Detection of Division of Labor in Multiparty Collaboration

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Abstract. In the research field of human-computer interaction, there are many approaches to predicting interactive roles, e.g., conversational dominance or active participation. Although interactive roles have been predicted for entire tasks, little attention has been given to evaluating how such roles are reorganized during a task. This paper explains how to construct a model for predicting emergent division of labor and the reorganization of labor in multiparty collaboration using verbal and non-verbal cues. To build the model, we adopted stepwise multiple-regression analysis, which is a type of statistical model analysis, using both behavioral data and third-party evaluations. We confirmed useful verbal and non-verbal parameters for predicting interactive roles and their reorganization through this model.

Keywords: Emergent division of labor, reorganization, statistical model analysis, verbal and nonverbal behavior, third-party evaluation.

1 Introduction

Recent human-computer studies have focused on a framework for CG characters or communication robots participating in multiparty interaction among people [1, etc.]. Predicting emerging interactive roles in group collaboration is a key task for constructing such a framework.

In group work among people, the interactive roles of leaders and followers emerge and reorganize themselves. Participants participate in group work while perceiving the emerging interactive roles and their reorganization from each other's verbal and non-verbal behaviors [2,3,4,5,6].

The purpose of this study is to develop a ubiquitous computing technique that can automatically predict the players of interactive roles in multiparty interaction. This paper focuses on how verbal and nonverbal behaviors contribute to natural leader and follower emergence and role-reorganization during interaction. In this study, a participant who has the ability to motivate other group

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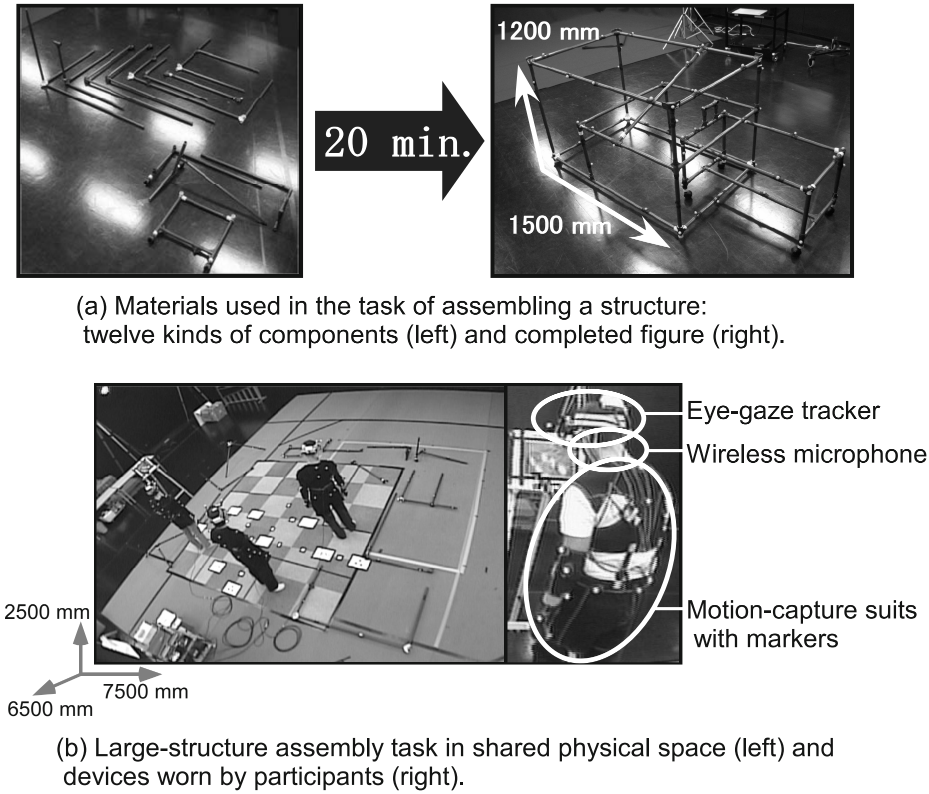

Fig. 1. Materials used in assembly task: twelve components (upper left) and completed figure (upper right), large-structure assembly task in shared physical space (lower left), and devices worn by participants (lower right)

members to achieve the task is considered a leader. Similarly, a participant who has the ability to effectively follow and support a leader is regarded as an active follower, while a less able follower is regarded as a passive follower, based on Bjugstad's definitions [7].

