and temperature sensors are recorded. The moisture sensor is the major unit to understand the soil condition and placed at the center of root area. The sensor detects the initial water content in the soil, dryness level for cultivation and input data on water flow. The recorded data of the light and temperature sensors from the moisture sensor is shown in Figure 8 and Figure 9 respectively.

Water that seeps out of the emitter through a porous material wall and distributed into the soil fills the soil pores according to the soil moisture potential and soil hydraulic conductivity. Seepage on the walls of the ring emitter porous material is the most important performance aspect of the ring irrigation system, as it will determine the crops water requirement and the efficient use of irrigation water.

The result of the measurement of emitter wall seepage shows the rate of seepage and that the accumulation of seepage is influenced by the physical condition of the soil around the ring emitter. The ability of porous ring emitter walls to respond to changes in soil moisture can supply water in accordance with the water requirements of plants. If the evapotranspiration is high then the seepage rate will increase. Thus, the ring emitter system can provide an effective water supply and minimize water wastage. The emitter inside a pot without a plant is tested in three selected planting media which come from the same mixing soil for the convenience of analyzing data.

The seedlings of Choy-sum leaves with an initial withered appearance is observed to be fresh after two d in the new media as it adapted to the new environment during the first stage of the initial ten d, slight growth is observed whereas later, during the second stage (11-20 d), seedling leaves are replaced by real leaves and during the third stage (21-30 d) displayed a fast growth towards harvest. The performance results are tabulated in Table 6.

Table 4 Results of a withered Choy-sum plant with an intelligent irrigation system.

Stages of experiment	Soil type	Average temperature (˚C)	No. of d in the new media	Observation
(Stage 1)	Dry soil	29	10	Fresh appearance in 2 d Slight growth in 10 d
(Stage 2)	Dry-wet soil	34	20	Seedling leaves are replaced by real leaves
(Stage 3)	Wet soil	32	30	Fast growth towards harvest

Figure 5 LCD display with informative details.

Figure 6 The developed ring-shaped emitter based on Kansei Engineering.

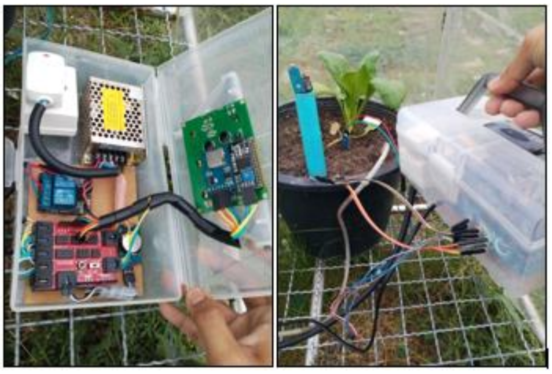

Figure 7 The developed portable intelligent irrigation system.

