Application of AI Robot Technology for Biophilic Design

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Abstract

To enhance human health and well-being, Biophilic design has been increasingly recognized in recent years. This design is characterized by the integration of natural elements such as plants, nature light, and water into spaces. However, challenges are posed by the maintenance of live plants, as their decline can be caused by insufficient environmental conditions. The aim of this study is to propose a robotic system of autonomously relocate houseplants to environments optimized based on sensor data, including light, temperature, and humidity. Through the integration of AI robotics with ecological design principles, it is aimed to enhance sustainability and redefine the relationship between humans, nature, and technology, fostering a harmonious interaction among "robots, nature, and humans.".

Keywords: Biophilic design, Ecological design, Space design

1. Introduction

This research aims to explore new space design methods using AI robot technology, drawing on plant ecology and physiology knowledge.

The study focuses on biophilic design using AI robot technology. Biophilic design is based on the Biophilia hypothesis, which suggests that humans tend to focus on and affiliate with nature and other life forms [1]. It is a methodology for designing building environments that achieve long-term sustainability by restoring and enhancing people's positive relationships with nature [2]. Since then, many studies have shown that the natural environment positively affects human psychological and physiological health [3][4].

Living plants are essential to biophilic design. Maintaining optimal environmental conditions including adequate light, water, and nutrients—is crucial for plant survival. However, the ongoing maintenance and associated costs present significant challenges to the large-scale incorporation of houseplants. To address these issues, Plantroid has been developed [5] that moves autonomously to a sunny location based on the voltage generated by the solar cells mounted on the plant. Focusing on plant photosynthesis, research is also being conducted on a method for controlling the movement of a flowerpot robot to maximize photosynthesis within a limited space and time [6]. Additionally, research has focused on evaluating indoor environments for plant growth, including methods for analyzing light conditions using specific wavelengths [7] and assessing photosynthesis indices in buildings [8].

This paper proposes a robotic system designed for the autonomous relocation of houseplants, ensuring their healthy growth by enabling them to select and move to suitable environments for their survival. The study will specifically address developing a robot that moves plants and generates an "environmental gradient map," enabling houseplants to determine their optimal moving route.

2. Method

2-1 Experimental environment

The experiment was conducted at “Fancγ”, the Research Center for Neuromorphic AI Hardware base. This space was designed under the theme of “Creating Biophilic Design for People and Robots”. The design of this space was proceeded through the crowdfunding [9]. A collaboration was established in 2023 between the laboratories of Life Science and Systems Engineering, the Laboratory of Environmental Design, and the Laboratory of Architectural Design within the Department of Civil Engineering and Architecture at Kyushu Institute of Technology. This space is designed for the development of robots through a range of experiences and learning opportunities in human living environments that people use daily for meetings and relaxation. As shown in Fig. 1, the continuous space is organized into distinct zones, including a Gallery・Archive space, a Meeting space, a Work space, and a Refresh space.

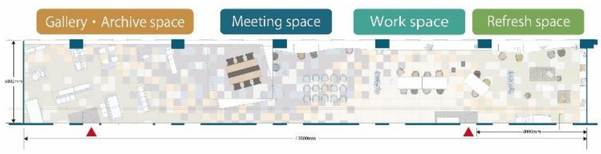

Fig. 1 Floor plan of “Fancγ”

2-2 The demonstration of moving houseplants using AI robots

We developed a system for moving houseplants using autonomous transport robots called Kachaka. These robots were tested by transporting plants along a designated route. Our platform integrates Kachaka with plants and features a voice command system for controlling the robots.

2-2-(1) Autonomous houseplant transport robot

This study used the Kachaka robot from Preferred Robotics, designed for transporting items in homes and workplaces [10][11]. Measuring 24 cm wide and 38.7 cm deep, the Kachaka can carry up to 20 kg with its specialized bases. We selected three species and eight houseplants growing well in low light. Using two Kachaka units, we placed the plants on six bases and moved them around as needed.

The plants were placed on a Kachaka base, as shown in Fig. 2, with two designated positions: home and sunbathing. The home position separates the workspace from the refresh space, while the sunbathing position is near the window. Kachaka has a map of the room, where we manually marked the positions. The robot uses a LiDAR sensor for localization and can be instructed via a voice recognition system called Whisper. When a human says, "relaxation mode," the robot moves the plants to the home position. If "seminar mode" is commanded, the plants are moved to the sunbathing position to expand the room capacity.

Fig. 2 Kachaka with houseplants

2-3 Measuring data and generating an “environmental gradient map”

To develop a system that helps houseplants move to optimal growth environments, it is vital to collect data on temperature, illuminance, and humidity. These factors are crucial for plant health and can be used to generate an "environmental gradient map" for the robot's reference.

