Personalized Energy-Saving Behavior Promotion System Based on User Utterance Analysis and LLM

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***Abstract*—In recent years, climate change, particularly global warming, has become a major concern, with global average temperatures continuing to rise. In response, the Japanese government has declared its commitment to achieving a zero-carbon society where the difference between CO_2 emissions and absorption becomes zero. While energy conservation is crucial for achieving this goal, this research specifically focuses on energy-saving behaviors in general households. Previous research has proposed methods to promote energy-saving behaviors through dialogue between systems and users. However, these methods have several issues: they can only provide predetermined responses, they use costly 3D models, and they cannot determine whether users are at home. Considering these issues, this research proposes EcoWiz, a system utilizing large language models and Live2D. Additionally, the system implements presence detection and periodic notifications using motion sensors and Pub/Sub architecture. Based on the proposed method, we implemented the system and verified its operation through case studies.**

***Index Terms*—Zero carbon, Energy-saving behavior, Large language model, Live2D**

I. Introduction

Currently, climate change, including global warming, has become a significant global issue. The average global temperature continues to rise, leading to various problems such as sea level rise and extreme weather events [1] [2]. In response to these challenges, the Japanese government has declared its commitment to realizing a zero-carbon society [3]. A zero-carbon society refers to a society in which the net emissions of CO_2 are reduced to zero by balancing emissions with absorption. Achieving this goal requires a significant reduction in energy consumption [4] [5]. The goal of this paper is to develop a system that promotes personalized energy-saving behaviors tailored to individual household users, enabling users to voluntarily engage in energy conservation activities. Previous studies have proposed energy-saving behavior promotion methods that integrate power consumption management services with Virtual Agent (VA) energy-saving behavior promotion services. However, these methods have the following limitations.

P1: Only predetermined responses are possible

P2: Use of 3D models as virtual agents

P3: Unable to determine if the user is at home

In light of these limitations, this study proposes a novel system, **EcoWiz**, based on conventional approaches. The proposed system is designed using the following four approaches.

A1: Response using Large Language Model (LLM)

The system analyzes user utterances using a Large Language Model (LLM) to generate appropriate responses, enhancing flexibility in user interactions.

A2: Use of Live2D

The system employs Live2D for its virtual agent, reducing the costs associated with model and animation creation while providing a more personalized service.

A3: Presence detection using motion sensors

The system employs motion sensors to determine user presence. Notifications are sent only when the user is at home, promoting energy-saving behaviors.

A4: Periodic notifications using Pub/Sub

The system utilizes Publish/Subscribe (Pub/Sub) to periodically retrieve notifications from the power consumption management service, allowing users to receive regular updates from the system.

In this research, we implemented the system based on the aforementioned approaches. Additionally, in a case study, we verified whether the implemented system correctly facilitated user interactions and energy-saving behavior notifications, confirming its functionality.

II. Preliminaries

A. Global Warming and Zero Carbon

In recent years, climate change, particularly global warming, has become a significant global issue. According to research, the average temperature of the Earth in 2020 was approximately 1.1°C higher than pre-industrial levels (1850-1900) [1]. This warming phenomenon has intensified heavy rainfall and increased the frequency of heatwaves, significantly impacting various sectors of industry [2].

Greenhouse gases, which are the primary cause of global warming, are continuously emitted through economic activities and daily life. Notably, emissions resulting from basic human activities such as clothing, food, housing, and transportation are reported to account for approximately 60% of the total [6].

To address these challenges, the Japanese government announced in October 2020 its commitment to achieving a **zero-carbon (carbon-neutral)** society by 2050, in which greenhouse gas emissions and absorption are balanced to net zero [3]. Achieving this target requires a substantial reduction in emissions of greenhouse gases, particularly CO_2, which is closely tied to energy-related issues [4] [5]. Promoting energy-saving behavior is an essential component in achieving this goal; however, it is important that such promotion is personalized and does not impose excessive burdens on individuals [7].

B. Related Work

1) Power Consumption Management Service: As a prior study, an **power consumption management service** was developed to promote energy-saving behavior. This service manages appliance-specific power consumption data collected via IoT devices. On the service platform, a baseline is automatically set, representing the user's basic power consumption level. Notification messages are generated by comparing actual power consumption with the baseline. The baseline is set as a value obtained by applying a specific coefficient to the predicted future power consumption, estimated using machine learning techniques. The coefficient is adjusted based on user feedback, enabling personalized baseline settings and notifications.

The service also includes visualization features that present power consumption data in various formats such as graphs and tables. Additionally, appliance control through IoT devices is supported. Visualization of power consumption has been shown to increase user awareness regarding energy-saving [8]. Through this service, users receive customized notifications based on individually adapted baselines [9]. Screenshots of the power consumption management service are shown in Fig. 1 and 2.