Conventional studies on multiparty conversations with positionally fixed participants have pointed out the crucial role played by verbal and nonverbal behaviors in the process of natural leader emergence [8,9]. Previous studies on the relationship between dominance and conversational behavior show that gaze, as well as speech, contributes to the establishment of higher-status persons [10,11,12]. Related works on conversational dominance have also tried to detect a single interactive role, either dominance or activeness [13,14].However, no research has yet shown what kinds of verbal and nonverbal behaviors contribute to the development of multiple interactive roles in multiparty collaboration.

In this study's task, people assembled a large structure consisting of pipes. No participant was assigned a particular role. As the participants moved in a

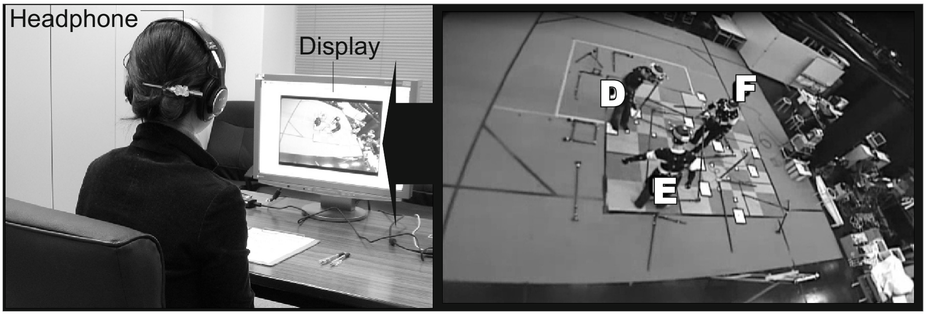

Fig. 2. Third-party rating experiment (left) and movie scene used for third-party evaluation (right)

shared physical space to assemble the structure, their gaze, speech, motion, and position data were captured by sensors. The captured data were analyzed to investigate the relationships between verbal/nonverbal behaviors and natural interactive role emergence [15,16,17].

In our previous analysis results, we found no significant difference between the leading and supporting roles in a task from the self-evaluations of the participants [16]. To examine the co-occurrence relation between an observer's judgment and verbal/nonverbal behaviors in the task, we asked neutral third parties to select the participant playing the leading role and the one playing the supporting role in the assembly task [18,19].

This paper presents a method of constructing a model for detecting the interactive roles of leader, active follower, and passive follower. We perform stepwise multiple regression on the model by using the results of both behavioral data and third-party evaluations. This model could be useful for detecting interactive roles and their reorganization in multiparty interaction.

2 Method

2.1 Task of Assembling a Large Structure

We focused on how both verbal and nonverbal behaviors help us to understand emerging leadership and followership through group work while the participants are moving. A preliminary experiment was conducted on the task of assembling a large structure in a shared physical space while checking a picture of the completed structure.

Figure 1(a) (upper left) shows twelve types of components, and Fig. 1(a) (upper right) shows the picture of the completed structure (PCS) used in this experiment. Gaze, speech, and distance among participants were captured within a space of $7500 \times 6500 \times 2500$ mm (width/depth/height) (Fig. 1(b) (lower left)). Each participant wore an eye-gaze tracker attached to a cap, a close-proximity microphone, and optical markers on a body suit for use by the motion-capture device (Fig. 1(b) (lower right)).

