Distance-adjusted Fuzzy Interpersonal Motions Expression for Mobile Eye Robot in Mascot Robot System

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Abstract: Interpersonal motions and their expression using a fuzzy inference based on a mental distance type pleasure-arousal space are proposed for a mobile eye robot in a mascot robot system. An interpersonal motion that consists of an interpersonal distance, a motion speed, and a motion trajectory is determined according to verbal information received from human in an interactive situation using a proposed fuzzy inference based on a mental distance type pleasure-arousal space. Interactive experiments with two scenarios are performed in an information recommendation situation with the mascot robot system. Subjective estimations using psychological scale and impression estimations using SD method with the factor analysis are conducted for 11 subjects. Since the results of the subjective estimation show 3.08 and 2.62 (out of 6), the validity of the fuzzy interpersonal motions expression is confirmed. The results of the impression estimation show that the mobile eye robot gives a feeling of closeness. The system provides user-friendly and casual information recommendation, which is essential for wide spread family use.

Keywords Interpersonal distance, Interpersonal motion, Mentality expression, Communication robot, Fuzzy inference, Mascot robot system.

1. Introduction

In an IT society, one of the hoped-for missions of robots is to actively bridge the digital divide caused by certain individuals such as elderly and the physically challenged. Robot interfaces are superior to text-based interfaces and software agents on displays in information support situations [1]. Robots which support human living should be equipped with abilities to communicate in casual and friendly fashion, just like humans. The casual and friendly communication is provided by combinations of following four types of messages: verbal level, symbolic level, direct mentality level, and implicit mentality level of messages. The verbal, symbolic, and direct mentality messages have been designed for robot communication [2-4], and implicit mentality messages should be taken into account in casual communication with robots as well.

Mobile robots are suitable for expressing implicit messages based on interpersonal distances. WAMOEBBA that is an emotional mobile robot expresses emotion using LCDs [5]. Emotional expressions based on motion trajectory have already proposed for an autonomy mobile robot [6]. And the combinational emotional expressions by motion trajectory and robot’s performance have proposed [7, 8]. In these researches, motion trajectories and their performance have been fully considered, but effects of distance changes in communication have not been considered, that is to say, implicit messages have not been considered.

Interpersonal distance between human and robot is considered [9, 10]. In these researches, interpersonal distance is considered only when human or robots remain stationary, and these robots do not change their distance from human as the situation demands. Speed adaption for a robot walking is proposed when human and Robovie-4 walk together [11]. The robot adapts its walking speed along with a human. But the mentality condition of the robot is no considered. A mobile robot displays the following motion of the robot using eyeball on a display, but without any emotional expression [12]. In all these mobile robot researches, interpersonal distance for expressing mentality is not considered.

An interpersonal motion based on interpersonal distance is proposed to express implicit mentality messages. The interpersonal motion consists of an interpersonal distance, a motion speed, and a motion trajectory. A mental distance type pleasure-arousal plane that is an extension of the pleasure-arousal plane is proposed to express interpersonal motions. An interpersonal motion is decided according to observed human speech in an interactive situation using a proposed fuzzy inference based on a mental distance type pleasure-arousal space.

Interactive experiments with two scenarios are performed in an information recommendation situation by the mascot robot system. Subjective estimations using psychological scale and impression estimations using SD method with the factor analysis are conducted to evaluate the proposed expression system.

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The arrangement of the robots in the room

The appearance of a mobile mascot robot

An overview of the mascot robot system is given in 2. Interpersonal motions based on interpersonal distance and fuzzy interpersonal motions expression based on the mental distance type pleasure-arousal space are described in 3. Interpersonal evaluation experiments in information recommendation situations are shown in 4.

2. Mascot Robot System

2.1. Information Recommendation by Robot

Information recommendation systems include text-based interfaces, software agents, and robot agents. Robot agents are superior to the two other types of agents in terms of familiarity and usability [1].

In the mascot robot system, the eye robots are used for a communication interface of information recommendation system. The eye robots include two types. One is a fixed type, and the other is a mobile type of eye robot. The mentality expression system of a fixed eye robot has already been proposed for friendly communication between robots and human interlocutor. In this paper, interpersonal motions and their expression method based on mental distance for a mobile eye robot are proposed for user-friendly and casual information recommendation in home environment.