2-3-(1) Preliminary survey

This study employs bilinear interpolation to estimate data at non-measured points. A preliminary survey was conducted to assess this method, with sensors placed at five locations within a 2000 mm × 2000 mm grid: the four corners and the center. The sensors used were “OKUDAKE Sensor Loggers” from SUN ELECTRONICS CO., LTD., with measurement errors of

±0.4°C for temperature, ±5% for illuminance, and ±3% for humidity (0% to 80%), increasing to ±4.5% for humidity (80% to 100%). The values of the center point were interpolated from the corner data, and accuracy was evaluated by comparing these calculated values to the actual measurements.

2-3-(2) Measuring environmental information

Temperature, illuminance, and humidity were measured in the refresh space of the experimental space "Fancγ." Over a 24-hour period, sensors recorded data from 12 indoor locations and 1 outdoor location at 5-minute intervals. The indoor sensors were positioned 1000 mm from the floor, matching the level of the houseplant leaves that the robot would move. Details of the experiment are shown in Figs. 3 and 4.

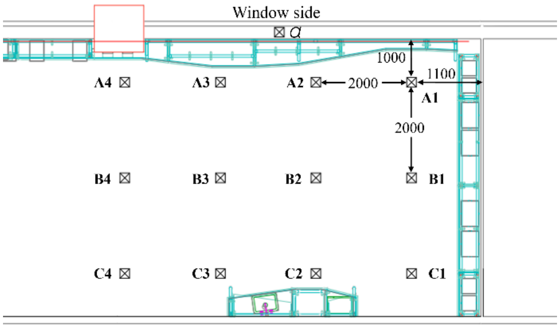

Fig. 3 Sensor arrangement diagram

Fig. 4 Refresh space with sensors installed

2-3-(3) Data analysis process

We analyzed the environmental data from the experimental space by interpolating non-measured points at 100 mm intervals to create continuous data. We converted the minimum, maximum, and median measurements into RGB values and plotted them as a scatter plot to visually represent the environmental gradient over time.

3. Results

3-1 The demonstration of moving houseplants using AI robots

The demonstration was conducted in the Fancγ. Two Kachaka were used to move six Kachaka bases with the plants, confirming the system's basic functions. In the demonstration, parameters, such as the position of the plants and the timing of the movement, were set manually. We introduce environmental sensors to set these parameters automatically by reflecting environmental conditions and human behaviors.

3-2 Measuring data and generating an "environmental gradient map"

3-2-(1) Results of preliminary survey

The center values were interpolated using bilinear interpolation from sensor data at the corners of a 2000 mm × 2000 mm grid. The Mean Square Errors (MSE) were as follows: temperature MSE was 0.00126, illuminance MSE was 0.297, and humidity MSE was 0.5625. This indicates that bilinear interpolation is suitable for estimating values at non-measured points in this study.

3-2-(2) Environmental data and environmental gradient map

The results of temperature, illuminance, and humidity measurements from each sensor are presented in Figs. 5, 6, and 7. Fig. 5 shows that the room temperature rises at 9:00 a.m., coinciding with an increase in the outside temperature. Data from window-side sensors, such as A3 and A4, exhibited trends similar to outside temperature. In the illuminance of A4 and B4 changes similarly to the illuminance outside the room. It can be read from this data that sunlight was reaching those locations. Fig. 7 shows that indoor humidity is stable between 36% and 41%, with no significant changes. In addition, changes in outside humidity and indoor humidity were similar between 8:00 and 9:00 a.m. and between 7:00 and 11:00 p.m.

Furthermore, environmental gradient maps were generated every 5 minutes from the measured data. Environmental gradient maps of temperature and illuminance at 9:00 a.m. are shown in Figs. 8 and 9. They show that the temperature and illuminance are higher on the window side and decrease as they approach the corridor side. Since different types of houseplants require different temperatures, this map could be used to determine where the robot carrying the houseplants should move. For the humidity environment map, there was not much change in indoor humidity at the same time.

