COLUMN: Discovering the User Invented Behaviors Through the Interpersonal Coordination

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Abstract. We developed soccer ball-shaped interactive artifacts (COLUMN) consisting of eight modules that are connected to twelve servomotors. Our motivation is to explore a variety of a robot's body configuration for rolling behaviors which are invented by three user's coordination. In the interaction, COLUMN becomes a social mediator to prompt the connectivity of the users. We explore how and what are the effects when a robot become a social mediator and investigate the conflict rates and interpersonal coordination of the users. Finally, we discover different body configuration patterns (sequences) from the user's connectivity in each group. Each sequence of body configurations are directed to extract essential parameters to the rolling behaviors.

Keywords: Social mediator · Interpersonal coordination · Visually-mediated connectedness · COLUMN

1 Introduction

We all had have the experience of seeing people walk on the street or playground with their dog as part of their daily exercise for both the person and the dog, and as a kind of companionship for the walker. During the walk, the dog often appears as the stimulus in initiating an experience with some unknown or known person who is willing to talk to the owner, as they mostly have to question how to initiate their conversation in an appropriate-way. In this context, their conversation mostly starts on the topic of their dogs and afterwards smoothly strengthens their relationship toward the topics. The above scenario can be convincing in showing that the dog plays a vital role as a social mediator to establish the conversation between the people. All of the above instances directed at an animal, people, object (e.g., TV), etc., can be turned into a social mediator to establish interactions among the people.

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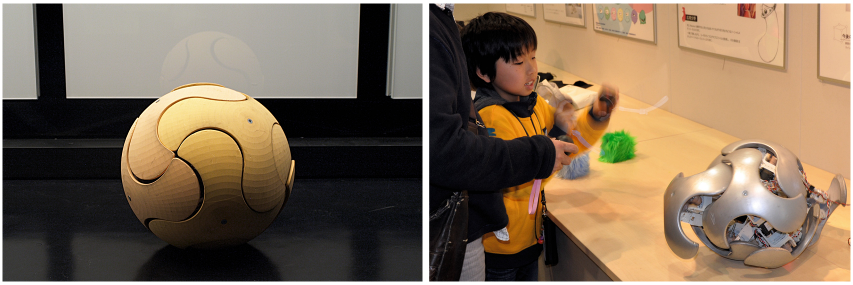

Fig. 1. Appearance of the COLUMN

Following the above manners, HRI community has been exploring how robot can become social mediators for children with special needs (autism) to enhance their social interaction by investigating a variety of collaborative (with caregiver or teacher, parent ect) play [1,2]. The play scenarios were designed by centralizing the robot-based interaction which comport as social mediator to the context while grounding the communicative connective among the children, teacher/caregiver, and parent [3,4]. All of the above terminations indicate the usage of the robot as social mediator [5,6].

In contrast to the above approach, strategically we can utilize a robot as a social mediator to connect the users while establishing the co-action in order to extract patterns of dynamic connectives of the users [7,8]. Moreover, our motivation is to explore how a social mediator can be utilized to discover a variety of behavior patterns (Exploring the user's connectivities) with essential parameters of unique artifacts call COLUMN.

The COLUMN is a soccer ball-shaped interactive artifact consisting of eight modules that are connected to the twelve servomotors. We can transfer the COLUMN body shape by moving the actuators with modules, and these actuators can be controlled by a wireless communicator called a "COLUMN Gear". Each of the users (three participants) can control the 4 servo-motors of the COLUMN, and a user can swing the COLUMN gear to change its body shape (transfer its modules). In this study, three users have to move the COLUMN from the starting position to the end point by coordinating their interactions (changing the shape of the COLUMN) [9].

During the defined interaction, interesting encounters will emerge; how does a robot become a social mediator (through visual perception, verbal and nonverbal communication, etc.)? What are the reciprocal coordinations (interpersonal) between users, where the people start to coordinate their actions? etc., [10,11]. By answering a combination of the above questions, it might lead to determine the robust approach to generate the artifact's behaviors/motions.

Initially, users have to realize which channel or media (communicative) is mostly used to distribute the information to ground their joint efforts (coordination); visual information (shape of the robot), and kinematic information is used (by combining the perpetual information of swing acceleration and shape of the robot), etc. It might possible to employ both or either communicative channel or media. Even initially they do not have an idea how individuals do their actions (swing), how/when they need to coordinate with the partner, how individual adapt to the partner, and how/when the individual switches the coordination etc. [12].