2) VA Energy-saving Behavior Promotion Service: The VA energy-saving behavior promotion service delivers notification messages obtained from the power consumption management service using a Virtual Agent (VA). A Virtual Agent (VA) is a software-based character interface capable of interacting with users through voice or text. It often embodies a persona and is used to deliver information or perform actions in a more human-like and engaging manner. In our laboratory, a 3D model named "Mei-chan" is used as the virtual agent. The system checks every hour whether the user is at home via a sensor, and if so, delivers the notification. In addition, the system allows users to operate appliances by responding to the system's questions. Users can also set energy-saving goals within this service and check the amount of electricity they aim to save over a specific period [9]. A screenshot of the VA energy-saving behavior promotion service is shown in Fig. 3.

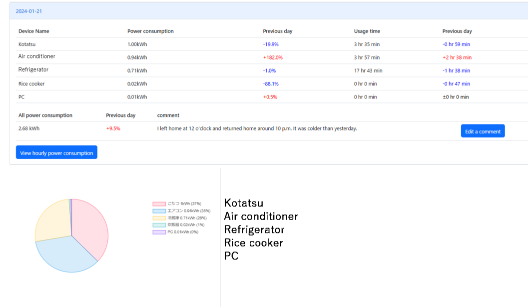

Fig. 1: Power consumption management service screen (daily consumption graph and table) [9]

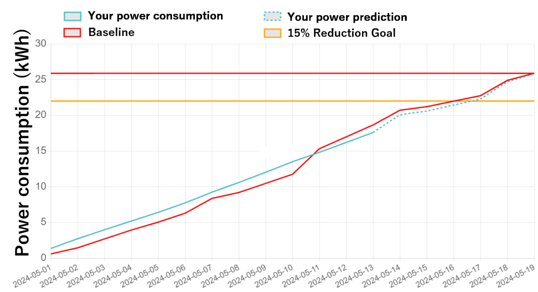

Fig. 2: Power consumption management service screen (reduction goal graph) [10]

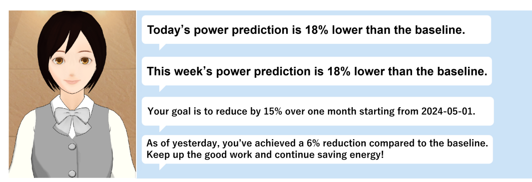

Fig. 3: VA Energy-saving behavior Promotion service screen [9]

C. Issues in Previous Research

Previous research has identified the following three issues:

P1: Only predetermined responses are possible

Although the current VA energy-saving behavior promotion service can deliver notifications and control appliances, user responses are limited to fixed phrases such as "yes" or "no" when asked by the system. Moreover, users cannot request notifications or operate appliances outside of predetermined times. The system also only transmits preset sentences configured by the administrator. Enhancing flexibility in dialogue is essential to deliver more personalized services.

P2: Use of 3D models as virtual agents

In previous research, the virtual agent used a 3D model ("Mei-chan"). While 3D models can express more realistic facial expressions and movements, creating the models and animations incurs high costs. To provide services tailored to individual users, a technology that enables easier creation of various models and animations is required.

P3: Unable to determine if the user is at home

In the current VA energy-saving behavior promotion service, notifications are sent periodically regardless of whether the user is at home. If notifications were only sent when the user is at home, it would be more effective in promoting energy-saving behavior.

To address these issues, it is necessary to enhance the flexibility of user interactions and apply technologies that enable more personalized services.

D. Live2D

Live2D is an animation tool developed by Live2D Inc. that enables 2D characters to be animated by moving facial parts [11]. This technology allows characters to be animated in a way that preserves the original art style more effectively than 3D modeling and can be created at a lower cost. Live2D Cubism Editor is the modeling tool used for creating Live2D models and setting animations, allowing for relatively easy model development [12]. Created models and animations can be rendered in applications using the Live2D Cubism SDK [13].

E. ChatGPT

Large Language Models (LLMs) have made remarkable progress in recent years, and among them, **ChatGPT** has attracted significant attention. ChatGPT is an LLM developed by OpenAI that specializes in interactive tasks, capable of generating natural dialogue through conversations with users. OpenAI also provides an API for ChatGPT, allowing for easy integration into various services. Compared to other models, ChatGPT demonstrates strong natural language processing capabilities, enabling flexible interaction with users [14].

