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Verification of the Psychological Effects of the IoT Flowerpot System Aiming at Life Support

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In this study, we have developed an IoT-based plant growing system to address the pressing issue of supporting individuals with developmental disabilities and other challenges in their daily and social lives. The primary objective of the system is to facilitate environmental adaptation by monitoring the user's daily routine and indoor environment, while also providing assistance in plant cultivation. The flowerpot system we have developed is equipped with various sensors, including temperature, humidity, light, and moisture sensors. These sensors enable the comprehensive monitoring of both the plant growing process and the indoor environment. Additionally, the system features a built-in display and speaker, serving as a user interface that facilitates communication between the user and the anthropomorphic flowerpot character. The objective evaluation of the system was conducted through electroencephalography (EEG) measurements, whereas subjective evaluation involved the use of questionnaires and interviews. The results confirmed that the system has a relaxation effect on the users.

1. Introduction

1.1 Background

According to a report by the Ministry of Health, Labor and Welfare, more than 480,000 people in Japan were diagnosed with developmental disabilities in 2016.(1) According to a 2022 survey, 8.8% of elementary and junior high school students in regular classrooms have significant difficulties in learning and living.(2) In the United States, about 17% of children between the ages of 3 and 17 were reported to have a developmental disability.(3) Including those who have not been diagnosed, there are actually many people who have difficulties in their daily and social lives, and support for these individuals is a pressing issue around the world. Developmental disabilities such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and learning disabilities (LDs) have different symptoms and each individual has different difficulties. Therefore, it is important to choose a support method and a support system that suits the individual and supports their daily life.

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Agricultural and welfare cooperation is being promoted in Japan.[4] This is a partnership between agriculture and welfare, whereby people with disabilities are encouraged to play an active role in the agricultural sector in the hope of securing workers in the agricultural field with aging workers and improving the quality of life by connecting the physically challenged to employment. Especially in recent years, the use of smart technology has been promoted in agricultural and welfare cooperation.[5] Common characteristics of people with developmental disabilities include forgetting to take care of themselves, difficulty following abstract instructions, inability to schedule tasks, and inability to prioritize, all of which may be supported by Information and Communication Technology (ICT). Not only for developmental disabilities, smart agriculture uses sensors, robotics, AI, and IoT technologies to semi-automate operations, simplify information sharing, and analyze weather and image data to achieve more advanced cultivation.[6]

Plants have the ability to reduce anxiety and refresh the mind.[7,8] Horticultural therapy has been reported to be effective in not only maintaining and improving motor skills but also improving memory, cognitive abilities, social skills, problem-solving skills, and social self-efficacy through growing plants.[9,10] People with developmental disabilities have a stronger sense of self-doubt when they fail than people with typical development,[11] and their anxiety about failure and low self-esteem have a negative impact on their performance, and one failure can lead to further failures and a vicious cycle. Therefore, it is desirable to have as many successful experiences as possible in plant cultivation. It has also been reported that people diagnosed with ADHD and ASD have found that interacting with dogs and owning pets can reduce symptoms and improve quality of life,[12,13] but many people give up on keeping pets due to housing restrictions, income, and characteristic issues such as forgetting to take care of their pets. Systems for communication using facial expressions of plant environmental information have been studied, aiming at plant-based counselling and animal therapy effects.[14,15] However, this communication is only about environmental information for plants, and the relaxation effect is also targeted at highly stressed people.

With the above background, we decided to develop a system in which those with developmental disabilities and who want to work in agriculture in the future can receive support in growing plants through ICT technology, while also having a positive impact on their own lives in the daily care of their plants.

1.2 Purpose

We developed a communicative flower pot system[16] and verified its effectiveness. The flower pot system is expected to have the following two effects.