In this case, all that might be represented is one's own action part ("ME"), the fact that someone will take care of another action part ("Y") required to achieve the joint goal, and the joint action goal (ME +Y) achieved by combining the individual action parts. Therefore, during this process each of them has to coordinate with each other while adapting to their own action (swing interaction) under real-time constraints [10,13]. In addition, when the user experiences with several interactive sessions, they can predict the partner's action (time constrain of the swing), who controls the shape (vertical, horizontal, etc.) of the COLUMN, and also when is the best time to afford one's own contribution, etc. We can define the above users' connection as an interpersonal coordination, and with experience in interactive sessions, the users enhance their action (swing interaction) synchronization toward obtaining the COLUMN's rolling behaviors. Therefore, the motivation of our study is to extract the patterns of user's interpersonal coordination when establishing the COLUMN as a social mediator. It is also interesting to explore how these patterns lead to imagine behavior for an artifact which has different degree of freedom of its body than the existing.

2 Designing Architecture of the COLUMN

The artifact becomes a cubic when servo-motors extend their motors with maximum intensity. The modules (eight) are situated at the corners of the cubic, and each module is designed for gibing with other modules. The cross-section of the module where other modules are fit is cut at a tilt for avoiding interfering with other modules. Because of absorbing the frame distortion by using the ball-shaped moving part of joint, the COLUMN is protected from damage. The modules are made of artificial wood (chemical wood) and are moderately hard but lightweight. We used AX-12+ for the servo-motors, which are small-scale but high-powered and used mainly for the self-produced robot. The electrical circuit of the COLUMN is specialized for controlling AX-12+. AX12+ servomotors connect to a ZigBee wireless communication module via a microcomputer. We can transfer the COLUMN body shape by moving the actuators with the modules, and these actuators can be controlled by a wireless communicator called a "Column Gear". The acceleration of swing (each of the users) map to change the degree of the servo motors; changing the body shape of the COLUMN is proportional to acceleration of the swing (Fig. 1). The COLUMN gear is a spherical-shape device that is 50 mm in diameter with a weight of 50 gms, and is comfortable to grasp by human hand. The exterior of the column gear is constructed by chemical wood, and it has translucent plastic for penetrating the light of the LED between the exteriors, which indicates the power of the swing.

In this study, three users have to move the COLUMN from a defined starting point to end point (goal). During the interaction, users have terminus to obtain the COLUMN's rolling motion while having to coordinate with others by their swing motion. Since people's coordination is gradually set-up with the desired goal of the users (COLUMN moving from start to end) which indicates that the COLUMN becomes a social mediator by connecting each other through the interactions.

3 Experiment

We have arranged the experiment setup as shown in Fig. 2. Three users have to proceed to the COLUMN from the starting point to goal point by using their swing interaction while coordinating with each other efforts. Within five minutes users have to reach the goal, otherwise, again they have to begin at the starting point. At least each of the groups has to participate in five trials, and the groups also have to undertake more trials if they cannot reach the goal at least once within five trials. The reason for the five-trial setup is that sometimes it is possible for a group to reach to goal with their random swings during the initial trials. Five groups (15 users, aged between 22-24 years old) participated in the experiment and were randomly assigned as members of a group. All of the users had no prior experience about controlling a robot. During the interactions, we gathered the user's swing acceleration, COLUMN degree of freedom, and videos (to obtain the states of rolling and behaviors).

Fig. 2. Image sequences show that during the interaction, one of the groups was rolling the COLUMN through their swing interactions.

4 Results

4.1 COLUMN as a Social Mediator

Initially, our motivation was to encounter any user's connection during the interactions. If we determined any user's connectivity, then the result could ensure the COLUMN became a social mediator for the interactive users.