F. SwitchBot Motion Sensor

The **SwitchBot Motion Sensor** is an IoT device capable of detecting human movement via infrared sensors. When movement is detected, it can trigger predefined actions. One such action includes calling a specific API via a Webhook, enabling integration with various services [15]. An image of the SwitchBot Motion Sensor is shown in Fig. 4.

G. Pub/Sub

Publish/Subscribe (Pub/Sub) is a messaging system that enables asynchronous communication by decoupling the sender and receiver of messages. In Pub/Sub, the message sender publishes messages to a topic, and receivers subscribed to that topic receive the messages. This architecture eliminates the need for the receiver to constantly check for new messages, thereby reducing response time.

Fig. 4: SwitchBot Motion Sensor

III. Proposed Method

A. Objective and Key Idea

The objective of this study is to develop a service that promotes more personalized energy-saving behavior. The key idea is to build a new system based on the existing service using a Large Language Model (LLM) and Live2D. The proposed method consists of the following four approaches:

A1: Response using a Large Language Model (LLM)

The current VA energy-saving behavior promotion service only allows predetermined responses in user interactions. By introducing an LLM, it is expected that the system can offer more flexible and natural dialogue.

A2: Use of Live2D

The previous system used a 3D model ("Mei-chan") as the virtual agent, but creating models and animations is costly. Live2D allows for easier creation of various models and animations, making it more feasible to provide a personalized virtual agent.

A3: Presence detection using motion sensors

Motion sensors are used to determine whether the user is at home. Notifications are only sent when the user is detected to be present, which helps promote energy-saving behavior.

A4: Periodic notifications using Pub/Sub

The system uses Pub/Sub to periodically obtain notifications from the power consumption management service, ensuring that users receive regular updates.

Based on these approaches, we propose a service named **EcoWiz** that promotes energy-saving behavior.

B. Overall System Architecture

Fig. 5 illustrates the overall system architecture proposed in this study.

First, we explain the process of acquiring notifications. When the motion sensor detects that the user is at home, it sends a Webhook to the receiving server. The receiving server then sends a request to the EcoWiz backend to retrieve the notification message, which is obtained via the power consumption management service. The acquired notification is then sent to the EcoWiz frontend through Pub/Sub, and the user is notified.

Next, we describe the process during user interaction. When the user initiates dialogue with EcoWiz via the frontend, the

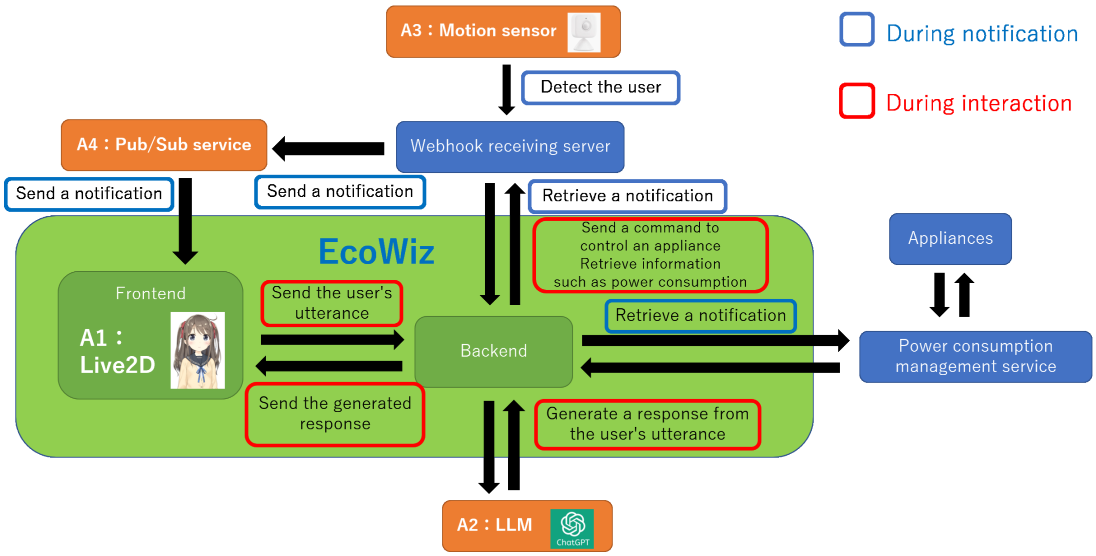

Fig. 5: System Architecture

content is sent to the backend. The backend uses an LLM to interpret the user's utterance. Based on the interpretation, if it is necessary to control appliances or obtain information such as power consumption or energy savings, a request is sent to the power consumption management service. The response is then used by the LLM to generate an appropriate reply. If no request to the power management service is needed, the LLM directly generates a suitable response based on the user's utterance.

