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Development and Evaluation of Mixed Reality Co-eating System: Sharing the Behavior of Eating Food with a Robot Could Improve Our Dining Experience

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***Abstract*— Eating with others enhances our dining experience, improves socialization, and has some health benefits. Although many people do not want to eat alone, there is an increase in the number of people who eat alone in Japan due to difficulty in matching mealtimes and places with others.**

In this paper, we develop a mixed reality (MR) system for co-eating with a robot. In this system, a robot and a MR headset are connected enabling users to observe a robot putting food image into its mouth, as if eating. We conducted an experiment to evaluate the developed system with users that are at least 13 years old. Experimental results show that the users enjoyed their meal and felt more delicious when the robot ate with them than when the robot only talked without eating. Furthermore, they eat more when a robot eats, suggesting that a robot could influence people's eating behavior.

I. Introduction

"Co-eating" which means eating meals with other people enriches our dining experience. Co-eating makes us enjoy our food more [1] and has other benefits, such as reducing the risk of depression and mortality [2], [3] and preventing obesity and underweight [4]–[6]. However, in the recent years, the increase in solitary eating has become a social problem in Japan. According to "Shokuiku Promotion Policies: FY2017 (White Paper on Shokuiku)" by the Ministry of Agriculture, Forestry and Fisheries in Japan [7], the percentage of people who ate every meal of the day alone for at least half the week in 2017 was 15.3%, which is 1.5 times higher than 10.2% in 2011. In the questionnaire on eating every meal of the day alone, which was asked to those who ate every meal alone more than once a week, 35.5% answered "I do not want to eat alone, but I cannot help it because my mealtimes and locations do not suit others" and 31.1% answered "I do not want to eat alone, but I cannot help it because nobody is available to eat with me." It is thought that the increase in one-person households especially among older adults, childless households, and single-parent households contributes to the increase in people who are compelled to eat alone.

This research aims to enrich our dining experience by co-eating with a robot to mitigate this social problem. Among the many factors that can improve our mealtime experience, this research focuses on co-eating with a robot. The results of an experiment conducted with humans show that the chocolate's taste and flavor were improved when the eating experience was shared with another person compared to when the person was present but did not eat the chocolate [8]. In this paper, we develop a system that presents a robot eating using mixed reality (MR) technologies as shown in Fig. 1, and investigate the effects of sharing eating behavior with a robot on our dining experience.

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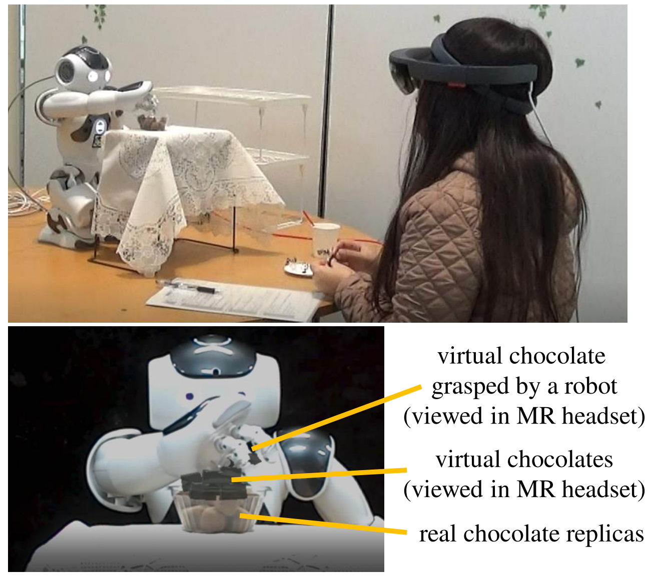

Fig. 1: Overview of the developed mixed reality (MR) co-eating system. Through a MR headset, participants can see a robot eating.