1.2.1 Cultivation support

This system acquires information on the surrounding environment (temperature, solar radiation, and moisture content) using various sensors installed in flowerpots and supports user in understanding the processes necessary for cultivation and remembering to take appropriate care of their plants on a daily basis. This results in successful cultivation, a sense of accomplishment, and an improvement in self-esteem, which leads to motivation to work.

1.2.2 Life and communication support

Information acquired by various sensors is used not only for plant cultivation but also for user support. It supports the adjustment of the user's daily rhythm by requesting daily plant care, the improvement of self-esteem by expressing gratitude for the care, and the control of a comfortable environment for humans based on information such as temperature and illumination. In addition, a character's face will be displayed on the screen to create the effect that the user is raising a pet rather than just a plant.

2. Methods of System Development

The functions required for the system are as follows:

(a) a function to collect information on the environment surrounding the plants and the user ('temperature', 'illuminance', 'soil moisture content', 'light intensity', and 'time'),
(b) a function to judge whether the environment is suitable for the plant or not, on the basis of the environmental information collected in (a), compared with the preset values,
(c) a function to judge whether the environment is suitable for the user by using the predefined values from the information collected in (a) and the time information,
(d) a function that communicates with the user using the results of the judgments made in (b) and (c), and
(e) a function to store sensor values and daily waking/sleeping/caretaking times in the storage attached to the system and provide advice on daily life rhythms.

The following devices were used for development:

- M5Stack Basic (development environment: Arduino IDE ver 1.8.12),
- environmental sensor unit for M5Stack ver. 2 (ENV II),
- soil moisture sensor unit for M5Stack,
- PIR sensor unit for M5Stack,
- expansion hub unit for M5Stack,
- Conta illuminance/proximity integrated sensor module, and
- MicroSD 32GB (SanDisk Extreme PRO).

A diagram of the system is shown in Fig. 1. The process flow is shown in Fig. 2. The microSD card inserted into the M5Stack Basic contains a character and Japanese font data in the form of an anthropomorphic flowerpot as shown in Fig. 3. The display usually shows the character's sleeping face, and when a user approaches within 500 cm of the flowerpot system, the infrared sensor reacts and the image of an awakened character and greeting message is displayed. There are three greeting messages, "Good morning", "Good afternoon", and "Good evening", which are used according to the time obtained from the NTP server. When the time has passed the preset bedtime, the system outputs "I'm sleepy" to encourage the user to go to bed, and if the

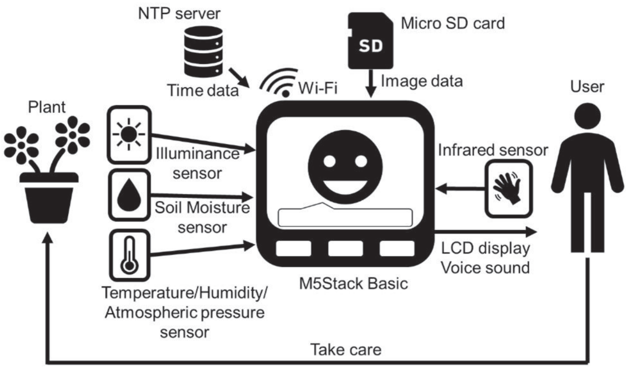

Fig. 1. (Color online) System diagram.

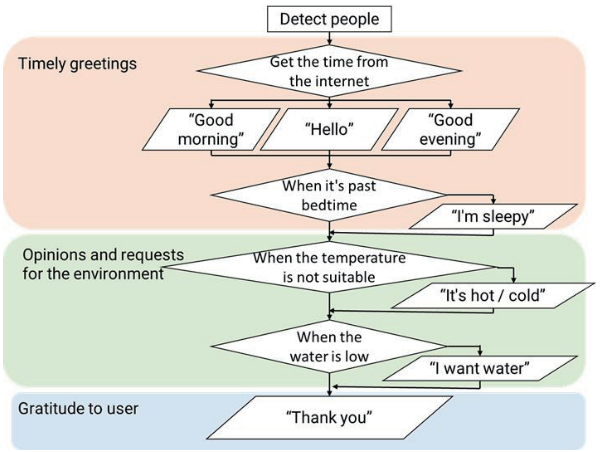

Fig. 2. (Color online) System process flow.

