Sensecomputing for Human-Machine Collaboration through Human Emotion Understanding

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The Japanese working-age population is estimated to fall to about half of the total population by 2060. Along with this change in society, new working lifestyles such as working remotely and co-working with robots are becoming popular. Coming together with others within the workplace in the real world can create advantages for organizing our work life, but current computer technologies—including robots and other autonomous artificial intelligent systems—have not helped to create the same advantages in remote working spaces yet. Sensecomputing Research Center in Fujitsu Laboratories takes on this research issue regarding people's need for relatedness. We aim to develop computer-supported cooperative remote working spaces that satisfy people's basic psychological need for relatedness. In this paper, we introduce a preliminary study on building design for future remote working spaces. This paper presents findings obtained on how a user interacts with other persons using his/her interpersonal relationship building behaviors in virtual reality settings. It then shows that future remote working spaces will let a user be informed that another person would like to approach or avoid him/her, using where the other person's body parts are positioned, how angled the other person's upper body is, etc. This paper also includes the background for the study and the preliminary results of user observations, including its methodology and system configurations.

1. Introduction

"People sometimes act against their best interests." This is the basic concept behind behavioral economics, which attracted attention when economist Richard Thaler was awarded the Nobel Prize in Economic Sciences in 2017[1] for his contributions to this field of study. In fundraising for measures to fight poverty, for example, a story of a starving girl, rather than an explanation using numerical data, is often used to appeal to people. In this way, by devising the content of information to be provided and the order of presentation with people's emotional changes taken into consideration, support is given to facilitate people making good decisions for all of society.

Recently, behavioral economics and behavioral science are being utilized in a practical manner in Europe and the US.[2] This concept is also important to information systems faced with people, who act against their best interests. This is because a system is not considered to be capable of offering support in a way that is appropriate for people until it can present information in view of human behavioral principle and emotional changes.

Based on this concept, Fujitsu has set a vision to realize a Human-Centric Intelligent Society.[3] In taking this human-centered approach, Fujitsu Laboratories started working on sensecomputing in 2017. This is a cutting-edge area of study to allow information systems to have a deep understanding of people, including emotional and psychological aspects as well as human senses and sensitivity. This study requires a broad interdisciplinary point of view encompassing engineering, cognitive science, and psychology. Accordingly, we are actively working on joint research together with world-renowned university researchers in Japan and overseas in fields such as human-computer interaction (HCI) and computer-supported cooperative work (CSCW).

This paper first describes an information system collaborating with people, a goal aimed at by sensecomputing. Next, it presents a study and new findings obtained on interpersonal relationship building, which is an important factor for collaboration.

2. Information system collaborating with people

2.1 Background

The working-age population of Japan, which is increasingly aging with a declining birthrate, is estimated to fall to about half of the total population by 2060.[4) In order to prepare for labor shortages in the near future, people's work styles will unavoidably change. Situations will increase in which people work with intelligent computers and robots, and generations that work while raising children and giving nursing care will require flexible work styles and workplaces.

2.2 Purpose

One essential and important factor of people's working actively and humanly is the existence of and interaction with other people. However, the changes in working lifestyles described above will inevitably lead to decreased interactions between working people. We think that computer-supported future work styles will be able to fulfill people's basic psychological needs for relatedness. In addition, we believe these work styles will be able to maintain the same advantages that real world workplaces offer by providing partners and/or working spaces to work together. For example, people will be able to build interpersonal relationships with affective intelligent computers, including robots, and/or people will be able experience connections with co-workers in virtual/augmented reality (VR/AR) spaces even if they are working in geographically separate locations.

An information system capable of making use of the advantages resulting from the existence of and interaction with other people to facilitate people working humanly even in future working lifestyles—this is the information system that collaborates with people that Fujitsu Laboratories aims for.

The following sections present the results of a study on support in interpersonal relationship building between remote users as part of the approach to realize this information system that collaborates with people.