II. Related Researches

A. Researches About Co-eating Systems

Wei et al. developed "Codine," an interactive multisensory system for remote dining [9]. Codine enables people in different locations to see each other and serve food mutually. Their system addressed location issues. Noguchi et al. developed "KIZUNA," a video-mediated time-shifted co-dining system that addressed time issues [10]. In this system, people watch a recorded video of each other, therefore making communication noninteractive. Takahashi et al. developed a virtual co-eating system [11], which allows a virtual projected female agent to communicate and imitate the facial expression of the person eating. We cannot interact physically, like handing over seasonings while eating, because it

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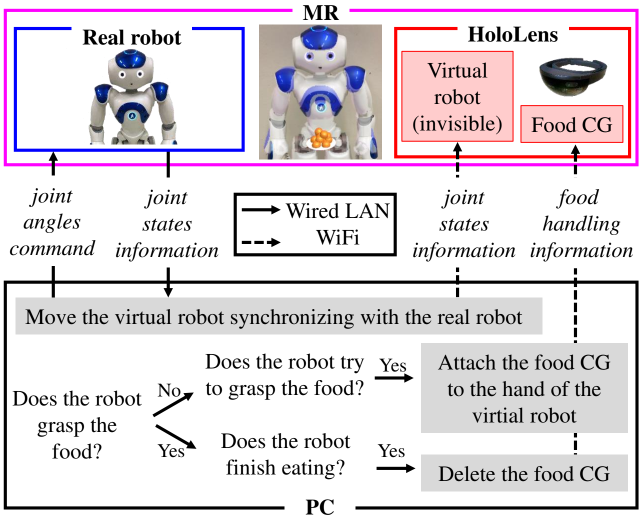

Fig. 2: Description of the MR system. WebSocket protocol provides a connection between the robot and an MR HMD and the interaction between the robot and virtual food.

is a video-only experience. In this research, we propose a co-eating system using a robot.

B. Researches About Robots Related to Meals

Various meal-related robots have been developed over time. Some robots feed older adults and people that are physically challenged [12]–[15] and wipe their mouths [16]. Others teach about nutrition [17] and encourage older adults to eat [18]. However, these studies use robot as a tool, and there are no researches on co-eating with a robot. In this paper, we verify the importance of robot eating when functioning as a meal partner.

III. MR System for Robot Eating

This section describes the robot eating system using MR as shown in Fig. 2.

A. Overview of the System

In this system, the WebSocket protocol was used to connect a real robot and an MR head-mounted display (HMD). People who wear the HMD can see the robot putting food models into its mouth, as if eating.

B. System Components

A small humanoid robot called NAO V6, developed by Softbank Robotics Europe, with 25 degrees of freedom and an approximate height of 58 cm, was used in the experiment.

We used HoloLens, an MR HMD developed by Microsoft Corporation. HoloLens has a transmissive display that enables the fusion of the virtual and real world and provides Simultaneous Localization and Mapping (SLAM) function using environment understanding cameras.

We used Robot Operating System (ROS) and Unity to develop the system that connects the robot and the HMD. The developed system enables the robot to handle the food models seen in the HMD.

(a) (b) (c)

Fig. 3: Process of robot eating. (a): The robot reaches out for the virtual food and attaches it to the hand. (b): The robot picks up the virtual food and brings it to the mouth. (c): The robot eats, and the virtual food disappears.

C. Synchronization of Robot Movement and Images Viewed in HMD

The position of the robot model, which exists in the images seen in HMD and the position of the real robot is pre-adjusted and moved simultaneously by sending and receiving messages about joint angles. When adjusting the position of the robot model in HMD, we use the Augmented Reality marker to set an approximate location and then tweak manually using a wireless controller. After the adjustment, the position of the robot model is retained by the SLAM function of HoloLens, and its mesh is made invisible. Consequently, people who wear the HMD can only see the food model and the real robot.