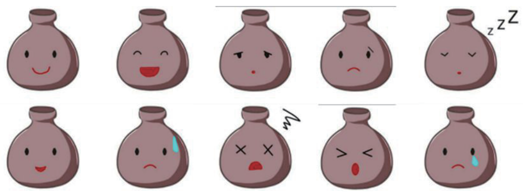

Fig. 3. (Color online) Character expressions displayed in the flowerpot system.

illuminance is high earlier than the wake-up time, it outputs "You're up early", to help the user adjust to the daily rhythm. The system then uses the values acquired from the illuminance and temperature/humidity/barometric pressure sensors as references, and converses with the user to create an appropriate environment for the plant and user. Specifically, when the illumination is low, the system outputs “It’s too dark”, and when the temperature is too hot or too cold, it outputs “It’s too hot” or “too cold” to encourage the user to take action. In this system, hydroponic cultivation has been assumed for the stability of operation. A resistance of 3000 or more output by the soil moisture sensor unit was defined as the environment in which watering is necessary. If the soil is dry, the system outputs “I want water”, followed by “OK, that’s enough, thank you” when enough moisture is obtained. If there is enough moisture, it will say “I don’t need water yet. Thank you for coming!” and then output “I’ll be waiting for you tomorrow” at the end to encourage continued care. Every five minutes, the values obtained by the various sensors, the time at which the flowerpot system responded, and the time of watering are stored in CSV format on a microSD card. A photograph of the developed flowerpot system is shown in Fig. 4.

3. Results of System Evaluation

An evaluation was conducted objectively, using EEG to determine the degree of relaxation when using the system, and subjectively, using a questionnaire to evaluate the system.

3.1 Participants in the evaluation

The total number of participants of the evaluation experiment and questionnaire survey was 38 (26 males, 11 females, and 1 not answered) with ages between 6 and 48 years old (*mean* 17.8, *SD* = 9.3). 16 of the participants have a diagnosis of developmental disability. The relaxation effect verification was participated by 11 people with typical development and 16 people with developmental disabilities. The 11 people with typical development (8 males and 3 females) were between 19 and 48 years old (*mean* 24.8, *SD* = 10.8), and the 16 people with developmental disabilities (10 males, 5 females, and 1 not answered) were between 6 and 20 years old (*mean* = 9.9, *SD* = 3.2). The questionnaire survey about the flowerpot system was participated by 11 people with typical development (8 males and 3 females) with ages between 21 and 24 years old (*mean* 22.5, *SD* = 1.0) who did not participate in the verification of the relaxation effect and by 15 people with developmental disabilities (9 males, 5 females, and 1 not answered) with ages between 6 and 12 years old (*mean* = 9.3, *SD* = 2.0) of those who participated in the verification of

Fig. 4. (Color online) Picture of the developed flowerpot system.

the relaxation effect. The experiment was explained in advance and consent was obtained from the participants and their guardians in the case of minors.

3.2 Verification of the relaxation effects

To objectively verify the relaxation effects of the developed flowerpot system, the degree of relaxation was determined by EEG measurements.[17] The experimental flow is shown in Fig. 5. First, the resting EEG was measured for 1 min with the eyes open and used as the baseline. Next, the three tasks described below were performed and the EEG was measured during the tasks. The order of the tasks was counterbalanced for each participant to eliminate order effects. Finally, interviews were conducted on each of the tasks performed in the experiment, on the EEG machine, and on the experience of growing plants.