3. Study of support in interpersonal relationship building

3.1 Related work

Support in interpersonal relationship building is taken up in areas of study such as computer-mediated communication (CMC), in addition to HCI and CSCW. Examples of study include a software agent that builds relationships with people and a video conference system that supports the building of relationships between people. Interpersonal relationship building is difficult with verbal behavior alone, and many studies are conducted by incorporating nonverbal behaviors (such as eye contact and nodding) used during conversation by people in the real world.

Bickmore et al. have attempted to implement many conversational strategies (such as the prevention of face-threatening of the other party) and examples of nonverbal behavior in a conversational agent capable of displaying body movements as animations.[5) Otsuka et al. have used a display showing movements that mirror people's head motions in a remote conversation between multiple people to allow eye contact between people and develop a system that realizes natural communication similar to that in face-to-face situations in the real world.[6)

Past studies for support of interpersonal relationship building gave priority to support in conversational behaviors (such as utterances and attentive hearing). Accordingly, the focus was on the utilization of conversational strategies assumed to be important in studies of conversational behavior in the real world and of nonverbal behaviors (such as eye contact and nodding) during utterances and attentive hearing.

3.2 Focus of this study

In the real world, people sometimes adjust their physical distance from the other party according to the intimacy with other people. For a person to feel the existence of others and experiences interactions with others in teleworking, which involves the cooperation of people in distant places, we consider communication through nonverbal behavior at a level closer to reality as important or more so than relationship building for the purpose of making conversation function, which was discussed in related work.

One known theory relating to the adjustment of interpersonal relationships is the equilibrium theory of intimacy.[7] This theory assumes that a person behaves to build relationships according to the level of intimacy that he/she desires to establish with others. The theory also explains that, when others behave at a level of intimacy assumed by himself/herself, the person behaves to adjust interpersonal relationships with others by using things such as eye gaze, facial expressions, and physical distance.

For example, when Person A and B, who meet for the first time, have a conversation, Person A assumes a low level of intimacy toward Person B. If Person B suddenly comes very close in this situation, Person A recognizes that the balance between the level of intimacy assumed by himself and the real situation has been upset. To deal with this, Person A adjusts his behavior to restore the state of a lower level of intimacy, which is in balance with his own assumptions, from the present situation with its excessively high level of intimacy. Specifically, Person A may avoid making eye contact with Person B or turn away from Person B.

In this study, based on previous studies,[7)-11)] we picked out 18 types of behavior relating to known behaviors for adjusting interpersonal relationships in the real world, including those presented in the equilibrium theory of intimacy (**Table 1**). The table shows these 18 types of interpersonal relationship adjustment behavior classified into five categories based on the type of motion. These adjustment behaviors are observed in the real world and a remote environment and compared to obtain findings relating to interpersonal relationship building in remote environments.

4. User observations

This section presents user observations intended for building an information system that allows interpersonal relationship adjustment behavior between remote users in the same way as interpersonal relationship building that takes place in the real world. The observations were conducted in the design phase of the system. The purpose of user observations is to identify what is happening on-site through observations of interactions (not limited to conversation) between users to obtain findings to be reflected in the system design.

In this study, we obtained data on interpersonal relationship adjustment behavior between users in the real world (Step 1) and data on interpersonal relationship adjustment behavior between remote users (Step 2), observing with a focus on the differences in behavior.

4.1 Design of user observations

The information system for interpersonal relationship building between remote users is assumed to be applied to all scenarios in which interpersonal

Table 1
18 types of interpersonal relationship adjustment behavior.

Category name	[Identifier] Overview
Physical distance: Interpersonal relationship adjustment behavior by changing the physical distance	[SB01] Move the upper body closer [SB02] Move the upper body away [SB03] Move the face closer [SB04] Move the face away [SB05] Move body parts closer [SB06] Move body parts away
Attention: Interpersonal relationship adjustment behavior by changing the gaze attention	[SB07] Look at each other (bodies included) [SB08] Look away from the other party [SB09] Look at the same object with the other party [SB10] Follow the other party's gaze
Orientation: Interpersonal relationship adjustment behavior by changing the orientation with reference to the person on the other end of the conversation	[SB11] Turn the face toward the other party [SB12] Turn the face away from the other party [SB13] Turn the upper body toward the other party [SB14] Turn the upper body away from the other party
Leaning forward/backward: Interpersonal relationship adjustment behavior by leaning forward/backward	[SB15] Lean forward [SB16] Lean backward
Gesture: Interpersonal relationship adjustment behavior through gestures	[SB17] Make a gesture with a positive meaning [SB18] Make a gesture with a negative meaning