2.2. Mascot Robot System

In a home environment, robots should assist users in a casual way just like human, e.g. conversation and friendly expression. A mascot robot system has already been proposed as an easily visible information terminal.

2.3. Mobile Eye Robot

The appearance of the mobile eye robot is shown in Fig.2. The mobile eye robot has a sound source directional detection function and an ultrasonic sensor for distance surveying, and moves based on the sound source directional detection. The dimensions of the mobile eye robot are: width 405mm, depth 400mm, and height 611mm. The mobile mascot robot has two drive wheels with stepping motors and one carrying wheel for moving motion.

3. Fuzzy Interpersonal Motion Expression for Mobile Eye Robot

3.1. Interpersonal Motion based on Interpersonal Distance for Mobile Eye Robot

Robots which work in living space (e.g. home environment) should be equipped with abilities to communicate in casual and friendly fashion. Not only functions of verbal communication, but functions of nonverbal communication need to be considered for design of friendly robots. There are four major levels of transmission of message in human communication from communication design point of view. Ordered by verbal degree, they are: verbal level, symbolic level, direct mentality level, and implicit mentality level. Verbal level messages are based on language, including oral or spoken communication and writing. Symbolic level messages are not verbal message, but have particular meanings in each message, including hand signals, gestures, body motions, and eye contact. Direct mentality messages express mentality states with awareness (e.g. facial expressions). Implicit mentality messages express mentality states without awareness (e.g. posture and interpersonal distance). The combinations of these four types of messages provide casual and friendly communication between humans. The verbal, symbolic, and direct mentality messages have been designed for robot communication [2-4], but implicit message should be taken into account in casual communication with robots as well. An interpersonal motion based on interpersonal distance is proposed to express implicit mentality message. The interpersonal motion consists of an interpersonal distance, a motion.
The mental distance type pleasure-arousal space  
Fig. 3. the fuzzy inference system for expressing the interpersonal motions

![Image showing the fuzzy inference system for expressing the interpersonal motions.](image)

Fig. 4. the typical motion trajectories

![Image showing typical motion trajectories.](image)

The mental distance type pleasure-arousal space

![Diagram showing the mental distance type pleasure-arousal space.](image)

Fig. 5. the mental distance type pleasure-arousal space

An interpersonal distance between humans has been proposed by Hall from the view point of proxemics. The distances between humans depend on the mental state. Interpersonal distance for human communication is classified into following four types: intimate distance (from 0 to 50cm), personal distance (from 50 to 120cm), social distance (from 120 to 360cm), and public distance (from 360cm). This classification is applied to the mobile eye robot in robot-to-human communication.

Interpersonal distance for the mobile eye robot is decided on a physical distance and a mentality distance. The physical distance is a distance between the robot and a human in a real environment. The physical distance changes according to interlocutor’s actions and the robot’s actions including executions of tasks and mentality expressions. The mentality distance is a distance decided by the system according to the mentality of the robot, and changes according to the communication with a human interlocutor based on an after-mentioned fuzzy inference using an extended pleasure-arousal space. In the system, the interpersonal distance $d_{\text{interpersonal}}$ is decided as a weighting addition of a physical distance $d_{\text{physical}}$ and a mental distance $d_{\text{mental}}$ as

$$d_{\text{interpersonal}} = w_{\text{physical}}d_{\text{physical}} + w_{\text{mental}}d_{\text{mental}} \quad (1),$$

where $w_{\text{physical}}$ and $w_{\text{mental}}$ are weighting coefficients and based on turning the fuzzy inference of the system, the ratio of the weights is set to 1:2.

A motion speed is related to the arousal-sleep axis. When the mentality level of arousal is high, the motion speed increases up. When the state is closer to the sleep region, the motion speed tends to become low.