While the system incorporates features commonly found in smart home applications, such as appliance control and motion-based presence detection, it is specifically designed for easy integration into ordinary households. Users do not require specialized home automation systems; the necessary functionality can be achieved through consumer-grade IoT devices and standard internet connectivity.

C. A1: Response using a Large Language Model (LLM)

To understand the user's utterances and generate appropriate responses, we use a Large Language Model (LLM). In this context, user utterances are assumed to be provided as either speech (converted to text) or directly as textual input.By analyzing the utterance with the LLM, we classify it into one of three categories: a command to control an appliance, a request to obtain information such as power consumption or energy savings, or neither.

In the case of appliance control, the system determines which appliance to operate and how, based on the user's utterance. If any information is missing, the system asks follow-up questions to obtain the necessary details. Then, the request is sent to the power consumption management service to perform the control.

For retrieving power consumption or savings data, the system sends a request to the power consumption management service and generates a response based on the reply.

For example, when a user says, ”I want to turn on the air conditioner,” the system cannot determine whether to activate cooling or heating mode, nor at what temperature. In such cases, the system follows up by asking for clarification— such as whether the user prefers cooling or heating, and what temperature setting is desired. Based on the user ’ s response, the system then sends the appropriate control command to the appliance.

If the utterance does not correspond to either category, the system generates a natural response using the LLM. This approach enhances the flexibility of user interaction and enables natural communication.

D. A2: Use of Live2D

Instead of the previously used 3D model ”Mei-chan,” we use Live2D, which allows for easier creation of various models and animations. This enables the provision of virtual agents that are more personalized and can potentially increase user motivation for energy-saving behavior.

E. A3: Presence Detection Using Motion Sensors

To determine whether the user is at home, the system uses a motion sensor. When the sensor detects the user's presence, it sends a Webhook to the receiving server. The server then retrieves the notification message from the power consumption management service via the EcoWiz backend. The message is delivered to the frontend through Pub/Sub and shown to the user. This ensures that notifications are only sent when the user is at home.

F. A4: Periodic Notifications Using Pub/Sub

To periodically retrieve notifications from the power consumption management service, the system uses a Pub/Sub messaging mechanism. A topic dedicated to energy-saving notifications is pre-configured in the Pub/Sub service. The receiving server, upon receiving a Webhook from the motion sensor, sends the message to this topic. By subscribing to the topic, the EcoWiz frontend can receive notifications on a regular basis. For instance, if the power consumption of the refrigerator significantly increases, the system generates a notification to alert the user. However, sending this notification when the user is not at home may not be effective. Instead, the message is published to the Pub/Sub topic, and when the presence sensor (as described in A3) detects that the user has returned home, the frontend receives the notification from Pub/Sub and notifies the user. This design enables context-aware and timely delivery of important energy-saving alerts.

IV. Implementation

Based on the proposed approaches, we implemented the EcoWiz system as follows:

A. Implementation of A1

For the large language model (LLM), we adopted ChatGPT. Among various LLMs, ChatGPT was selected due to its superior natural language processing capabilities and ease of integration via API. In this study, we used GPT-4o, the latest version available as of March 2025.

B. Implementation of A2

We used the sample model "Hiyori Momose" provided by Live2D Inc., which was created with the Live2D Cubism Editor. This model was used as the virtual agent for the EcoWiz frontend. The model was embedded in the web application using the Live2D Cubism SDK for Web. The frontend was developed using React.

C. Implementation of A3

The SwitchBot Motion Sensor was used for presence detection. This infrared sensor detects human movement and is configured through the SwitchBot application. The application allows the sensor to send Webhook requests to a specified endpoint when motion is detected.

D. Implementation of A4

For the Pub/Sub messaging system, we used "cs27PubSub," a simplified version of Google Pub/Sub developed in our laboratory. A dedicated topic for energy-saving notifications was created in advance. When a motion detection Webhook is received, the server sends a message to this topic. The EcoWiz frontend subscribes to this topic and receives periodic notifications.

E. Overall System Implementation

Combining A1 to A4, we developed the complete EcoWiz system. The frontend was developed using the JavaScript library React, and the backend was implemented using the Python framework FastAPI. The entire system was containerized using Docker, and a Docker Compose configuration allows all components to be launched together. A screenshot of the deployed EcoWiz interface and the motion sensor is shown in Fig. 6.