D. Details of Robot Eating

Fig. 3 shows the MR image viewed by the person who wears the HMD when the robot is eating. First, the real robot moves its hand toward the virtual food model's location in HMD, and the transparent robot model in the HMD moves at similar joint angles. Then, the food model is attached to the hand of the virtual robot model as shown in Fig. 3(a). Second, the real robot moves its hand to its mouth, and the transparent robot model makes a similar move. Consequently, only the attached food model appears to follow the real robot movement, as shown in Fig. 3(b). Subsequently, the real robot moves its neck vertically as eating behavior, and the mesh of the food model disappears to express the swallowing, as shown in Fig. 3(c).

IV. Experiment

A. Hypothesis

In this paper, we investigate the effects of co-eating with robots during mealtimes. Kimura et al. defined Shared Mealtime Quality (SMQ) as "sharing enjoyment in the presence of others at mealtime" [19]. Studies on co-eating in humans show that sharing the experience of eating could improve the taste and flavor of chocolates [8] and that behavioral mimicry could affect the amount of food taken in [20]. We verify the following three hypotheses about co-eating with robots.

Hypothesis 1

Robot eating makes the dining experience more fun than a robot that is not eating.

Hypothesis 2

Robot eating makes the food more delicious than a robot that is not eating.

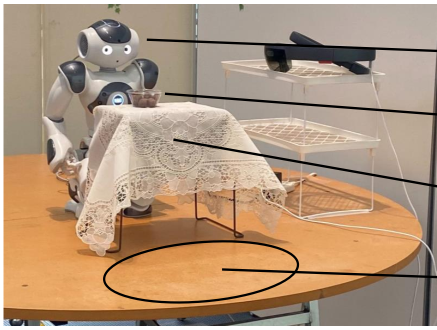

Fig. 4: Overview of the experience settings. The robot uses a small table to set the food within reach. Food replicas and virtual food viewed in the HMD are set approximately at the eye level of participants.

Hypothesis 3
People eat more with a robot eating than with a robot that is not eating.

B. Environment

The experiment in this paper was conducted at free admission open space at the National Museum of Emerging Science and Innovation in Japan. The overview of the experimental setup is shown in Fig. 4. A robot and a small table for the robot were placed on a table provided as the eating space for participants. We used a small table for the robot in order to set the food not only within reach of the robot but also at the level of participants' eyes since the field of view of HoloLens is limited.

C. Procedure

In this experiment, each participant experienced two conditions: Condition A, in which a robot ate chocolates with the participant, and Condition B, in which a robot only talked but did not eat. In each condition, a questionnaire was administered and the experience was video-recorded. In Condition A, the robot performed the eating behavior twice. Each participant was served two chocolates in both conditions, and the chocolates were the same in both conditions. The robot told the participants that they could eat all the chocolates but did not have to eat all. The participants ate the chocolates while wearing the HMD, and the chocolate models viewed in HMD appeared to be placed on the real chocolates(replicas). The duration of the experiment for each condition was approximately 90 seconds, and the order of Conditions A and B was randomized for each participant. The protocol for the experiment is as follows:

1) Participants fill out the informed consent form and the questionnaire on the profile and daily eating habits.
2) The HMD is attached after the brief explanation.
3) The robot introduces itself and signals the start of the experiment.
4) Experiment I is started. (Condition A or B)
5) The HMD is removed, and participants answer the questionnaire about Experiment I.
6) Participants drink water to wash out the mouth, and the HMD is attached again.
7) The robot chats for approximately one minute and signals the start of the experiment.
8) Experiment II is started. (the condition not conducted in Experiment I)
9) The HMD is removed, and participants answer the questionnaire about Experiment II.
10) Participants answer the questionnaire about the total experiment, and the experiment is explained.

The actions and conversations of the robot in the experiment were fixed and unaffected by the response of the participants. Examples of the dialog of the robot in Condition A include "I like this good flavor of cacao" and "I like sweets very much," while examples in Condition B include "Chocolates have good effects such as the improvement of concentration and elimination of constipation" and "What kind of chocolate do you like?". Chats between Experiments I and II varied to make the flow of the experiment natural. When Condition A came first, the robot reported that it got full, and when Condition B came first, the robot became hungry.

