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Empirical Evaluation of Service Robot for Library Helpdesk Using Cloud Computing Services with Artificial Intelligence*

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***Abstract*— This study presents a library service robot rapidly developed using cloud artificial intelligence (AI) services and empirically demonstrates the robot's service in a public library. The developed robot system interacts with a cloud service for speech recognition and synthesis with high accuracy and low latency over a short duration. The robot has been in operation for three years in a university library. To conduct demonstration experiments at a public library, a book search system that does not use personal information was used, which differs from the system that has been in operation at the university library for several years. In addition, for the demonstration experiment at the public library, we formally negotiated with the library and set conditions such as the questioning method for the verification experiment. We show the feasibility of the proposed system with a spoken dialogue service robot by conducting demonstration experiments in the university and public libraries.**

I. INTRODUCTION

Recently, there has been considerable research on human-robot communication systems, and robots are expected to be increasingly used to support human tasks [1]–[4]. For example, a robot system for guiding people to the entrance of a university library [5] and a tele-response system to support helpdesk operations have been developed and operated for a long timeand a teleresponse system to support helpdesk operations have been in operation for several years [6]. To construct the robotic services in the public environment, spoken dialogue is a powerful means of verbal communication that is normally performed by humans and is non-contact. Various studies have been conducted on social robots, involving tasks such as storytelling [7] and implementing persuasion strategies through daily recommendations [8].

This study describes the rapid development of a tabletop-communication-based support robot system for library service helpdesks [9], [10]. Fig. 1 shows an overview of the developed robot system. Librarians not only serve customers at the reception desk but also perform many tasks away from the helpdesk, such as organizing bookshelves and performing administrative work, often leaving the helpdesk unmanned. This can be inconvenient for users and leads to a loss of service provision opportunities [11]. To solve this problem, we developed a system that enables library staff to respond to user requests without being present at the helpdesk.

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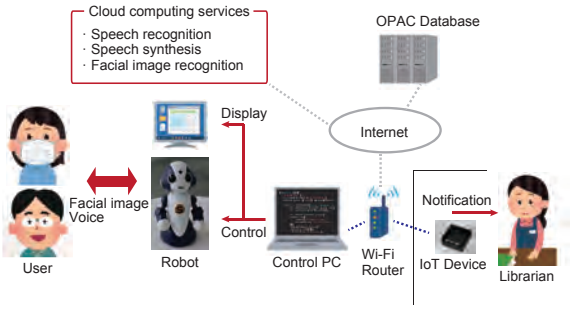

Fig. 1. Overview of the library support robot system.

The developed library service robot was empirically evaluated in a public library to verify the feasibility of the proposed system [12] in this study. Through usability evaluation [9] and long-term operation in a university library, we determined that it is necessary to verify the acceptability of the robot interface among users from different age groups. By introducing a library robot with an interactive voice interface, we aim to enable users who are not not technologically oriented to utilize the information services provided by the library. To demonstrate the feasibility of this method, the system was improved and demonstration experiments were conducted at university and public libraries.

The contributions of this study can be summarized as follows:

1) We develop a high-performance (high accuracy and low latency) interactive robot system in a short period using cloud services. Further, we demonstrated how this robot works in a real environment, such as a university library, by exploiting the high performance of recently developed speech-related cloud services.
2) The feasibility of this method was demonstrated through the long-term operation of the developed robot system, improvement of the system for demonstration tests, and demonstration tests conducted at a public library.

II. RELATED WORKS

This section introduces several related studies to clarify the basis of this study. Our study involved the rapid development of a robotic system to support the professional work of librarians in university libraries. Several related studies have been conducted, including those on robots for working in libraries and robot systems for guiding receptionists.

One task of librarians is to organize shelves and guide users to the location of their desired books. Kim et al.

proposed a method for handling and organizing books on shelves, where books and their information are structured using radio frequency identification (RFID) [13]. Prats et al. conducted an experiment focusing on organizing books on the shelves of a university library based on image recognition and force control, and demonstrated the usefulness of the approach [14]. Martinez-Martin et al. developed a visual library inventory and book-localization system using drones in a library environment [15]. Mikawa et al. showed how to guide users to shelves using a laser pointer and a robot arm [16]. Lin et al. proposed a mobile service robot with communication functions for a children's library [17]. Tomizawa et al. developed a remote book-browsing system using a mobile robot that searches for the target book on book shelves [18]. In the above studies, librarians' work was realized using mobile functions and robot manipulation.