There were three tasks in the experiment. Task A was the "pouring water into a flowerpot" task. A flowerpot identical to the flowerpot system was placed in front of the participant, who was asked to pour about half of the water into the flowerpot with a watering can. Task B is the "pouring water into a flowerpot with a plant" task. A flowerpot with the same plants as the flowerpot system was placed in front of the participant, who was asked to pour about half of the water with a watering can. Task C is the "pouring water into the flowerpot system" task. The flowerpot system was placed in front of the participant and water was poured while listening to messages from the system.

To objectively verify the relaxation effects, EEG measurements were taken using a Littlesoft spectacle-shaped EEG machine (Fig. 6). The data measured by the EEG meter was sent via Bluetooth to the "LM Logger" smartphone application, and band power values were calculated from the signal waveform data. In this study, the sum of low alpha (7.5–9.25 Hz) and high alpha (10–11.75 Hz) was treated as the alpha wave (7.5–11.75 Hz) band power value, and that of the low beta (13–16.75 Hz) and high beta (18–29.75 Hz) was treated as the beta wave (13–29.75 Hz) band power value. Alpha waves indicate a state of relaxation, whereas beta waves indicate a state of arousal. We calculated the alpha/beta ratio and used it as the relaxation level, and considered that a high relaxation level reflects increased alpha and/or decreased beta.

3.2.1 Relaxation effects on participants with typical development

The participants' mean relaxation level for each task is shown in Fig. 7. T-tests showed that the relaxation level was significantly higher in Task C (pouring water into the flowerpot system) than at baseline ($p = 0.0026$) and in Task A (pouring water into the flowerpot) ($p = 0.0002$).

3.2.2 Relaxation effects on participants with developmental disabilities

The participants' mean relaxation level for each task is shown in Fig. 8. T-tests showed that the relaxation level was significantly higher in Task C (pouring water into the flowerpot system) than in Task B (pouring water into the flowerpot with a plant) ($p = 0.033$).

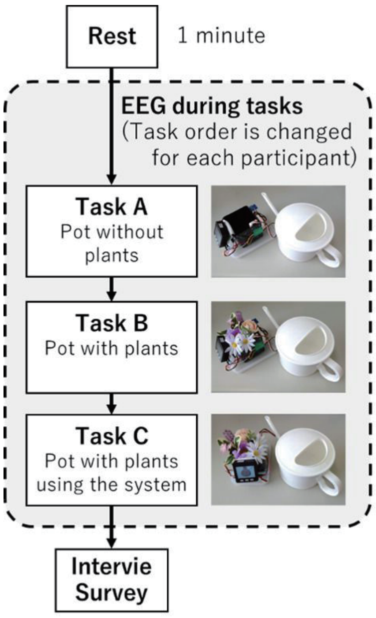

Fig. 5. (Color online) Experimental flow to verify the relaxation effects.

Fig. 6. (Color online) Spectacle-shaped EEG machine

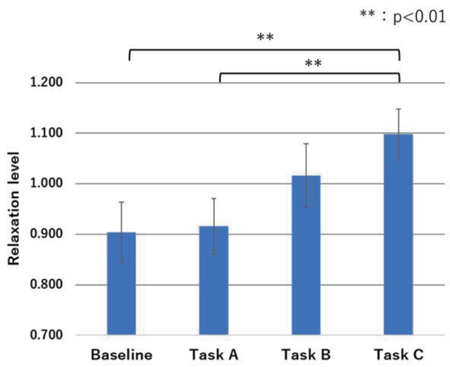

Fig. 7. (Color online) Relaxation level in each task with participants with typical development.

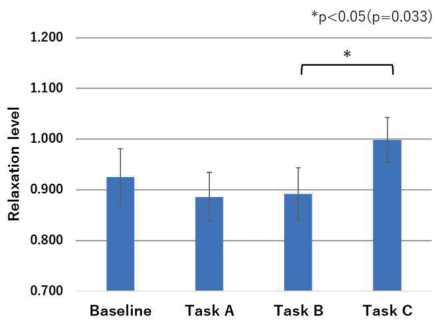

Fig. 8. (Color online) Relaxation level in each task with developmentally disabled participants.