D. Measurements

Questionnaires were answered on a seven-point scale based on the experience condition such as the fun of the experience, chocolate flavor, and robot consideration. Furthermore, questionnaires were administered on opinions and demands on the concept of eating with a robot and evaluations of the developed system after the experiment with both Conditions A and B. Furthermore, the number of chocolates eaten by the participants under each experimental condition served as the objective index. Two video cameras set diagonally in front of and behind the participants, recorded their behaviors and reactions. The software EZR [21] was used to conduct paired t-tests, and the level of statistical significance was set at $p<.05$.

E. Participants

This experiment included 29 participants (16 women and 13 men) with ages between 13 and 72 years. Fifteen of them (eight women and seven men) experienced Condition A first, while fourteen (eight women and six men) experienced Condition B first.

V. Results

A. Hypothesis 1

Left graph of Fig. 5 shows the mean and standard error of the questionnaire results about the fun of the experience in each condition answered on a seven-point scale from 1 ("It was not fun at all") to 7 ("It was very fun"). There is a significant difference in the level of fun experienced by the participants ($n=29$, 4.83 ± 0.322 vs 4.52 ± 0.320, $p=.0238$).

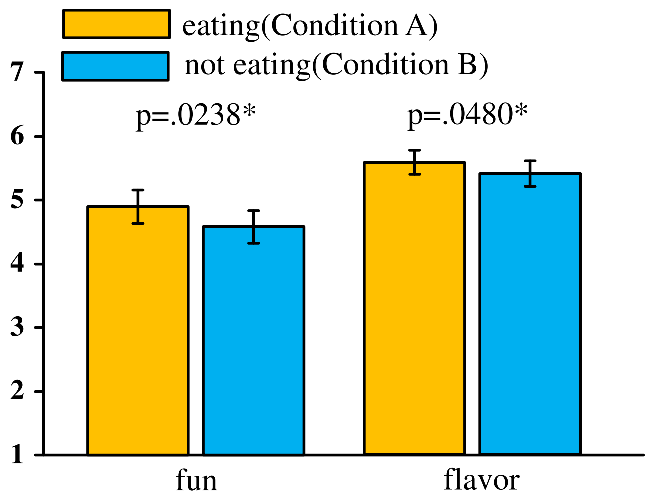

Fig. 5: Questionnaire results about the fun of the experience and the flavor of chocolates. (*: p<.05)

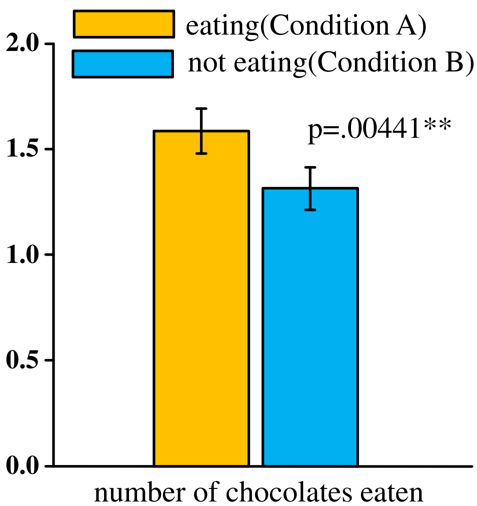

Fig. 6: The number of chocolates eaten by the participants. (**: p<.01)

B. Hypothesis 2

Right graph of Fig. 5 shows the mean and standard error of the questionnaire results on the deliciousness of the chocolates in each condition answered on a seven-point scale from 1 ("It was not delicious at all") to7 '("It was very delicious"). Significant differences exist in the flavor of chocolates eaten by the participants, except in one participant who did not eat the chocolate (n=28, 5.54 ± 0.233 vs 5.36 ± 0.242, p=.0480).