A receptionist robot with voice interaction capabilities has also been developed [19]. Gardecki et al. implemented and evaluated a Pepper-based reception robot for facial recognition [20]. Karunasena et al. developed a receptionist robot that interacted with people using open-source hardware [21]. Ichihara demonstrated a human-tracking navigation system for a museum-guide robot [22]. The goal of these studies was to develop a receptionist robot capable of interaction through movements and dialogue.

III. LIBRARY SERVICE HELPDESK SYSTEM

There are various tasks at the university library helpdesk considered in this study, such as responding to queries about graduate research, making photocopies of literature, borrowing books, using shelves, and responding to KONAN Library Certificates, a project run by the authors' university to evaluate and certify students' abilities based on the university's philosophy. The helpdesk was staffed by professional librarians. Librarians are often away from the helpdesk, not only for reception desk tasks, but also for administrative work, organizing bookshelves, and providing guidance to students elsewhere in the library. Therefore, we constructed a support system that can respond to users at remote locations and, if necessary, move to the helpdesk to respond directly to any queries.

In this study, we implemented the library service desk system for various helpdesk functions, as listed below:

1) Response to requests for Library Certificates.
2) Book searches.
3) Book recommendations.
4) Making photocopies of literature.

A. System Configuration

Fig. 1 shows an overview of the developed robot system for library service helpdesks. This system was constructed using a 28 cm tall tabletop communication robot Sota (Vstone Co., Ltd., Japan). Sota has functions such as arm and neck motion and LED-generated facial expressions. The system consists of a control PC, liquid crystal display (LCD), generic webcam, microphone, speaker, Internet of Things (IoT) device (M5 Stack), and Wi-Fi router system. We used an external webcam, microphone, and speaker rather than Sota's built-in camera to ensure the flexibility of the software development environment.

The LCD display shows the results of book searches and recommendations. The webcam detected the face of the user, and the microphone and speakers enabled voice communication with the user. The Wi-Fi router was used to configure the robot, PC, and IoT devices in one network and connect to the Internet, and the IoT device was used to call the library staff.

The Google MediaPipe face detection, a machine-learning library, enabled the detection of the user's face in real time. Microsoft Azure was used for speech recognition and synthesis to achieve fast and accurate recognition processing. VstoneMagic, a development kit for Sota, was used to generate the robot motion.

B. System Flow for Response to Users

Fig. 2 illustrates the process of responding to users. When a user is seated in front of the robot, the robot detects their face using the webcam installed on the LCD display, and determines whether the user is a helpdesk user if the face is recognized for more than three seconds. After the system detected the user's face, the robot raised its head to look at the user's face and raised its arm. The robot then asks the user about their requirements using a synthetic voice. When the user responds to the robot's question, the robot nods and listens through speech recognition. If the robot cannot understand the user's request, it can listen to the user's request up to three times. After hearing the user's request, the robot responds according to the flow shown in Fig. 2.

We made the robot move its arms and neck actively during the response to make users feel that they were interacting with the robot. After 10 s of processing, the robot returned to the face detection process.

IV. IMPLEMENTATION OF HELPDESK SUPPORT ROBOT SYSTEM

This section describes the implementation of functions developed to support library helpdesks. In this study, we implemented four functions to respond to user requests without requiring librarians. In addition, we introduced improvements to the robot service for implementation in the university library.

A. Response to Library Certificate Requests

When the system receives a query regarding library certificates, it provides a short explanation in a synthetic voice. When the user wishes to apply for a library certificate, the system sends a notification to the IoT device via user datagram protocol (UDP) communication and calls the librarian holding the device. While the librarian is being summoned, the library certificate webpage is displayed in front of the user.