relationships are considered important. Examples of such scenarios may include job training given remotely, the seeking of medical advice from a remote place, and the sharing of a sense of presence that makes a person feel as if he/she is with his/her colleagues in remote places. The following describes the concept we used as the basis for designing the interaction scenario between users for us to observe from among these wide-ranging scenarios of application.

In this study, we considered the following two points in addition to ease of gathering of the group to observe. And in light of these considerations, we chose English conversation learning as the interaction scenario.

Firstly, we made a point of reducing variety in the interaction content. The content of utterances made during English conversation learning is limited to the improvement of conversation skills. Therefore, there is less variation in the content of utterances between learners than that in other scenarios, and the difference in the conversation content is less likely to have an influence.

Secondly, we attempted to ensure that the standpoints and roles of users would not significantly change during the experiment. Generally, the standpoints and roles of the English instructor and the learner do not significantly change during English conversation learning. Accordingly, the results are less likely to be influenced by changes in standpoints and roles.

4.2 Overview of user observation

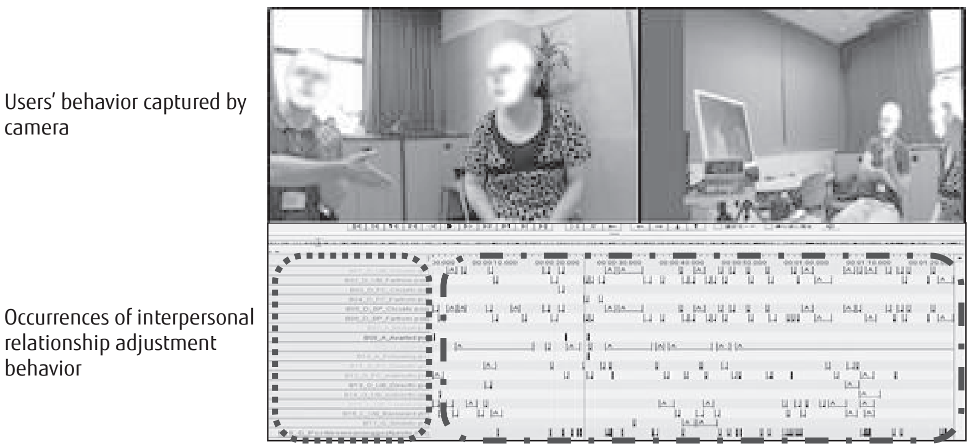
In user observations, we assigned one of the following three experimental conditions to English learners to collect data on the users' interpersonal relationship adjustment behavior in each of the conditions. The three conditions are:

- the condition of instructing to behave in a way so as to become friends with the English instructor (condition of approaching),
- the condition of instructing to behave in a way so as not to become friends with the English instructor (condition of avoiding), and
- the condition of not giving any instruction.

1) Observation of interpersonal relationship adjustment behavior between users in the real world (Step 1)

Step 1 is the observation of users facing each other in the real world. We observed an instructor and learners in the real world to find out what interpersonal relationship adjustment behavior would take place between them.

The 18 types of behavior in the real world in Step 1 are organized into **Figure 1**. Two cameras were used to capture how users behaved, and a tool to tag the behavior afterwards was used to organize the occurrences



- List of types of interpersonal relationship adjustment behavior enclosed in dotted frame
- Occurrences of respective types of behavior (duration shown is a little less than 1.5 minutes) enclosed in dot-dashed square
- Faces have been obscured in consideration of privacy

Figure 1
Data for interpersonal relationship adjustment behavior in the real world.

of each type of behavior shown at the bottom of Figure 1 in time series. The two images at the top left and right of Figure 1 are what were shot with the cameras installed in front and on the side of the English learners.