C. Hypothesis 3

Fig. 6 shows the mean and standard error of the number of chocolates eaten by the participants in each condition. There is a significant difference in the number of chocolates eaten by the participants (n=29, 1.59 ± 0.105 vs 1.31 ± 0.101, p=.00441).

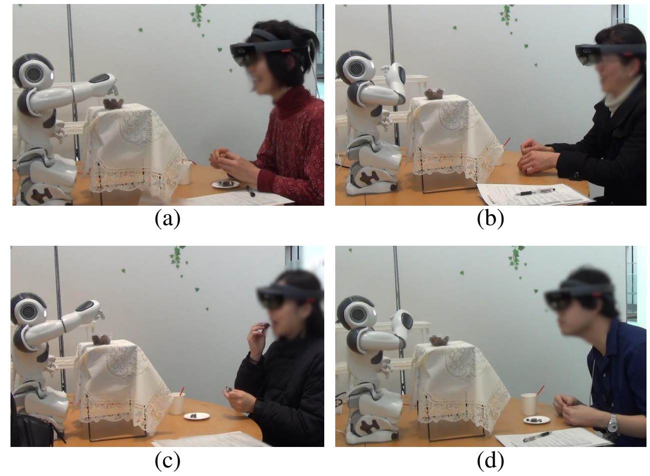

Fig. 7: Examples of the reactions of the participants while eating with the robot.

VI. Discussion about Statistical Results and Behaviors of the Participants

A. Dining Experience

There are significant differences in hypotheses 1 and 2. Also, some participants smiled when the robot started eating, as shown in Fig. 7(a) and (b). The dining experience results, including the dining experience becoming more fun and the food tasting more delicious when co-eating with the robot than when not co-eating with a robot, show that eating with a robot could improve our dining experiences.

Furthermore, when the robot started eating, some participants were surprised and stopped eating, as shown in Fig. 7(c). Others stared carefully and tried to look at the movement of the robot and the food model from the side, as shown in Fig. 7(d). These reactions show that the eating behavior of the robot is unprecedented and can be a novel solution for solitary eating.

B. Number of Chocolates Eaten

The number of chocolates eaten by the participants significantly increased when the robot ate. The questionnaires contained descriptions of eating speed, such as "I thought that I have to match the speed of eating with the root and ate two chocolates at the same time" and "I felt that the progress of the meal changed depending on the eating speed of the robot." These descriptions indicate that a robot could influence people's eating speed. However, it may be related to a phenomenon termed social facilitation of eating [22], [23], when people eating with others eat more than when they eat alone. Previous research on social facilitation of eating shows that people ate more when watching others eat in a video than watching others call on the phone in a video [24]. Further research will be needed to investigate whether people change eating speed following the robot's eating pace.

C. Results of Children under 13

During the experiment, 14 children, under 13 years old, experienced eating with a robot. We excluded their answers from the statistical results because of the absolute rating format of the questionnaires. Six children answered 7 ("It was very fun") to the question on the fun of the experience in both experimental conditions, and ten children answered 7 ("It was very delicious") to the question on the flavor of the chocolates in both experimental conditions. A different result can be obtained if questionnaires in the form of relative evaluation are used. Differences were recorded in the experimental conditions in five children for the number of chocolates eaten. Four children ate less in the first experiment and were shy before the robot. The unfamiliar robot and experimental environment may have affected their behaviors. Future experiments should have maximum consideration for children.

VII. Discussion about the Total Experiment

A. Demands for Eating with a Robot

We asked "Do you want to eat with a robot rather than eating alone?" in the questionnaire taken after both experimental conditions. Fifteen participants answered "Yes", thirteen answered "No" and one answered "Neither." We asked "What do you expect from the robot?" to the participants who answered "Yes" and "Neither." Eleven participants answered, "I want to talk with the robot."; seven answered, "I want to get the feeling of eating with someone"; four answered, "I want to share the deliciousness of the food"; and two answered, "I want to eliminate the loneliness of eating alone." Co-eating with a robot is expected to give a feeling of communicating at mealtimes and reduce loneliness while eating alone.