A motion trajectory is decided for expressing typical mentality states based on [6]. The typical motion trajectories are shown in Fig. 4. In a ‘normal’ state, the mobile eye robot goes straight ahead or astern. In a ‘happiness’ state, the robot runs around a human interlocutor. In ‘fear’, the robot goes backwards taking steps. In ‘anger’, the robot goes besides an interlocutor. In ‘surprise’, the robot goes straight backwards, and then stands back with a small step. In ‘disgust’, the robot turns its back. In ‘sadness’, the robot shakes its body. These states are arranged on a pleasure-arousal plane [3].
Tab.1. Examples of fuzzy rules: [interpersonal distance: Positive, language category 4]

<table>
<thead>
<tr>
<th></th>
<th>pleasure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NL</td>
</tr>
<tr>
<td>PL</td>
<td>(AZ, NL, NE)</td>
</tr>
<tr>
<td>PS</td>
<td>(NS, NS, NE)</td>
</tr>
<tr>
<td>AZ</td>
<td>(NS, NS, NE)</td>
</tr>
<tr>
<td>NS</td>
<td>(NS, AZ, NE)</td>
</tr>
<tr>
<td>NL</td>
<td>(NL, AZ, NE)</td>
</tr>
</tbody>
</table>

The values show: (pleasure, arousal, interpersonal distance)
pleasure axis, arousal axis: five grades (Negative Large, Negative Small, Approximately Zero, Positive Small, Positive Large)
interpersonal distance axis: three grades (Negative, Approximately Zero, Positive)

calculated according to a mental state and the speech from an interlocutor. A mental distance axis is added to a pleasure-arousal space. The mental distance type pleasure-arousal space is shown in Fig.5.

The mentality states, which are the coordinates of the mental distance type pleasure-arousal space are decided using the fuzzy inference. The system flow is shown in Fig.3. Inputs of the fuzzy inference are one language category information, two coordinates of the pleasure-arousal plane, and one interpersonal distance including a mental distance and a physical distance.
The outputs of the fuzzy inference are the coordinates of the mental distance type pleasure-arousal space, which are the coordinates of pleasure-displeasure, arousal-sleep, and mental distance. The interpersonal motion is decided based on the coordinates.
The language category information is decided according to the human speech by the speech recognition system [13]. The language categories are: ‘CAT1. positive to robot’, ‘CAT2. negative to robot’, ‘CAT3. positive interlocutor’, ‘CAT4. negative interlocutor’, ‘CAT5. difficult word’, and ‘CAT6. greeting’ [3, 6].

Pleasure-displeasure axis and arousal-sleep axis use five-grade, and interpersonal distance axis uses three-grade triangle-shaped membership function. The mental distance type pleasure-arousal space is divided into 75. 450 fuzzy rules can be assigned to the 6 types of language categories in the mental distance type pleasure-arousal space, but it is impractical considering the human inability to grasp all of the rules simultaneously and the computational capacity of the robot system. Therefore, only 162 of fuzzy rules are selected, which is a more practical number. Examples of the fuzzy rules in a situation when input word is ‘category 4’ and an interpersonal coordinate in the mental distance type pleasure-arousal space is positive are given in Tab.1. These rules are defined based on the natural reactions of humans. To obtain fuzzy quantization, membership functions are defined for each input feature. To obtain the outputs, the center of gravity method is used as a defuzzification method.

The typical transitions in mental type pleasure-arousal space caused by the inputs of language category information are shown in Fig.6. In the figure, the physical distance depends only on the interpersonal motion.

The mobile eye robot expresses these interpersonal motions composed of the interpersonal distance, the motion speed, and motion trajectory as a response to humans.

3.2. Fuzzy Inference based Interpersonal Motion Expression in Mental Distance Type Pleasure-Arousal Space

A mentality states can be arranged on a pleasure-arousal plane. Arrangements of expression motions on the two-dimensional pleasure-arousal plane and its extension enable to express the mentalities in interaction. Deferent communication channels have different arrangements and their extensions. A mentality expression motion has arranged on an extended pleasure-arousal space with affinity axis for eye motions, symbolic and direct mentality messages [3]. But mentality expression models for implicit messages have not been proposed. A mental distance type pleasure-arousal space that is an extension of the pleasure-arousal plane using interpersonal distance is proposed for the mental model of interpersonal motion, implicit message.