2) Observation of interpersonal relationship adjustment behavior between users in remote places (Step 2)

Step 2 is the observation of users in remote places. A VR space was utilized to observe users to find out how interpersonal relationship adjustment behavior occurred between the English instructor and learners and whether it was used in the same way as in the real world.

In this step, observations were conducted on the 18 types of behavior, and the occurrences were organized in time series in the same way as Step 1 in terms of whether the types of behavior were used to adjust approaching and avoiding in interpersonal relationships between remote users. In the VR space, we gave instructions on seating positions to the English instructor and learners to provide the same arrangement as that in Step 1.

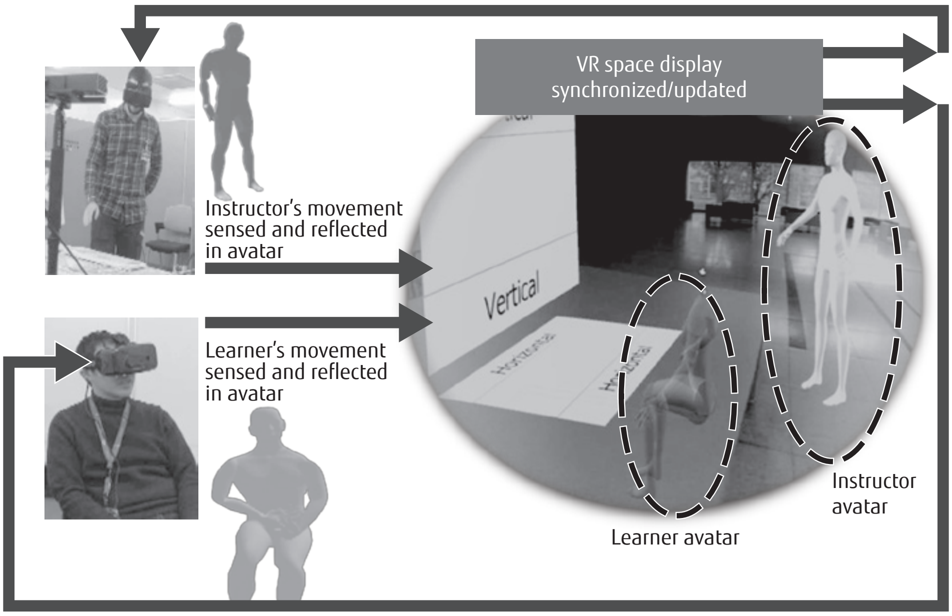
2-1) VR space

Figure 2 outlines the system built for observing the interpersonal relationship adjustment behavior between remote users. In the VR space, the English instructor and learner can express their own interpersonal relationship adjustment behavior by using the standing avatar and the sitting avatar in the figure.

A head pose sensor for detecting each user's VR headset position and a depth sensor mounted in front of each user for detecting user's body part positions are used to sense each user's head and body movements. The data obtained by the respective sensors are mapped to the position of the avatars and the angle of rotation of the respective body part joints. These movements are reflected in avatars in the VR space seen by remote users. In this way, the individual users can see the interpersonal relationship adjustment behavior taken toward them by remote users. In response, they can further adjust their own behavior.

2-2) Use case

Figure 3 shows an example of the field of vision of users obtained when they take part in interpersonal relationship adjustment behavior in the VR space. Here we use a use case to give an explanation about possible ways in which users take part in interpersonal

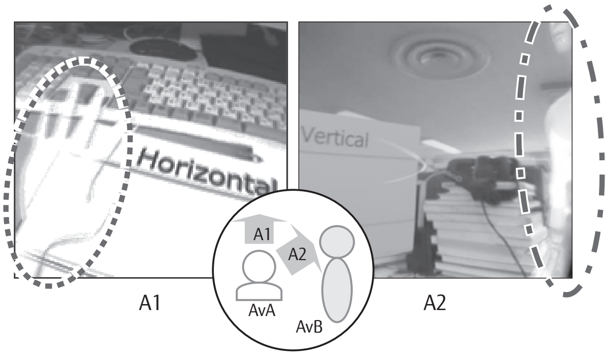


Omnidirectional image of the real world captured with a 360-degree camera used for configuring the VR space

Figure 2
System overview.