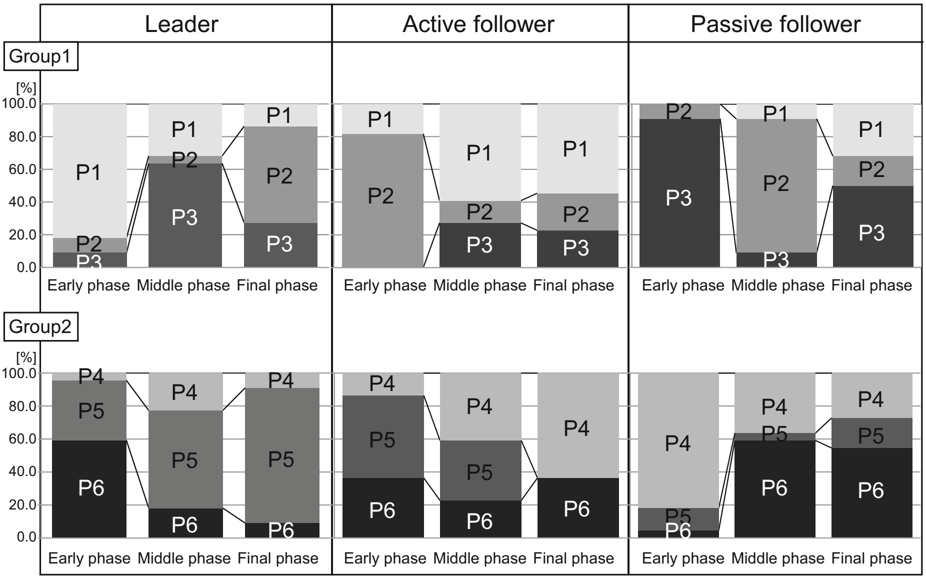

Fig. 3. Results of third-party evaluation: (a) leader (left), (b) active follower (middle), and (c) passive follower (right)

Two groups (C1 and C2), each consisting of three participants, took part in this preliminary experiment. Before the task, the participants had never met each other. No participant was assigned a particular role, such as leader or follower. At the start, all participants shared equal status. Group C2 successfully assembled the large structure in just over 13 minutes, but group C1 failed to complete the task within 20 minutes. For details, please refer to the previous work [15,16,17].

2.2 Method of Third-Party Evaluation

We conducted a third-party rating experiment on predicting the emergent interactive roles of leaders and followers to investigate the relationship between an observer's judgment and the participants' verbal/nonverbal behaviors.

Twenty-two people from 20 to 38 years old were recruited as raters. These raters consisted of eleven males and eleven females. They did not take part in the task of assembling the large structure.

We used movies made by recording the task of assembling the large structure (Fig. 2 (right)). The raters watched the movies of both C1 and C2 groups. In the rating experiment, the order of watching the movies was counterbalanced between the two groups. Each movie was evenly split into thirds: early, middle, and final phases of the task. Each rater was assigned to a computer with headphones (Fig. 2 (left)) and told that they would watch a movie of an assembly task and then select the task's leader as well as its active and passive followers.

Table 1. Correlation coefficient between results of third-party evaluation and verbal/nonverbal behaviors

Verbal/nonverbal behavior	Correlation coefficient		
	LD	AF	PF
Frequency of task-oriented utterances	**.484***	**-.441**	-.111
Number of task-oriented utterances	**.735****	**-.413**	**-.362**
Frequency of response utterances	.150	.126	**-.232**
Number of response utterances	.172	.021	-.173
Frequency of utterances for sharing CS	.035	**.256**	**-.225**
Number of utterances for sharing CS	**.214**	.105	**-.274**
Frequency of other utterances	.163	-.134	-.048
Number of other utterances	**.263**	-.045	**-.206**
Frequency of all utterances	**.300**	-.123	-.182
Number of all utterances	**.631****	-.186	**-.437**
Frequency of closer VC with PCS	**.270**	-.085	-.183
Amount of closer VC with PCS	**.417**	.071	**-.434**
Frequency of farther VC with PCS	**-.301**	-.117	**.363**
Amount of farther VC with PCS	**-.235**	.004	**.212**
Frequency of total VC with PCS	-.111	-.134	**.202**
Amount of total VC with PCS	.095	.050	-.124
Total moving distance	-.138	-.084	.189
Distance to other participants	**-.237**	-.103	**.294**
Frequency of facing each other	.181	.167	**-.291**
Frequency of overlapping utterances	.022	-.062	.026
Number of overlapping utterances	-.047	-.039	.072
Frequency of gaze to others	.122	-.064	-.064
Amount of gaze to others	-.072	**.249**	-.121
Frequency of mutual gaze	-.112	.035	.076
Amount of mutual gaze	.068	-.025	-.043
Frequency of gaze to components	**.244**	**-.216**	-.061
Amount of gaze to components	.042	-.050	-.001
Frequency of JA to components	.108	-.059	-.054
Amount of JA to components	.070	.016	-.077
Frequency of JA to PCS	.029	-.026	-.007
Amount of JA to PCS	.046	-.010	-.035

LD: leader, AF: active follower, PF: passive follower, VC: visual contact, CS: current status, PCS: picture of completed structure, JA: joint attention
$**$: $p < 0.01$, $*$: $p < 0.05$

In this experiment, the determination of which participant takes over the leadership of the task is based on that person's asking for the support of the other participants. As for the other roles, the participant who best shows the ability to effectively follow and support the leader is regarded as the active follower, while the other is regarded as the passive follower. For details, please refer to the previous work [18,19].