A motion speed and a motion trajectory can be arranged on a pleasure-arousal plane. As for the interpersonal distance, a physical distance and a mental distance should be taken into account. The physical distance can be calculated using information by an ultrasonic sensor. A mental distance needs to be
The third is that the mobile eye robot expresses the mentality expressing trajectory with appropriate speed, but without changing the distance between the robot and a subject. (pattern 2: trajectory and speed). The third is that the robot expresses the trajectory with appropriate speed and interpersonal distance, namely, interpersonal motion (pattern 3: interpersonal motion). These three patterns are enough for confirming the effectiveness of the proposed method. There is no other comparison method to change automatically a distance between a robot and a human in communication situations where both a robot and a human move. In the scenarios, the three patterns are performed in no particular order.

Two typical interactive scenarios are prepared for the questionnaires. The procedure of the experiments is as follows:

Step1) the subject is informed about the experimental scenarios and the mobile eye robot.
Step2) the subject performs an interactive scenario with the robot.
Step3) after the performance, the subject fills out the subjective estimation questionnaire.
Step4) steps2) and 3) are repeated for the three action patterns.
Step5) steps2), 3), and 4) are repeated for another scenario in the same way.
Step6) the subject fills out the impression estimation questionnaire.
Step7) the subject is interviewed about the experiments.

Two scenarios are prepared to eliminate incidental elements. One has cuts when the distances between the robot and a subject, apart from interpersonal motions, are changed. The other does not have cuts. The details of the scenarios are as follows:

Scenario1) Scenario 1 is a TV program recommendation situation for a person in home. The scenario includes three cuts and four scenes, ‘1. greeting’, ‘2. information recommendation by the mobile eye robot’, ‘3. remarks about the information from the person’, and ‘4. parting’. A subject plays the role of the person.

Scenario2) Scenario 2 is a cocktail recipe recommendation situation for an inhabitant in home. The scenario includes only one scene, and no cuts. A subject plays the role of the inhabitant.

The dialogs and their categories in the two scenarios are given in Tab.2 and Tab.3. The transitions of the states in mental distance type pleasure-arousal space are shown in Fig.8 and Fig.9. The subjects for the experiment are 11 engineering students.

### 4. Interpersonal Evaluation Experiments in Information Recommendation Situations

#### 4.1. Psychological Evaluation on Interactions

To estimate human impressions on the proposed fuzzy interpersonal motion expression, interactive experiments are performed in information recommendation situation. Two types of questionnaires are conducted. The first questionnaire gives a subjective estimation using psychological scale for verifying the validity of the interpersonal motion. The second is an impression estimation using SD (Semantic Differential) method and factor analysis to check the impression on the mobile eye robot. Experimental situation involves the mobile eye robot recommending the information to a subject in an interior space simulating a home environment. Fig.7 shows experiment’s disposition.

To verify the influence of interpersonal expression, the following three types of action patterns are performed by the mobile eye robot, and compared to one another. The first pattern is that the mobile eye robot does not move at all (pattern 1: no motion). The second is that the mobile eye robot expresses the mentality expressing trajectory with appropriate speed, but without changing the distance between the robot and a subject. (pattern 2: trajectory and speed). The third is that the robot expresses the trajectory with appropriate speed and interpersonal distance, namely, interpersonal motion (pattern 3: interpersonal motion). These three patterns are enough for confirming the effectiveness of the proposed method. There is no other comparison method to change automatically a distance between a robot and a human in communication situations where both a robot and a human move. In the scenarios, the three patterns are performed in no particular order.

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The dialogs and their categories in the two scenarios are given in Tab.2 and Tab.3. The transitions of the states in mental distance type pleasure-arousal space are shown in Fig.8 and Fig.9. The subjects for the experiment are 11 engineering students.
4.2. Result of the Experiments

4.2.1. Subjective Estimation using Psychological Scale

The results of the subjective estimations using psychological scale are shown in Fig.10 and Fig.11. These figures show the mean values obtained for each question in the two scenarios according to all the subjects. The six questions in the experiment are given in Tab.4. The experimental interlocution is evaluated on a scale from one to six in each question. Low values imply positive, and high values imply negative effect on the communication. The average evaluation values for all questions and each pattern are given in Tab.5.