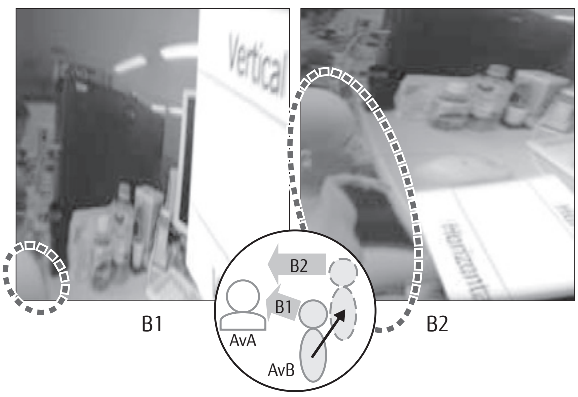
relationship adjustment behavior in a VR space, including how the field of vision of each avatar changes in that process.

- Example of interpersonal relationship adjustment through attention: Avatar AvA sees Avatar AvB. This causes the field of vision of Avatar AvA to change from a view of Avatar AvA's own hand (A1) to a view of Avatar AvB (B1), as shown in Figure 3 (a).
- Example of interpersonal relationship adjustment by leaning forward/backward: Avatar AvA leans forward. This causes the field of vision of Avatar AvA to change from a view of the documents, written as "Horizontal," on the desk in A1 of Figure 3 (a) to a closer view of the documents on the desk in sync with the forward leaning movement.
- Example of interpersonal relationship adjustment by physical distance: Avatar AvB moves away from Avatar AvA. This causes the field of vision of Avatar AvB to change from a view of Avatar AvA zoomed in (B1) to a view zoomed out (B2), as shown in Figure 3 (b).
- Example of interpersonal relationship adjustment by orientation: Avatar AvB changes the orientation of the upper body toward Avatar AvA. This causes the field of vision of Avatar AvB to change from a view of the documents, written as "Vertical," in front in B1 of Figure 3 (b) within the field of vision to a view of the documents in front moving out of the field of vision in sync with the movement of the upper body toward Avatar AvA.
- Example of interpersonal relationship adjustment by gesture: Avatar AvA folds its arms across its chest. This causes the field of vision of Avatar AvA to change from a view of its own hand visible on the documents, written as "Horizontal," on the desk in A1 of Figure 3 (a) to a view with the hand moving out of sight and the arms folded close to its body. The field of vision of Avatar AvB changes in sync with this movement to a view Avatar AvA sitting with the their arms folded, as shown in B2 of Figure 3 (b).



A1: Avatar AvA's own hand in dotted ellipse
A2: Avatar AvB in dot-dashed ellipse

(a) User A's field of vision



B1 and B2: Avatar AvA in dotted ellipse

(b) User B's field of vision

Figure 3
Examples of user's field of vision.

4.3 Results of user observations

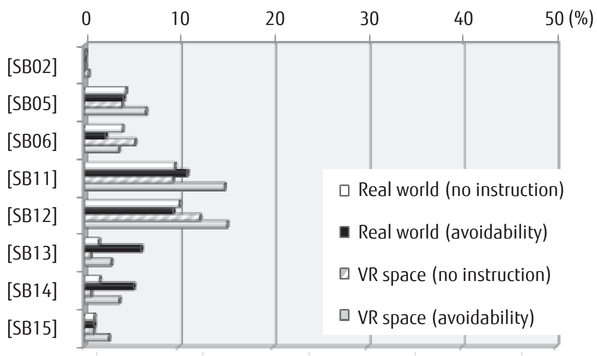
This subsection presents a comparison between data collected in Steps 1 and 2 in the previous subsection, the findings from the user observations in the present design phase, and two findings obtained to keep in mind in building the system.