Figure 3 shows the number of trials (x) against the rolling counts (y) for each group. The figure also indicates when the groups had experience with the interactive sessions (trials), the number of rolling converges between 5-15. In addition, there were fewer number of rolling counts when they successfully reached the final destination (goal-point) except during some trials of $G2$ and $G3$ groups. $G2$ and $G5$ reached the goal-point within 6-7 rolling counts, with an increase of rolling counts (more than 8) indicating that most of the time the COLUMN

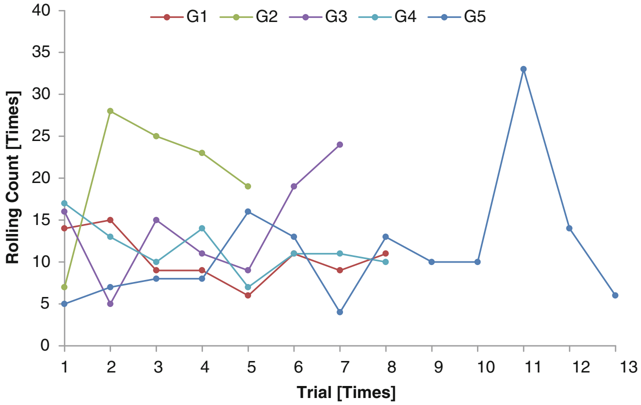

Fig. 3. Figure represents the rolling count in each trial to reach the goal point by considering each of the group. The x-axis represents the trial number and the y-axis represents the number of rolling counts.

moved away from the goal-point (rolling to different directions). $(G1, G4, G5)$ were able to reach the goal after having experience with more than five trials. $G2$ and $G3$ groups accomplished the goal within fewer number of trials, but their rolling counts were higher than those of $G1$, $G4$, and $G5$ groups. Overall the results indicated that when users had interactive experiences, the number of their rolling counts necessary to reach the goal point had decreased. This not have might happen without the establishment of interpersonal coordination among the interactive users.

4.2 Conflict Rates and Interpersonal Coordination

As pointed out, each of the users can control four servo-motors of the COLUMN and can change the shape of the COLUMN (either vertical, horizontal, and diagonal) by using their swing acceleration. According to the mechanism, if users established the smooth coordination for rolling behaviors, then each of the users have to equally contribute with their swing acceleration. If an interactive user increases the swing acceleration parallel to the partner's, then the conflict rate will be quite higher. Oppositely, if we have a lower conflict rate, then there is potential to having cooperation of the users. In our COLUMN mechanism, cooperation of interactions can be determined as interpersonal coordination of the users, because in order to obtain the rolling behaviors of the robot, each of the users has to coordinate their swings in the dynamic interactions.

Our next step is to explore conflict rate of the group by considering the pair of the users in each trial. To estimate the conflict rate of the users, we employed the swing acceleration to the following equation (Eq. 1, where $i, j = 1, 2, 3$) by considering each of the pairs.

$$Conflict_t^{u_i u_j} = Acceleration_t^{u_i} \times Acceleration_t^{u_j} \tag{1}$$

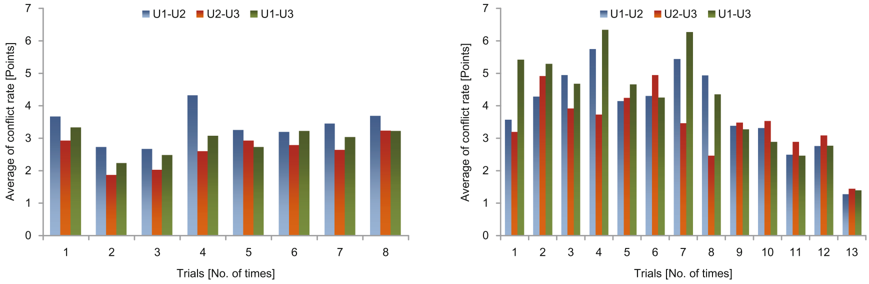

Fig. 4. Figure shows the average conflict rates of each user combinations in each trial for groups $G1$ and $G5$. Here the x-axis represents the trials and the y-axis represents the average conflict rate.

Figure 4 depicted the average conflict rate (x-axis) against the number of trials (y-axis) for group $G1$ and $G5$. In initial trials, every group has higher conflict rates than the later trials of the interactions. Also, the average conflict rate for every pair-combination of the users ($U1 - U2, U2 - U3$, and $U1 - U3$) became approximately equal in the later trials of the interactions. In addition, the conflict rates gradually converged to interval; e.g., in $G1$ it varied between 0-3, and between 0-2.5 for $G2$, etc., and the $G5$ group clearly showed a convergence in the conflict rate.

Table 1. Following table summarizes the user combinations of highest and lowest conflict rates (number of times) by considering the enter trials of the interactions. Here Gi and Uj represent the group number and the user's number, where $i = 1, 2, 3, 4, 5$ and $j = 1, 2, 3$.