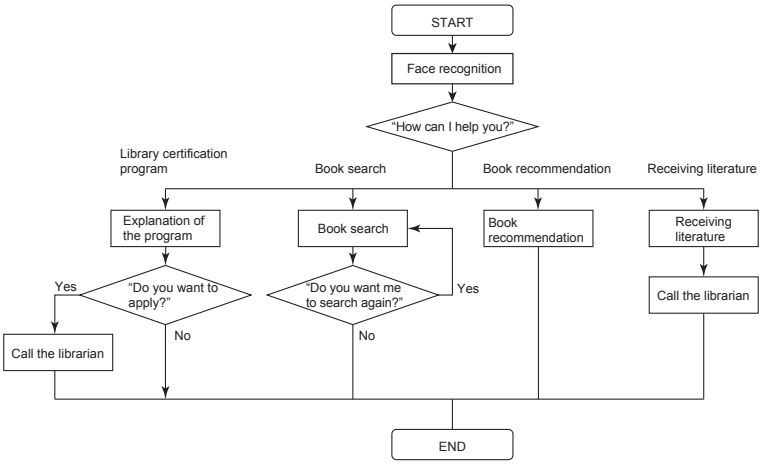

Fig. 2. System flow for a single user response.

B. Response to Book Search Requests

When the system receives a request to search for a book, it asks the user to state the title, author, or keywords of the book they are looking for and listens to the user through speech recognition. The keywords are then used to search the library's online public access catalog (OPAC) database via the library's web pages using web scraping, a software technology that extracts information from websites, and the results are displayed on the LCD screen.

Web scraping was performed using Selenium [c], which is provided as a Python library. This library can be used to control and retrieve information from webpages in the Google Chrome browser. The OPAC system used in this study does not have an open API and cannot be searched by external programs via commands; however, web scraping can be used to automatically search and obtain information as if the user is searching on a web page.

If the book the user is looking for is not found, the search can be resumed. The system displays the results of searches performed using different keywords.

C. Response to Book Recommendation Requests

When the system receives a request to recommend a book, it asks the user what genre of the book they are looking for and listens using speech recognition. Similar to a book search, the system searches the library's OPAC using web scraping and randomly introduces books from the search results. Information about each book is displayed on the LCD screen, and the title of the book is provided through speech synthesis.

D. Response to Photocopying Requests

Receiving photocopies involves an exchange of money that cannot be handled by a robot alone. Therefore, when a user wishes to pick up an ordered document, the system calls the librarian via an IoT device, as in the case of library certificate applications.

Fig. 3. Overview of experimental robot system at library helpdesk counter.

E. Improvement of Robot System for the Actual Operation

We illustrate the improvements made to the system during actual service operations in the library. This system is used in the operation of the help desk in the university library, as shown in Fig. 3. During the initial development of the system and first evaluation experiments, a general webcam was used. However, the system sometimes incorrectly detected a facial area from an image of the bookshelf in the background, and the system was activated even when the library was unattended. We replaced the generic webcam with an RGBD camera, Intel RealSense D435i, and modified the procedure such that the depth information was used to determine whether the user was seated in front of the robot. As a result, false positives were eliminated, and the robot was able to correctly detect whether the user was seated. We introduced the robot to assist with the help desk operation at the university library and confirmed that no false detections were observed since its introduction and operation.

In addition, after the system was launched at the university library, the latency between the robot and users was reduced by adjusting the timing of recognition of user responses to questions from the robot as shown in Fig. 4. Before the adjustment, library staff created and posted instructions on facial expressions and conversation based on their observations of users next to the robot. After the alternation latency was reduced, users were able to interact smoothly with the robot [23].

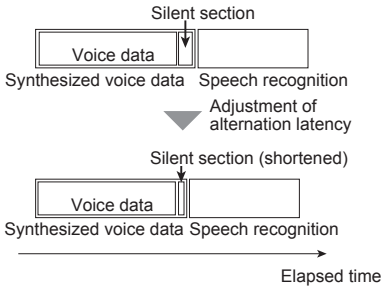

Fig. 4. Adjustment of alternation latancy for robot response.

Fig. 5. Robot system in a public library for empirical evaluation.

V. EMPIRICAL EVALUATION OF A LIBRARY HELPDESK SERVICE ROBOT IN PUBLIC LIBRARY

This section describes the usability evaluation conducted to verify whether the system works for the general users of public libraries. This experiment was conducted with prior review and permission from the Higashinada Library and Kobe City Library. In addition, this experiment was conducted after the review and approval by the Ethical Review Committee for Human Subjects Research at Konan University (Reception No: 21-17).