3.3 Questionnaire survey on flowerpot system

A questionnaire survey was conducted to investigate the subjective impressions when using the developed flowerpot system. Some of the participants who participated in the experiment to verify the relaxation effects answered a questionnaire voluntarily after the experimental interview. Participants who did not participate in the experiment answered the questionnaire after hearing about the purpose and operational flow of the system, and experiencing watering the flowerpot system.

As participants included children, all questionnaire surveys conducted in the form of interactive interviews. Experimental collaborators asked the following eight questions, and participants were asked to answer Q1–Q5 with four options: ‘Yes’, ‘Likely yes’, ‘Likely no’ and ‘No’. Q6–Q8 were answered freely.

- Q1 Have you been healed?
- Q2 Do you want to take care of this tomorrow?
- Q3 Do you want this system?
- Q4 Do you control the temperature when this says “It’s hot/cold”?
- Q5 Do you try to sleep when this says “I’m sleepy”?
- Q6 What would you like to hear from this system?
- Q7 What is good about this system?
- Q8 What do you feel needs to be improved?

3.3.1 Subjective evaluation of participants with typical developing

A graph of the responses by participants with typical development to Q1–Q5 is shown in Fig. 9.

To Q6 (“What would you like to hear from this system?”), the answers were “the condition of the plant”, “trivia”, “words to cheer me up”, and “words of appreciation”. To Q7 (“What is good about this system?”), the answers were “The fact that I know when to water”, “I don’t have to be tense when the plants tell me”, “I know how much water I should give”, and “The facial expressions on the plants”. To Q8 (“What do you feel needs to be improved?”), the answers were “I want more natural sounds”, “I want more variations in messages”, “I want an alarm function”, “I want to know the right amount of watering”, “I want more communication”, “I want a mute function because it is noisy when sound is played at night”, and “I want it to light up when I have something to tell it”.

3.3.2 Questionnaire for participants with developmental disabilities

A graph of the responses by participants with developmental disabilities to Q1–Q5 is shown in Fig. 10. To Q6 (“What would you like to hear from this system?”), the answers were “words of thanks”, “various greetings”, and “cheering up schoolwork”. To Q7 (“What is good about this system?”), the answers were “talking”, “saying thank you”, and “tells me that I need watering”. To Q8 (“What do you feel needs to be improved?”), the answers were “I want to plant my favorite flowers in larger flowerpots”, “I want the system to remember my name and start talking to me”, and “I want a button that when I press it, someone (supporter) will come to me”.

4. Discussion

4.1 Verification of the relaxation effects

The level of relaxation in Task C (when using the flowerpot system) tended to be higher than those in the resting state and Task A (pouring water into a flowerpot) for participants with

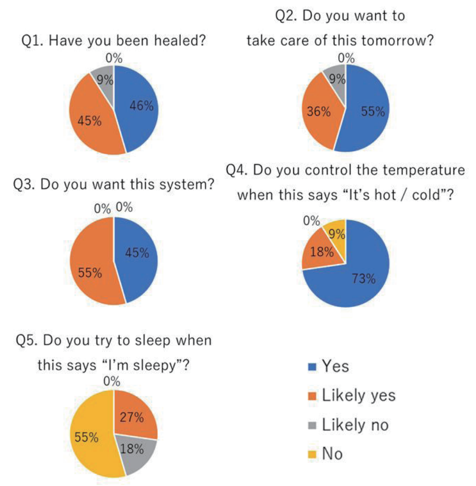

Fig. 9. (Color online) Questionnaire survey responses to Q1–Q5 by participants with typical development.