After the questionnaire, the following comments are received from the subjects:

Comment1: The subjects feel friendly toward the motion in which the robot comes up when the subjects make a positive remark after negative remarks.

Comment2: The distance is important. The actions accompanied by a distance change are easier to understand and more friendly than the action itself. For example, the subjects feel the robot goes into a sulk, when the robot expresses a sadness action at a distance.

Fig.10 and Fig.11 show that the pattern 3 is evaluated as the worst positive, pattern 1 as most negative, and pattern 2 in between for all the questions. Tab.5 shows that average values for all questions indicate the same tendency as well. The averages of the pattern 3 are 3.08 and 2.62. These are the most positive values in all three patterns. This means that the pattern 3, the interpersonal motion, gives more positive impressions to human subjects than other two patterns of motions. In particular, according to the comment 2, the distance change is important. The same comment is received from the several subjects. This means that the interpersonal distance is effective.

<table>
<thead>
<tr>
<th>Tab.4</th>
<th>the items of the subjective estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>questions</td>
</tr>
<tr>
<td></td>
<td>1 six scales evaluation value → 6</td>
</tr>
<tr>
<td>The robot is…</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>easy to talk to. – difficult to talk to.</td>
</tr>
<tr>
<td>2</td>
<td>congenial. – ungenial.</td>
</tr>
<tr>
<td>The motions are…</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>fit for the situation. – unfit for the situation.</td>
</tr>
<tr>
<td>4</td>
<td>natural. – unnatural.</td>
</tr>
<tr>
<td>5</td>
<td>easy to understand. – difficult to understand.</td>
</tr>
<tr>
<td>6</td>
<td>necessary. – unnecessary.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tab.5</th>
<th>the average evaluation values of the subjective estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>scenario 1</td>
</tr>
<tr>
<td>pattern 1</td>
<td>5.47</td>
</tr>
<tr>
<td>pattern 2</td>
<td>3.95</td>
</tr>
<tr>
<td>pattern 3</td>
<td>3.08</td>
</tr>
</tbody>
</table>

4.2.2. Objective Estimation using Psychological Scale

The objective estimation of the experiments using psychological scale is shown in Tab.6. The results are similar to the subjectiveestimation, and the instructional distance has an important role in this evaluation value.
Tab.6. the results of SD method and factor analysis

<table>
<thead>
<tr>
<th>Pair of adjectives</th>
<th>factor1</th>
<th>factor2</th>
<th>factor3</th>
<th>Avg.</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>comprehensible - incomprehensible</td>
<td>0.814</td>
<td>0.533</td>
<td>0.221</td>
<td>3.45</td>
<td>1.16</td>
</tr>
<tr>
<td>cozy - stiff</td>
<td>0.793</td>
<td>0.03</td>
<td>0.099</td>
<td>2.73</td>
<td>0.62</td>
</tr>
<tr>
<td>humanity - perfunctory</td>
<td>0.722</td>
<td>0.431</td>
<td>0.257</td>
<td>4.27</td>
<td>1.14</td>
</tr>
<tr>
<td>sympathetic - disgusting</td>
<td>0.633</td>
<td>0.12</td>
<td>0.117</td>
<td>2.82</td>
<td>1.03</td>
</tr>
<tr>
<td>dislikable - dislikable</td>
<td>0.049</td>
<td>0.995</td>
<td>0.047</td>
<td>2.82</td>
<td>0.94</td>
</tr>
<tr>
<td>approachable - unapproachable</td>
<td>0.22</td>
<td>0.701</td>
<td>0.257</td>
<td>2.82</td>
<td>1.03</td>
</tr>
<tr>
<td>interesting - boring</td>
<td>0.386</td>
<td>0.586</td>
<td>0.108</td>
<td>2.09</td>
<td>0.67</td>
</tr>
<tr>
<td>smart - foolish</td>
<td>0.047</td>
<td>0.232</td>
<td>0.969</td>
<td>4.00</td>
<td>1.04</td>
</tr>
<tr>
<td>quick - slow</td>
<td>0.228</td>
<td>0.018</td>
<td>0.688</td>
<td>4.36</td>
<td>1.15</td>
</tr>
<tr>
<td>amiable - unamiable</td>
<td>0.179</td>
<td>0.349</td>
<td>0.388</td>
<td>2.82</td>
<td>1.03</td>
</tr>
</tbody>
</table>