A. Implementation of Robot System for Empirical Evaluation

We implemented only the book search function of the robot system currently in operation at the university library for empirical evaluation. Users were asked to state the title and author of the book that they were looking for, and the system used speech recognition to listen to the user's voice. The keywords were then searched on the OPAC system via the library's web page using web scraping, a software for extracting information from websites, and the results were displayed on an LCD screen.

The system for the demonstration experiment was constructed by modifying the specifications that differed from those of the OPAC of the university library. To improve the accuracy of book searches, we used Google Books for web scraping to obtain bibliographic information from users' ambiguous keywords and voice recognition information, and then used OPAC's book search function. Google Books was used to correct author names that were incorrectly converted or those that were incorrectly remembered by users. For example, if a person with the same name but a different spelling is recognized by speech recognition, it is expected that the more appropriate person will be ranked higher in the book search results. Additionally, it is possible to correct the search results by assuming that the speech recognition result is a typo. We attempted to improve search performance using this function.

B. Communication with Public Libraries for Empirical Evaluation

An empirical evaluation was conducted within a public library. Prior to the evaluation, a proposal for a demonstration experiment was submitted to the Higashinada Library of Kobe City through the Regional Collaboration Center of the author's university. Following the written communication with the Higashinada Library, a cooperative response was obtained to the request for demonstration experiment under the following conditions:

- All the control PCs and the network equipment required was to be brought in as PCs and wireless networks in the library cannot be used.
- The user movement should not be obstructed.

The Higashinada Library circulated a proposal for a demonstration experiment to the Kobe City Library, which has jurisdiction over the Higashinada Library, and the experiment was approved to be conducted inside the library entrance. In addition, the content and methods of the questions asked to users during the experiment were reviewed and approved.

The library is very busy and usually has a large number of visitors waiting in long lines at the counter, with the number varying depending on the day of the week and the time of day. After discussions with the library director, it was decided to conduct the experiment during a period when the number of library users is relatively low, so as not to disturb them.

C. Experimental Conditions

The experimental space was set up next to the entrance to the first floor of Higashinada Library. Fig. 5 shows an overview of the robot system installed in the library. The experiment was conducted during the library's open hours for two days, November 30 (Day 1), December 1, 2022 (Day 2). Visitors were asked to participate in the experiment at the front of the experimental space in the library. The library permitted us to ask to the library users for participation of the experiments.

A total of 28 people participated in the two-day experiment: five under 10 years old, two teenagers, one in their 30s, five in their 40s, 14 over 60 years old, and one who did not respond. The frequency of library use by the experiment participants was as follows: one participant used the library less than once every six months, four participants used the library about once every three months, 14 used the library once or twice a month, seven used the library more than once a month, while two participants did not respond. The purpose of the experiment and use of the robot service were explained to the participants in advance. No audio or video recordings were made and the survey was conducted using a questionnaire.

To demonstrate the effectiveness of the library helpdesk support robot, the participants performed a book-retrieval

TABLE I

EVALUATION OF EASE OF THE ROBOT OPERATION.

Evaluation	Day 1	Day 2
1 (good)	7	7
2	3	3
3	2	2
4	2	2
5 (bad)	0	0

TABLE II

EVALUATION OF EFFECTIVENESS OF ROBOT OPERATION RESULTS.

Evaluation	Day 1	Day 2
1 (good)	3	4
2	5	5
3	2	5
4	3	0
5 (bad)	1	0

task that simulated remote assistance. The participants were seated in front of the robot and allowed to search for books in the library collection through dialogue with it. A series of tasks were completed by confirming the search results. After completing the task, the participants were asked to complete a questionnaire to evaluate their experiences with the robot system.

The book-search method was changed between the first and second days of the experiment. On the first day of the experiment, the robot searched Google Books for the author's name if the result of the semantic extraction was a person's name and otherwise for the title of the book. On the second day of the experiment, the participants searched Google Books as the author only when the semantic extraction result was a person's name, and in other cases, they searched the collection by directly inputting the result of removing fillers from the microphone speech recognition result as search keywords in the OPAC of the Kobe City Public Library.