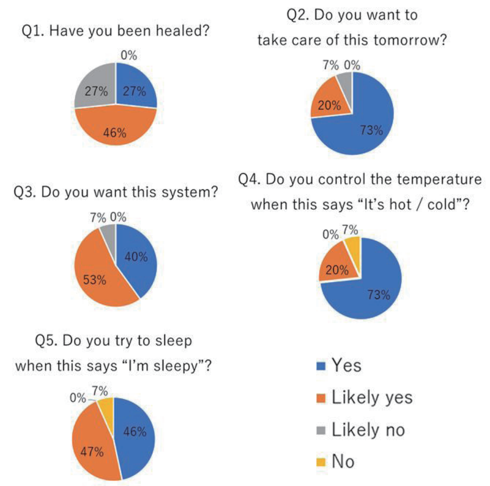

Fig. 10. (Color online) Questionnaire survey responses to Q1–Q5 by participants with developmental disabilities.

typical development, and in Task B (pouring water into a flowerpot with a plant) for participants with developmental disabilities. In particular, a significant trend was found in the degree of relaxation with and without the flowerpot system among the developmentally disabled, suggesting the relaxation effects of the flowerpot system. In the questionnaire survey, to Q1 ("Have you been healed?"), 91% of the participants with typical development and 73% of those with developmental disabilities responded "yes" or "rather yes", suggesting that the participants were subjectively relaxed using the flowerpot system. In some participants, the occupancy of alpha waves was higher in Tasks A and B without the flowerpot system in some cases. In the interview survey after the experiment, the participants with typical development expressed anxiety, such as "I did not know how to interact with the flowerpot system because I had never seen it before", and the participants with developmental disabilities expressed positive but not relaxing feelings, such as "It was fun" and "It was enjoyable. These feelings may have made the use of the flowerpot system less relaxing in some cases.

4.2 Questionnaire survey on flowerpot system

To Q2 ("Do you want to take care of this tomorrow?") and Q3 ("Do you want this system?"), 100% of the participants with typical development and 93% of those with developmental disabilities answered "yes" or "likely yes", and using the flowerpot system is considered to motivate people to care for plants every day. To Q7 ("What is good about this system?"), many participants answered that the system is good in that it shows the timing and amount of watering, and it is an appropriate method of cultivation support.

To Q5 ("Do you try to sleep when this says I'm sleepy?") was answered 'yes' or 'likely yes' by only 27% of participants with typical development, but by 93% of participants with developmental disabilities. For people with typical development, it is considered necessary to use other messages or methods to encourage bedtime, but for those with developmental disabilities, the flowerpot system can be used to influence bedtime by talking to them. To Q6 ("What would you like to hear from this system?"), the largest proportion of participants with developmental disabilities responded with 'words of thanks', and it appears that the use of the system increased their sense of self-esteem and helped them enjoy communication.

4.3 Future tasks

During the experiment, some participants expressed confusion and surprise at the system. This was because the experiment was conducted over a short period of time, and it is expected that these feelings will dissipate as participants become accustomed to the system over time. In addition, to promote useful behavioral changes for users, the system should have the abilities to monitor information about each user's problems and to provide advice/communication appropriate to the user's condition (events, emotional state, and physical condition) on that day. In the future, we plan to improve the system by adding these functions, a function to adjust the environment suitable for users by learning or by the users themselves, and patterns of output messages, and to verify the system through long-term use. Regarding support for plant cultivation, not only moisture, light, temperature, and humidity, which are currently being sensed, but also soil nutrients, fertilizers, and carbon dioxide concentration in air are related to plant growth. A plant with bioelectrical potential can sense the environment including these factors,[18] and we would like to consider introducing this technology in the future.

5. Conclusions

In this study, a flowerpot communication system was developed as a support system for people with difficulties in their daily and social lives, including those with developmental disabilities. Objective validation using EEG while using the developed flowerpot system showed a trend towards increased level of relaxation. In the questionnaire survey conducted as a subjective evaluation, many positive responses were also given, such as "It was relaxing." and "I would like to continue using this system." The results confirmed that the flowerpot system has a relaxation effect on the users.

Acknowledgments

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