First, the comparison shows that, of the 18 types of interpersonal relationship adjustment behavior used in the real world, some are seldom used in the VR space.

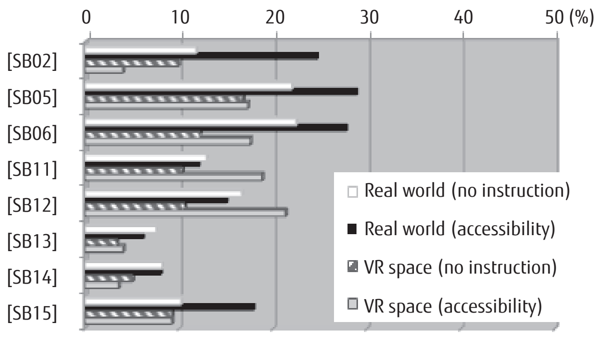
Figure 4 (a) shows data for an English learner, Learner 1. It is a comparison between the percentages accounted for by the amount of time for different types of behavior that occurred in relation to the entire period of the verification session with and without avoiding behavior. **Figure 4 (b)** shows data for another English learner, Learner 2. It is a comparison between the percentages accounted for by the amount of time for different types of behavior that occurred in relation to the entire period of the verification session with and without approaching behavior. For both Figure 4 (a) and (b), the types of behavior observed in the VR space for 50% or longer of the total time of the respective type of behavior observed in the real world were regarded as required in the VR space as well as in the real world, and eight such types of interpersonal relationship adjustment behavior were found.

Of these eight types of behavior, [SB02], [SB05], and [SB06] were related to the upper body and body part (head and hands) positions, [SB11] to [SB14] to the face and upper body orientations, and [SB15] to forward leaning of the upper body. It was observed that the types of interpersonal relationship adjustment behavior other than these eight types (e.g. behavior types [SB07] to [SB10] that use attention) were not used as often in the VR space as in the real world.

These results suggest that mutual communication using the positions of body parts and the orientation of the upper body—not regarded as important up to now in the field of study of nonverbal communication—is important for mutual communication of interpersonal relationship adjustment behavior of approaching and avoiding between remote users.



(a) Data for Learner 1



(b) Data for Learner 2

Figure 4
Amount of time for each type of interpersonal relationship adjustment behavior from of each session period.

Secondly, of the 18 types of interpersonal relationship adjustment behavior, some are used more often in the VR space than in the real world. This is explained by using type [SB11] of the interpersonal relationship adjustment behavior in Figure 4 (a). This is the behavior of turning the face toward the English instructor. A comparison of the increase in the interpersonal relationship adjustment behavior with and without the instruction condition of avoiding shows that the increase in the VR space is larger than that in the real world.

This implies that there are types of interpersonal relationship adjustment behavior that are more likely to be used in VR spaces. When designing the system, attention must be paid so that these types of behavior that are likely to be used can also be shared between remote users according to user situations.

5. Conclusion

This paper described a study for the realization of sensecomputing, where an information system understands human senses and feelings, and an information system that collaborates with people, both of which Fujitsu Laboratories is working on. It also presented, as part of the study, the work carried out in the design phase of a system that supports interpersonal relationship building between remote users with the aim of understanding and supporting people working in new ways in the future.

Through the user observations, we have made clear that it is important to share information about the positions of body parts and the orientation of the upper body between remote users, information that was not regarded as important in previous studies, in order for remote users to take part in interpersonal relationship adjustment behavior of approaching and avoiding.

This study has incorporated a broad interdisciplinary point of view through joint research with universities. In the future, synergistic development together with other organizations will be even more important in the field of business as well as the field of academia. For example, an information system that collaborates with people is expected to see synergistic growth, not only due to teleworking and other social demands but also due to the popularization of VR devices and AR devices.

At present, the study is progressing from the design phase based on user observation to the prototype system building phase. First, we will run this prototype system on a trial basis with a small number of users in FY2018 and repeat hypothesis testing together with collaborating researchers. We intend to repeat design and system construction in this way to work on the building of an information system that allows active cooperative work with team members.

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