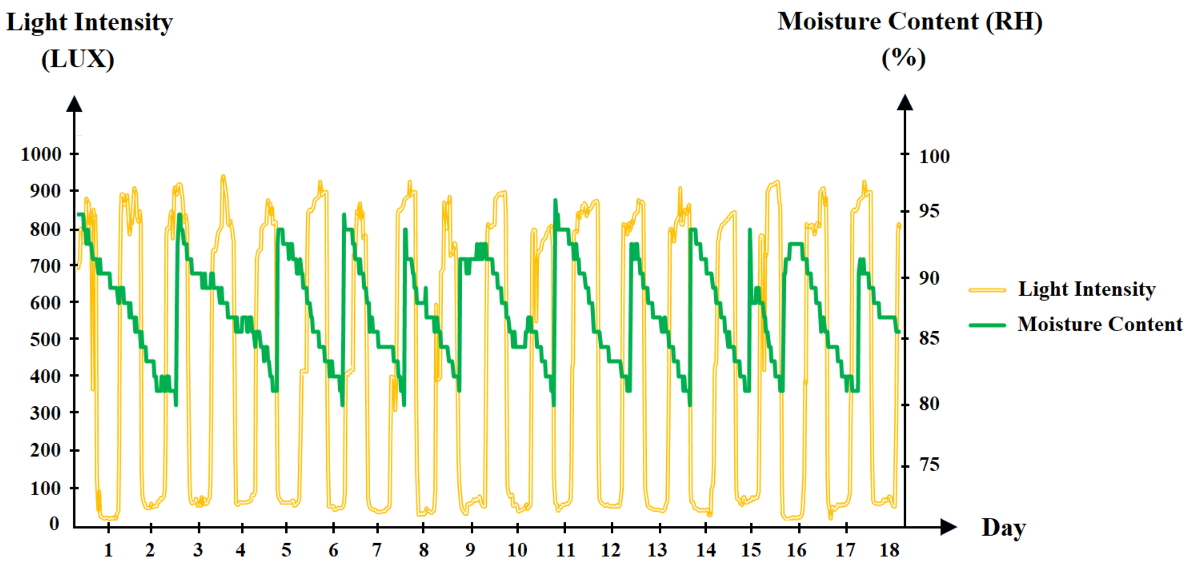

Figure 8 Experimental results from the light and moisture sensor.

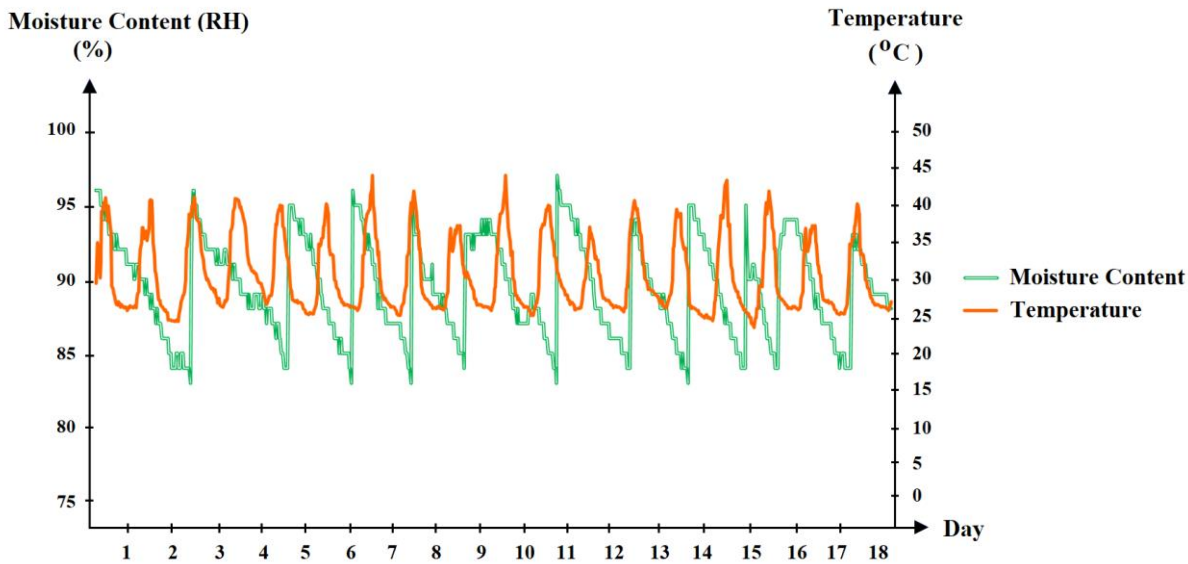

Figure 9 Experimental results from the temperature and moisture sensor.

The analyzed results of the irrigation system show the growth of a plant with 12 leaves, 31.3 cm in height and a weight of 195.6 g. The irrigation time schedule of the system is highly effective. The highest level of the soil humidity was at the beginning after the device released water into the soil which is 94% of the soil humidity while the lowest level is 79% of soil humidity at which point the controller waters the plant automatically. Furthermore, evaporation during the summer season is high with the environmental conditions of Pathumthani province where the experiments were done. The developed system can minimize evaporation while increasing the water content on the leaves. Most of the tropical countries in Asia have similar weather condition and thus, an opportunity to use the developed system is considered as the contribution of this research study. The product received a 93% positive satisfaction rate among the users while there were considerable expectations to improve the physical appearance of the system to an artistic model with various colors and patterns which were not requested during the initial stage of classification. Nevertheless, the users were satisfied with the operational condition of the system.

4. Discussion

A questionnaire was designed using 16 Kansei words related to an irrigation system. Each Kansei word is evaluated to achieve a function. The data was obtained from the questionnaire which was distributed among 54 experienced users from various provinces and tested using the Kaiser Meyer Olkin (KMO) test and Bartlett's test.

Initially, the average number of times each participant used a selected Kansei word is analyzed using factor analysis. Table 5 shows that the value of KMO test is 0.636 whereas the Bartlett's test is nearly 0.

Table 5 KMO and Bartlett test results.