Conversely, the primary reason participants do not want to eat with a robot is because "Eating alone is more comfortable." Eight participants gave this answer. Some participants were concerned about the robot during the experiment. There was no significant difference in the question "Were you concerned about the robot?" answered on a seven-point scale from 1 ("I was not concerned at all") to 7 ("I was very much concerned") in the two conditions (n=28, 3.36 ± 0.386 vs 3.64 ± 0.382, p=.199), though we feel awkward if other people eat nothing during mealtime. Furthermore, some participants felt fear and anxiety about the robot. The robot's behavior and presence need to be improved in the subsequent research so participants can feel more home with it.

B. Demands for the Conversation with a Robot During Eating

As mentioned in Section VIIA, many people expected to have the robot as a talk mate. Although the robot spoke only the predetermined words in both experimental conditions, most of the participants nodded and replied to the robot's speech and questions. For example, a participant replied with, "I like it." when the robot asked, "Do you like chocolate?" Another participant answered, "I like sweet ones." when the robot asked, "What kind of chocolates do you like?" Some participants tried to communicate actively with the robot. For example, a participant said, "You will have a nosebleed if you eat too many chocolates," in response to when the robot said, "I am careful not to eat too many chocolates."

However, in the questionnaires written during and after the experiments, 21 participants mentioned robot speeches and many of them thought that robot speeches and chats are noninteractive and unnatural. Furthermore, some participants who do not want to eat with a robot rather than eating alone answered "My opinion could change to eat with a robot if I can discuss with it." and "It depends on the interface and the contents of the communication." Participants' answers show that the ability to establish interactive communication is a crucial element when eating with a robot and can reduce concern and the feeling of awkwardness identified in Section VIIA when participants ate with a robot.

C. Evaluation of the Hardware and Software of the System

In the question about the challenges and concerns during the experiment of the developed system, fifteen people answered, "The HMD was an obstacle for me," and seven answered, "The gap between the images seen in the HMD and the movement of the robot was unpleasant." Future research needs to consider other methods such as a midair image [25] and improve the software and data signaling rate.

D. Limitation

The experiment had limited scope as participants ate only chocolates within a short time (approximately 90 seconds) using a specific design of the humanoid robot. Consequently, this may not apply to all food types, experiment duration, and robot designs. Moreover, the participants in this experiment are Japanese and Asian people who live in Japan. Previous studies showed that impression and attitude toward robots vary with countries and regions [26], [27], and dietary habits vary by culture. This experiment should be conducted in different countries, regions, and cultures.

Furthermore, the experiment gave many participants the privilege of seeing a robot for the first time. In the experiment on humans, previous studies show that co-eating with acquaintances increased the pleasure of eating experience, while co-eating with strangers did not [28]. Similarly, another study shows that the relationship of dining companions such as friends or strangers is an essential factor for social facilitation [29]. Increasing the duration of contact with the robot may give a different result and raise further considerations.

Furthermore, wearing an HMD can negatively impact participants' willingness to eat with a robot since many participants saw HMD as an obstacle. Future research should investigate the effects of wearing HMD while eating with a robot.

VIII. Conclusion

This research aimed to achieve co-eating with a robot and developed the MR system in which people who wear the HMD can see a robot eating food by linking the movements of the real robot and the virtual food models displayed in the HMD. We evaluated the developed system by conducting an experiment at the science museum in Japan. The experiment result reveals that co-eating with a robot improved dining experience of the participants that are at least 13 years old by making the experience more fun and the chocolates more delicious. Furthermore, the participants eating more chocolates when they co-eat with robots suggests that robots could influence people's eating behavior.

In future work, we plan to investigate other dining experience elements besides those considered in this article, such as conversation and mutual interaction. Furthermore, we intend to improve the robot and MR systems for co-eating by enabling robots and humans to take food from the same plate and exchange foods and seasonings.

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