D. Questionnaire Items

The questionnaire consisted of a combination of frequency, success/failure, 5-level multiple-choice, and open-ended questions. In addition to questions on age group and frequency of library use, the questionnaire included the following questions.

1) Did you obtain information on your book? (Yes – No)
2) Was it easy to understand the operation of the robot? (1: easy to operate – 5: difficult to operate) (ease of operation)
3) Were you able to operate the robot as expected? (1: Yes – 5: No) (operation results)
4) Did you enjoy the use of the robot? (1: Yes – 5: No) (user satisfaction)
5) Please fill in any other points you noticed. (free description)

E. Results and Discussions

The results of the experiments conducted over two days are summarized below. Six of the 14 participants on the first day of the experiment and 10 of the 14 participants on the second day answered that the robot was successful in obtaining the necessary book information. The results

TABLE III

EVALUATION OF USER SATISFACTION FROM THE ROBOT SERVICE.

Evaluation	Day 1	Day 2
1 (good)	11	9
2	2	4
3	1	1
4	0	0
5 (bad)	0	0

regarding the ease of understanding the robot operation, the effectiveness of the service provided by the robot, and the user satisfaction from the service provided by the robot are shown in Tables I–III. Regarding the three evaluation indicators, a Wilcoxon rank sum test was conducted at a significance level of $p < .05$ based on the null hypothesis that there were no significant differences in the experimental results on each experimental day. As a result, no statistically significant differences were observed in any of the cases. The p-values for each experiment were 0.96 for ease of robot operation, 0.37 for whether the robot could be operated as intended, and 0.63 for satisfaction with robot operation.

From the tables, it was confirmed that there was no difference between the ease of robot operation and the user satisfaction from the robot service. On the other hand, although the results of robot operation were not statistically significant, they were relatively higher on the second day. This can be attributed to the fact that the percentage of participants that could obtain the required information increased on the second day of the experiment compared to the first day. Some participants answered that they could not search as expected because of problems with the accuracy of the search results and voice recognition.

In the free description column, various issues were identified, such as the need to examine the automation of services, including robot functions and the division of roles among library staff members; the need to narrow down additional keywords; and the need to improve the interface. On the other hand, there was a case in which a child under 10 years old was able to search for a book using this system, and was pleased to be able to "look up a book by myself."

When we checked the recognition results of the search, we confirmed on the first day of the experiment that the search for a book by Google Books was limited to one specific book and that the search result was zero if the book was not in the library. On the second day of the experiment, the function changed. For example, if the registration of a symbol or number differs from that of OPAC, the search function is no longer available and the search accuracy is reduced. However, when the title of a bibliography uses conventional reading, it was confirmed that misrecognition and misconversion can be corrected by searching for the book title in Google Books. Improving search techniques by narrowing down and selecting keywords is an issue that must be addressed.

Based on these results, we found that it is possible to use an interactive robot with spoken dialogue, developed through experiments, to provide services in public libraries. However, there were some problems in the presentation of

the search results and in the voice recognition of the authors, such as misrecognition. In addition, there are several issues of the further development of the robot system to broaden the service scope to include multi-turn dialogue, adaptive interfaces, and personalized recommendations to enrich user interaction. Future issues include the extraction of search information, book recommendations based on library user reading records and book reviews, and responses to changes in search systems.

VI. CONCLUSIONS

This paper describes the rapid development of a library service robot using cloud computing services with AI and a demonstration experiment of a robot service in a public library. The robot system has been in operation for three years in university libraries, and after improvements in the user recognition system, it has been in continuous operation without any misrecognition problems. In the demonstration experiment at a public library, a collection search support system that differs from the one used in university library, and does not use personal information, was constructed, with the robot system actually in operation. The feasibility of the system was demonstrated through an evaluation of the developed spoken dialogue service robot in a public library.

The issues to be addressed in future research include the extraction of search information, book recommendations based on library users' reading records and book reviews, responses to changes in search systems, the provision of new library services, and the operation of the system in libraries. The further development of the robot system to broaden the service scope to include multi-turn dialogue, adaptive interfaces, and personalized recommendations to enrich user interaction are the future work of this study.

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