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy		0.636
Bartlett's test of sphericity	Approx. chi-square	113.209
	Difference	66
	Significance	.000

Results from the KMO test is more than 0.5. The calculation result from Bartlett's Test of sphericity is 113.209 with a significance of 0.00017. Thus, Bartlett's sphericity test meets the requirements due to significance below $0.05\ (5\%)$. According to principal component analysis, three elements with an eigenvalue exceeding 1 are thus extracted. The rapid steepness of the extracted data indicates that there are three major factors to consider and the analysis is shown as a screen plot generation in Figure 10. The proportion of variance of each variable is calculated using the Eq. (6).

$$\%\ of\ Variance = \frac{Initial\ Eigen\ Values}{Total\ number\ of\ Components} \quad (6)$$

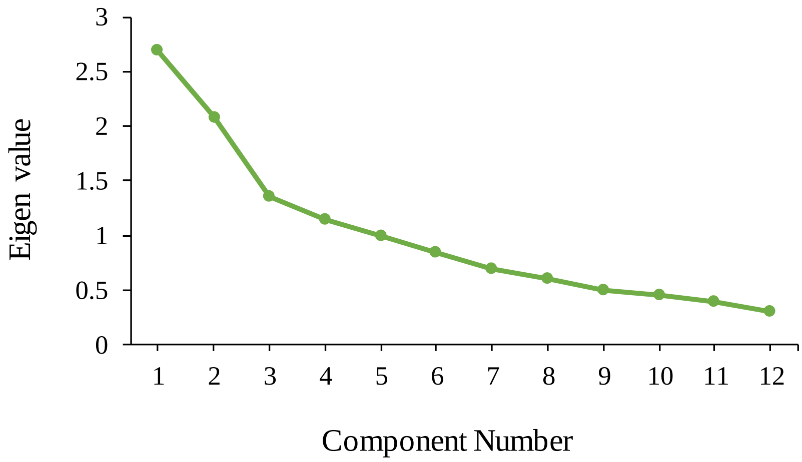

Figure 10 Relationship between Eigen values and component number.

Total variance is obtained from the 3 factors which have significant differentiation and the values are tabulated in Table 6. For the highest correlations between variables and the factors mentioned in Table 6, the highest value of loading coefficient is found in every factor; indicating a strong relationship. In this study, the factors are used to identify the consumer requirements as to whether an attribute should be raised or excluded based on positive or negative value respectively.

Table 6 Analyzation of variance of selected factors.

Initial Eigen values			Rotation sums of squared loadings of warm water (˚C)		
Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
2.651	22.089	22.089	2.322	19.352	19.352
2.039	16.988	39.077	2.126	17.717	37.070
1.312	10.935	50.012	1.553	12.942	50.012
1.137	9.473	59.486			
.993	8.274	67.760			
.854	7.119	74.879			
.695	5.789	80.669			

The three factors have significance and differentiation with the other factors and high variance. From the selected factors which have significant differentiation, the total variance is obtained. Variables with high values are well represented in the common factor space, while variables with low values are poorly represented. The highest variance value of the factor is of 22.089% which is the major effect on total variability data. The second and the third level of variance values are 16.988% and 10.935% respectively.

The factors which are not significant in the analysis are eliminated and in which three factors are generated and taken into account resulting in total variability of the sample as 50.012%. Rotated component matrix refers to the loadings which is the key output of the principal components analysis and contains the estimation of the correlation between variables and the estimated components. The highest value of the loading coefficient is examined for every factor to establish a strong relationship with other factors.

6. Conclusion

The developed intelligent system incorporates an automatic irrigation module and a water efficient module with a ring-shaped emitter at the sub-surface which directly provides water to the root of the plant area and minimizes evaporation. It can not only be applied in fields but also in apartments and houses in metropolitan cities with limited space. The system is developed using Kansei Engineering where customer requirements are converted into the desired design. According to statistical analysis, various factors including physical, feasibility and operational performance factors are considered in designing the system. In addition, the developed system exhibits good performance in soil conditions in dry and wet states with different temperatures. This novel approach is expected to minimize the existing activities including observing the environmental conditions, watering plants and providing feedback on the plants by allowing the intelligent irrigation system to nurture the soil and monitor the conditions autonomously. As for a future study, the developed system can be improved by allowing the system to communicate with other systems for large-scale farming and with users for in-house gardening. Furthermore, the physical appearance of the developed model can also be modified into an artistic model that can mimic an animal or gardening product using additive manufacturing.

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