Group	Higher conflict rate		Lower conflict rate	
	Combination	Number of times	Combination	Number of times
G1	U1-U2	7	U2-U3	6
G2	U2-U3	3	U1-U2	4
G3	U2-U3	3	U1-U3	4
G4	U1-U3	6	U1-U2	4
	U2-U3	6	U2-U3	4
G5	U1-U3	6	U2-U3	5

Table 1 summarized the higher (number of times within the trials) and lower conflict rates (number of times within the trials) according to the user combination by considering the enter trials for each group. These data showed which user combination had an interpersonal coordination (low conflict rate) in entering trials. Most of the time U1-U2 user combinations of G1 had a higher conflict rate than other user combinations, because the G1 group had eight trials to reach the goal-point, but during seven times U1-U2 had a higher conflict rates than the other groups. However, U2-U3 maintained the interpersonal coordination (lower conflict rate) during six times out of eight trials. These results indicate that during the interaction some users had an interpersonal coordination, while some of them did not possess an interpersonal coordination. A similar kind of interpersonal coordination was established in every group as depicted in Table 1. In the initial trials, most groups did not exhibit an interpersonal coordination among the each user's combinations; however, after having experience with a few trials, the results showed that some of the user's combinations were gradually starting to connect with each other. These kinds of interpersonal coordination disclose the variety of shape changes of the COLUMN to obtain the rolling behaviors.

4.3 Patterns of Body Configuration

We investigated all of the rolling patterns in each trial in each group. First, we explored the trials which had low rolling counts, less differences of acceleration between interactive users, and less conflict rates of each user's combinations. Most of the above conditions were satisfied when users experienced with a number of trials.

We have funded similar kinds of patterns for body configuration which satisfied the above conditions as shown in Fig. 5(left). Figure 5(left) depicted the time (x-axis) against the swing acceleration (y-axis) for $G1$ group at trial 8. Interactive users had an equal (approximately) swing acceleration between each other at the rolling point of the COLUMN, which implies less conflict among each user's combinations. In this pattern, we explored the statues of the machine (degrees of freedom) and swing acceleration of the users (Table 2). To obtain the rolling behaviors, users have to switch the COLUMN degrees of freedom as $100[deg], 135[deg]$, and $180[deg]$, and the swing acceleration as $(low, low, high), (log, high, middle)$, and $(low, high, middle)$ at starting, rolling, and finish stages.

In the second stage, we explored a variety of body configurations when two users have higher conflict rates. The reason for the investigation is sometimes even when the user has higher conflict rates, it s still possible to obtain different body configurations of the robot to obtain the rolling behaviors. However, random users' connectivity might obtain these patterns, which would most likely

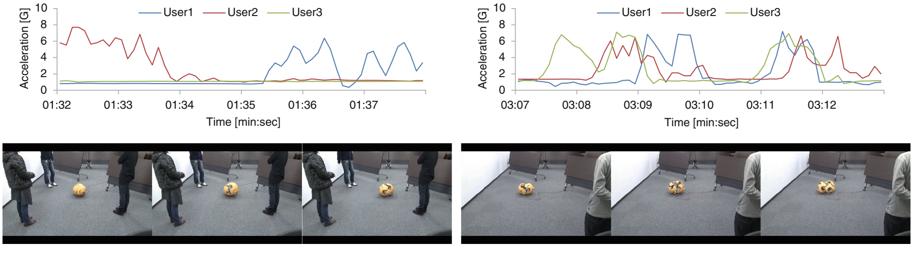

Fig. 5. Figure shows the discovered body configuration pattern in the 8th trial of group G1. All user combinations have a low-conflict rate at rolling behavior (Figure(left)). All user combinations having higher conflict rate at rolling behavior in trial 2 of group G5 (Figure(right)). Here the x-axis represented the time and y-axis represented conflict rate.

Table 2. Table depicts the switching sequences of COLUMN degree of freedom and swing acceleration in the discovered robot body configurations.