Figure 3 shows the third-party evaluation results for the emergent interactive roles of leader, active follower and passive follower with temporal alterations in

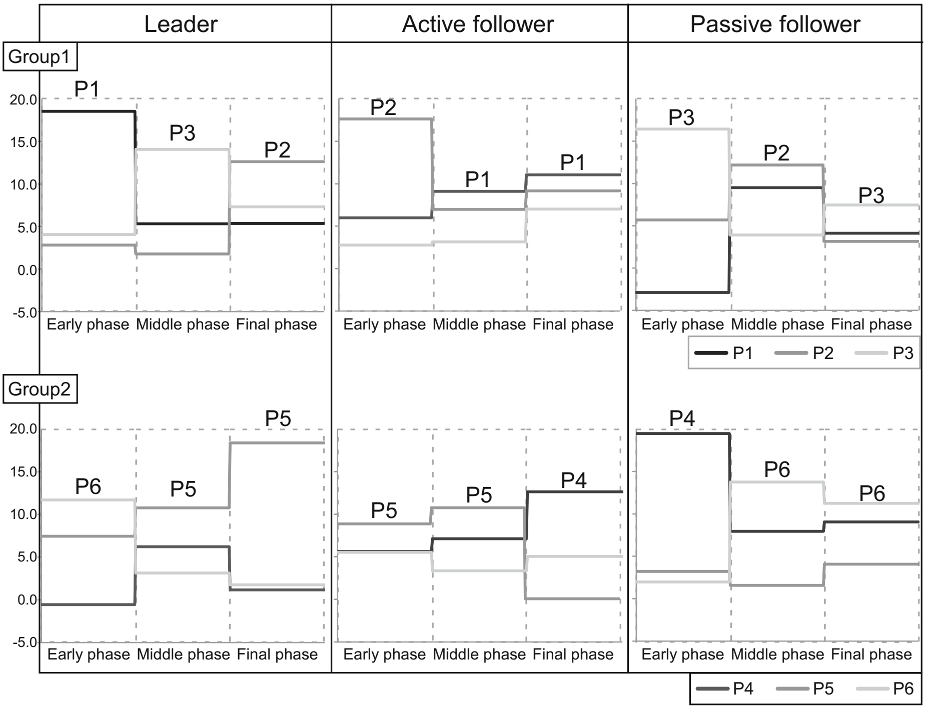

Fig. 4. Results of detecting emergent division of labor using a statistical model analysis: (a) leader (left), (b) active follower (middle), and (c) passive follower (right)

the assembly task. Table 1 shows the correlation coefficients between interactive roles and 31 sets of verbal and nonverbal behaviors.

3 Results and Discussion

We applied stepwise multiple regression for detecting the interactive roles of leader, active follower, and passive follower. We used 18 sets of verbal and nonverbal behavior data as independent variables (see 1) and the results of third-party evaluation as dependent variables. The 18 sets of behavioral data were selected from 31 such sets after deleting variable candidates with stronger correlation coefficients (0.7 or more). Table 2 shows the verbal and nonverbal behaviors as independent variables in stepwise multiple regression.

The regression equations for the interactive roles are as follows:

$$\begin{aligned}(\text{Leader}) = {} & 3.241 \times (\text{Number of task-oriented utterances}) \\ & + 1.424 \times (\text{Number of all utterances}) \\ & + 0.291 \times (\text{Amount of gaze to components}) \\ & - 0.039 \times (\text{Total moving distance}) + \mathit{const}. \end{aligned} \tag{1}$$

Table 2. 18 sets of verbal and nonverbal behaviors as independent variables in stepwise multiple regression

Number of task-oriented utterances	Distance to other participants
Frequency of response utterances	Frequency of facing each other
Frequency of utterances for sharing CS	Number of overlapping utterances
Number of other utterances	Amount of gaze to others
Number of all utterances	Frequency of mutual gaze
Frequency of closer VC with PCS	Amount of mutual gaze
Frequency of farther VC with PCS	Amount of gaze to components
Frequency of total VC with PCS	Amount of JA to components
Total moving distance	Amount of JA to PCS