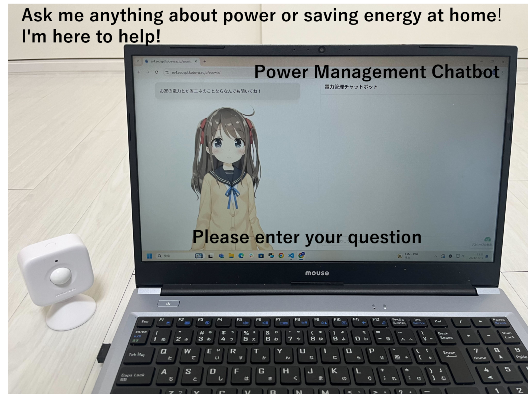

Fig. 6: EcoWiz interface and motion sensor

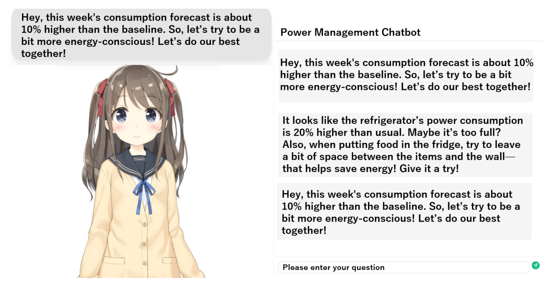

Fig. 7: EcoWiz screen delivering notifications

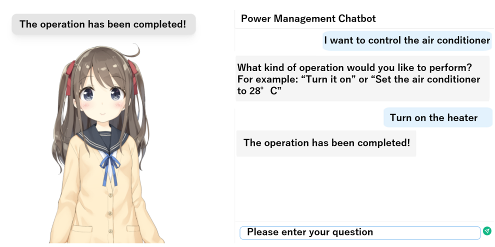

Fig. 8: EcoWiz screen operating appliances

V. Case Study

A. Setup

In this case study, we evaluated the following scenarios:

- Notifications are received when the user is at home.
- The user interacts with EcoWiz to obtain information about electricity savings.
- The user interacts with EcoWiz to operate appliances.
- The user engages in unrelated dialogue with EcoWiz.
- Appliances include an air conditioner and a refrigerator.

B. Results

Fig. 7 shows the notification delivery screen. Fig. 8 and 9 show screens for operating appliances and retrieving energy-saving information, respectively. Fig. 10 illustrates interactions unrelated to appliances.

C. Discussion

The results confirm that the system correctly interprets user inputs and generates appropriate responses via LLM,

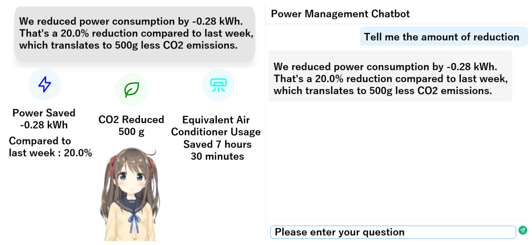

Fig. 9: EcoWiz screen retrieving energy-saving information

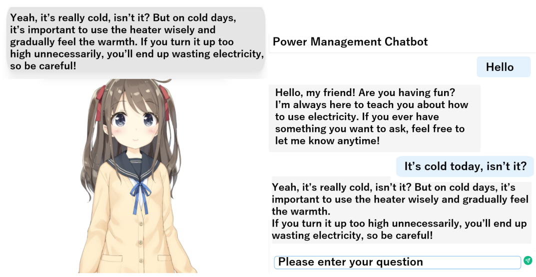

Fig. 10: EcoWiz screen handling unrelated conversations

resolving issue P1. The integration of the Live2D model into the interface was also successful. However, since we did not create a new Live2D model or animation in this study, we were unable to fully evaluate whether issue P2 (high modeling costs) was resolved. In future work, it will be necessary to compare the development effort and cost of creating Live2D models and animations with that of conventional 3D models to verify the cost-effectiveness of the proposed approach.

Moreover, presence detection using the motion sensor and periodic notifications via Pub/Sub were successfully implemented, addressing issue P3.

VI. Conclusion

In this study, we proposed and developed EcoWiz, a system designed to promote personalized energy-saving behavior. The proposed method consisted of four main approaches: responses using a Large Language Model (LLM), use of Live2D, presence detection using motion sensors, and periodic notifications using Pub/Sub.

Based on these approaches, we implemented the EcoWiz system and its supporting infrastructure. Through a case study, we verified that the system functioned as intended, including delivering notifications, controlling appliances, and retrieving energy usage information.

Future work includes developing personalized notification rules based on dialogue history. Currently, notification rules are predefined by the administrator. By analyzing dialogue history and automatically generating rules, the system can become more personalized. Additionally, since no new Live2D models or animations were created in this study, future work will involve creating them to fully evaluate the resolution of issue P2. Finally, field deployment of EcoWiz in actual households will be necessary to assess its impact on users' motivation for energy-saving behavior.

Acknowledgment

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