4.2.2. Impression Estimation using SD Method and Factor Analysis

The results of the SD method and the factor analysis are given in Tab.6. The mobile eye robot is evaluated on a scale from one to six on 10 question items. The proportions of variance and the average scores of the evaluation values for each item are shown in the table. Low values mean positive, and high values mean negative effect on communication.

The results give three factors. The first factor is named the “communication factor” (factor 1) related to “comprehensible-incomprehensible”, “cozy-stiff”, “humanity-perfunctory”, and “sympathique-disgusting”. The second factor is named the “closeness factor” (factor 2) related to “dislikable-dislikable”, “approachable-unapproachable”, and “interesting-boring”. The third factor is the “ability factor” (factor 3) related to “smart-foolish” and “quick-slow”.

In communication factor, the evaluation values of “cozy-stiff” and “sympathique-disgusting” show positive tendencies. The item “humanity-perfunctory” shows a negative tendency. In closeness factor, the evaluation values of the all related items show positive tendencies. In ability factor, the evaluation values of the all related items show negative tendencies.

From the result of the closeness factor, it is confirmed that the subjects feel the closeness toward the robot. In communication factor, the mechanical appearance of the eye robot head may make an effect on the evaluation value of “humanity-perfunctory”.

Due to the safety of human interlocutors, the speed of the mobile eye robot is reduced and this could be a possible explanation for the high values of the ability factor (i.e. the humans perceive the robot as slow or foolish).

As a result of factorial analysis, the mobile eye robot is suitable for a communication system in home environment where the closeness factor and communication factor is important.

5. Conclusion

Interpersonal motions and their expression using a fuzzy inference based on a mental distance type pleasure arousal space for a mobile eye robot are proposed for user-friendly and casual information recommendation in a mascot robot system.

An information recommendation module, a speech recognition module, and five friendly eye robots (four fixed type and one mobile type), are integrated into the mascot robot system with the aid of RT Middleware. This system has been tested in a living space simulating a home environment. Four fixed type eye robots are placed on the furniture and appliances such as TV, PC or a cabinet. The mobile eye robot moves along with users to assist them. The mobile eye robot has a sound source directional detection function and an ultrasonic sensor for distance surveying, and moves based on the sound source directional detection. The dimensions of the mobile eye robot are: width 405mm, depth 400mm, and height 611mm.

An interpersonal motion based on interpersonal distance is proposed to express implicit mentality messages which are necessary in a casual communication. The interpersonal motion consists of the interpersonal distance, the motion speed, and the motion trajectory. The motion speed is related to the arousal-sleep axis. The motion trajectory is decided for expressing typical mentality states based on [6]. The motion trajectories are arranged on a pleasure-arousal plane. For the interpersonal distance, a physical distance and a mental distance are taken into account. The physical distance is calculated using an ultrasonic sensor. The mental distance is calculated as one of the coordinates using the proposed fuzzy inference based on the mental distance type pleasure-arousal space. The fuzzy inference enables the mobile eye robot to express the interpersonal motions according to verbal information received from human in an interactive situation.

To estimate human impressions on the proposed fuzzy interpersonal motion expression, interactive experiments with two scenarios have been performed in an information recommendation situation aided by the mascot robot system. The subjective estimation using psychological scale and the impression estimation using SD method with the factor analysis have been conducted for 11 subjects. Since the results of the
subjective estimation shows 3.08 and 2.62, the validity of the fuzzy interpersonal motions expression has been confirmed. The results of the impression estimation show that the mobile eye robot gives a feeling of closeness.

The proposed system enables a robot to express implicit mentality messages. The system provides user-friendly and casual information recommendation, which is essential for wide spread family use.

References

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