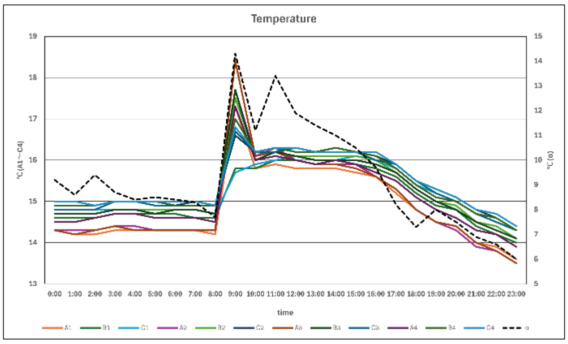

Fig. 5 Temperature change of sensor

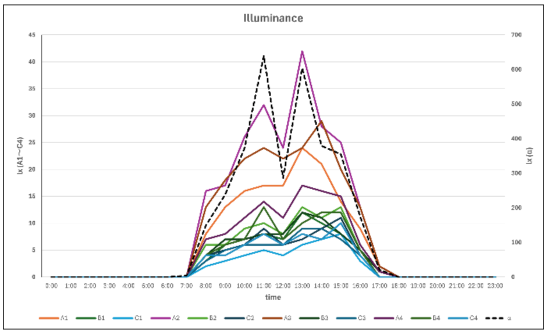

Fig .6 Illuminance change of sensor

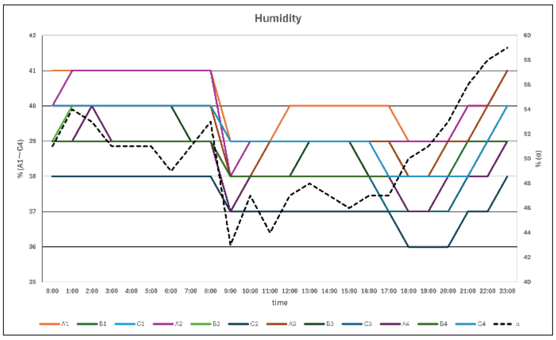

Fig .7 Humidity change of sensor

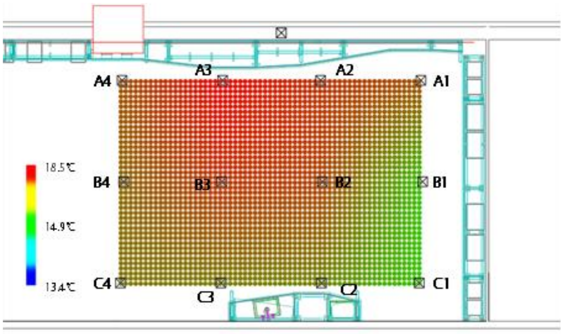

Fig. 8 emperature environment map at 9:00 a.m.

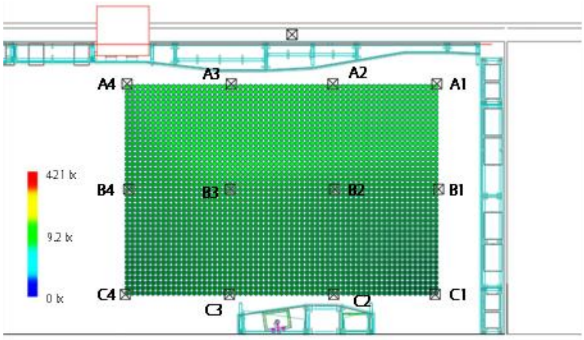

Fig. 9 Illuminance environment map at 9:00 a.m.

4. Discussion and Conclusion

In this study, we developed a system for the autonomous movement of houseplants using transport robots. While Plantroid focuses on plant growth, our robot responds to voice commands, allowing people to interact with plants. This enhances user convenience and promotes coexistence between humans and plants. Besides supporting healthy plant growth, the system also serves as an interior decorator and contributes to visual landscape design.

The environmental gradient maps utilize sensor data on illuminance, temperature, and humidity. Changes in these factors can help design optimal routes for plants to move along. The collected data indicates when and where plants should move throughout the day. However, continuous data collection is essential due to seasonal variations and human activities. Machine learning can effectively estimate conditions with fewer sensors, optimizing placement and reducing costs. Additionally, considering vertical data alongside horizontal data will enhance insights into plant growth and better optimization of plant movement in indoor environments.

Future research will focus on developing specific routes for relocating houseplants, referring to environmental gradient maps, to improve plant health and management efficiency. An integrated system will be established to continuously update these gradient maps by utilizing data collected from sensors on plants during their movement, enhancing the accuracy of environmental gradient maps and enabling houseplants' autonomous management. These results present new possibilities in biophilic design practices and houseplant maintenance methods. In addition, how a space composed of autonomously moving plants affects human space use and spatial perception will be further studied. This research is expected to propose new environmental and spatial design methods using AI robots, while new perspectives, such as plants as sensory organs in AI robots, are also introduced.

5. Acknowledgement

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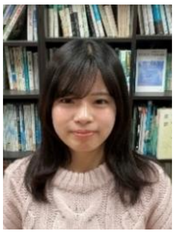

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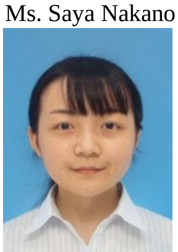

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