Group-Trial	Conflict	Time Features	Machine status	User	Acceleration
G1-T8	No conflict	Start	120[deg]	U1	Low
				U2	Low
				U3	Low
		Rolling	135[deg]	U1	High
				U2	Low
				U3	Low
		Finish	180[deg]	U1	Middle
				U2	Low
				U3	Low
G5-T1	U2-U3 conflicted	Start	100[deg]	U1	Low
				U2	Low
				U3	High
		Rolling	135[deg]	U1	Low
				U2	High
				U3	Middle
		Finish	180[deg]	U1	Low
				U2	High
				U3	Low
G5-T2	U1-U2-U3 conflicted	Start	110[deg]	U1	Low
				U2	Low
				U3	Middle
		Rolling	135[deg]	U1	Middle
				U2	Middle
				U3	Middle
		Finish	180[deg]	U1	High
				U2	Low
				U3	Low

occur during the initial trial of the interactions. After exploring the variety of patterns, we found that $G5$ at trial 1 has unique body configurations to obtain the robot's rolling behaviors (Table 2). As shown in Table 2, $U2$ and $U3$ have dissimilar swing accelerations which was affected by obtaining the conflict between users $U2$ and $U3$ at the statues of rolling, as shown in Table 2. According to Table 2, the degree of the body configuration shifted to $100[deg], 135[deg]$, and $180[deg]$, and the swing acceleration shifted to $(low, low, high), (low, high, low)$, and $(low, high, low)$.

Finally, we have explored the patterns of the body configuration trial that has different conflict rates among three users as shown in Fig. 5(right). Evidently, Fig. 5(right) shows that three users had considerable differences in their swing accelerations, which was effected by having the conflict rate between every user combinations. As shown in Table 2, the extracted body configuration patterns had

110[deg], 135[deg], and 180[deg] shifting degrees of freedom, and (low, low, low), (high, low, low), and (middle, low, low) switching accelerations between the users.

We have found the above three kinds of patterns of the body configuration of the COLUMN to obtain the rolling motions. Each of the patterns has different switching degree of freedom and swing accelerations. According to the results, less rolling counts, less swing acceleration differences, and less conflict rate conditions were directed by the smooth rolling patterns, and these kinds of patterns were obtained when the users had long term interactions. This might be obtained when a user became an expert in the task. But a user's unconscious (random) connectivity was also directed toward obtaining different patterns of the body configuration, with this pattern mostly obtained at the initial trial of the interactions, which can be posited as a weak connectivity of the users (beginners) with less experience on the task.

5 Discussion

The results showed that the defined interactive scenario was motivated by connecting the interactive users, which indicated the powerfulness of the COLUMN as a social mediator. However, initially most of the groups have spent considerable rolling counts to reach to the goal. The intended direction of the COLUMN rolling was away from the goal (random rolling); but after experience with several interactive sessions, the groups had fewer rolling counts. This might occur when the user understood the rolling mechanism of the COLUMN, and coordinated with each other, etc. The reduction of the rolling count provides some indication of the user connectivity around the COLUMN.

In reality, rolling behaviors can be obtained in two different circumstances: rolling behaviors can be obtained through the exact coordination of the users and sometimes through random user's connectivity. Therefore, the conflict rate is a suitable parameter to explore body configurations of the robot in each trial by considering the groups. To explore these patterns, we initially have to consider the trials which have less conflict rate among three users' combination (approximately zero), two user combination having conflict rate, and finally all of the user combinations having different conflict rates.

As depicted in Fig. 5 and Table 2, we found three kind of rolling patterns. However, when all user combinations have less conflict rates (all users were well connected), we found only one pattern of body configuration for rolling behaviors. But we found two kinds of body configuration patterns when at least one user combination had a significant conflict rate. The important summary of the beginning study is depicted in Table 2; however, Table 2 depicts the status of the COLUMN (degree of freedom) and swing acceleration for the extracted three patterns of the robot body configuration. The results indicate useful low-level features for a robot to obtain the rolling behaviors in different patterns of body configuration. Thus, we can consider these kinds of sequential switching for body configuration and swing acceleration (power of servo motors) to propose an automotive behavior generation mechanism by considering the above patterns and low-level features.

6 Conclusion and Future Works

In this study, we explored a variety of COLUMN body configurations which were invented by users. Those patterns were extracted by investigating the user's connectivity in the interactions. We can map the extracted body configuration into low-level features as degree of freedom and power of the servo motors. Therefore, our future work is to utilize the extracted body configuration patterns with low-level features to attain self-automation behaviors for COLUMN. Also, utilization of social mediator might be thoroughly beneficial to invent a variety of behaviors for this kind of unique artifact.

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