CS: current status, PCS: picture of completed structure, JA: joint attention

The equation (1) shows that number of task-oriented utterance, number of all utterances, amount of gaze to components and total moving distance from the 18 sets of behavioral data contribute to "leader".

$$\begin{aligned}(\text{Active follower}) = &-3.563 \times (\text{Number of task-oriented utterances}) \\ &- 0.004 \times (\text{Distance to other participants}) \\ &+ 1.129 \times (\text{Frequency of facing each other}) \\ &+ 1.168 \times (\text{Frequency of gaze to others}) \\ &+ 0.245 \times (\text{Frequency of utterances for sharing current status}) \\ &+ 0.056 \times (\text{Total moving distance}) + const. \end{aligned} \tag{2}$$

The equation (2) shows that number of task-oriented utterance, distance to other participants, frequency of facing each other, frequency of gaze to others, frequency of utterances for sharing current status and total moving distance from the 18 sets of behavioral data contribute to "active follower".

$$\begin{aligned}(\text{Passive followers}) = &-1.492 \times (\text{Number of task-oriented utterances}) \\ &- 1.306 \times (\text{Frequency of facing each other}) \\ &+ 0.003 \times (\text{Distance to other participants}) \\ &+ const. \end{aligned} \tag{3}$$

The equation (2) shows that number of task-oriented utterance, frequency of facing each other, and distance to other participants from the 18 sets of behavioral data contribute to "passive follower".

We obtained the above regression equation models for detecting leader (adjusted $R^2 = 0.706$, $p < 0.01$), active follower (adjusted $R^2 = 0.482$, $p < 0.05$), and passive follower (adjusted $R^2 = 0.427$, $p < 0.05$). The adjusted R^2 value shows the percentage of overall contribution of the above selected variables in the regression equations for each interactive role.

Figure 4 shows the scores for interactive roles as calculation results of the above equations. P1 to P6 means the participants of group 1 (P1 to P3) and group 2 (P4 to P6). In this figure, the participants with the highest scores are shown in three phases: early, middle and final. When compared with the results of third party evaluation (fig. 2), it seems to show a better recall. Nevertheless, P5 in the middle phase of group2 is selected as both a leader and an active follower.

In comparing the results of correlation coefficients in Table 1 with regression equations (1) to (3), behavioral data with correlation coefficients of 0.2 or more are mostly selected, e.g., number of task-oriented utterances, frequency of utterance for sharing current status, and number of all utterances. On the other hand, frequency of visual contact with the picture of the completed structure is not selected as a parameter for higher contribution, even though it has a moderate correlation coefficient. We should examine the adequacy of the model for application to other groups under similar experimental conditions.

4 Conclusions

We captured, analyzed, and evaluated verbal and nonverbal behaviors in group collaboration in an effort to find a method for automatically predicting the emergent division of labor.

To construct a model for detecting the emergent division of labor in the roles of leader, active follower and passive follower, we applied stepwise multiple regression as a statistical model. We used both the results of raters' judgments and verbal/nonverbal behaviors in an assembly task as variables for the model. Consequently, we obtained a model with a moderate contribution ratio.

These models helped to reduce the costs of capturing and analyzing multiparty cooperation. In the future, we will conduct an assembly task using more groups with simpler equipment than in our first trial. Using these data, we will again investigate the effectiveness of our findings for predicting leaders.

In our preliminary multiparty cooperation task, we created groups of strangers without checking their capacity for assembly tasks or their spatial cognition ability. In future work, we will also conduct a similar task and control the familiarity among participants or address their task adequacy. Accordingly, we will examine the performance of the model in predicting interactive roles when it is applied to various types of groups.

If we could make a model of the structure of interactive roles, including leader and followers in multiparty cooperation, and then automatically predict these roles from captured data, such an approach would be useful in the design of various future collaborative systems: (1) face-to-face cooperation-support systems that enhance the emergent division of labor through visualization of the status of interactive roles, or that optimize the performances and the contributions among participants [20, etc.]; (2) evaluation systems that control multiple cameras according to the detection results of the key person in multiparty cooperation [13, etc.] or that conduct comparative quality evaluation between remote and face-to-face meetings in relation to the emergent division of labor; and, needless to say, (3) communication robot systems that participate in and activate multiparty conversation [1, etc.].

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