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Analysis of body motion synchrony phenomenon in communities and between communities

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Abstract: We evaluate community activity in social network based on body motion synchrony of two people during face-to-face communication. In particular, we look at people's body motion synchrony when they are in the same communities and from different communities. Using wearable sensors, we measured individuals' time series body motion data and face-to-face communication data. From these data we detected communities in 6 organizations and statistically analyze the distribution of body motion rhythm difference in communities and between communities. The result showed the tendency that people who are in the same communities are easier to synchrony than people who are from different communities. Moreover, we make comparison on the result based on two different community detection methods. One detection method is based on real department information, the other one is based on real interaction information. The result showed that the above tendency is more common in community separation based on real interaction information. The present study will create a new path to evaluate communities detected in different community detection methods in terms of body motion synchrony.

Keywords: Synchrony, Community detection, Face-to-face interaction

1. INTRODUCTION

There are many networks in the world such as neural network, computer network and sensor network. These networks are applied widely in daily life. Recent years, one kind of networks, called "social network", is widely spread around the world. The secret of human behavior can be revealed by social network in some degree. However, there is one fatal defect in it. In social network people communicate with each other through text, picture and other digital media, and the network is very different from the face-to-face communication network (Fig. 1). Face-to-face communication is happened between people in a small distance (usually less than 2 meters). And in it, people convey information and emotion not only through sight and hearing, but also through other senses like tactile sensation and senses of smell. The information in face-to-face communication is much richer than the communication in social networks. Therefore, face-to-face network will become central to understand human group's behaviors. Unfortunately, until now, recording precise and reliable data on face-to-face interaction network has been difficult. To fill the gap, Hitachi center research laboratory developed a wearable badge to record real time data of people's face-to-face interaction and body motion. In this paper, we applied this kind of data to analyze face-to-face networks in organizations to reveal people's body motion feature when they have face-to-face communication.

As we known, when people have conversations, their bodies move unconsciously, such as nod and other gestures. These kinds of nonverbal communications are as important as verbal communications. Body motion synchrony phenomenon is one of the phenomena in nonverbal communications that attracts people's attentions. In fact, previous studies have shown that people's body motion rhythm tend to be synchronized when they have face to face communication. The phenomenon has been observed in many situations. For example, between mother and son, the speaker's and the hearer's body motion rhythms are synchronized [1] . Similarly, in puzzle solving case, the puzzle giver's and the puzzle solver's postures will be synchronous [2]. Besides, peoples' body motion also synchrony when they talk joke with each other [3]. On the other hand, many researches have been done to illustrate the effect of synchronization. For instance, if the interviewer nod to the interviewee in an interview, the interviewee seems to talk more, say the interviewee would become more confident [4]. Another research shows that students' and teacher's body motion synchronization are correlated with the quality of the lecture [5]. The previous study has showed that when people have face-to-face communication their body motions will synchrony, and the phenomenon of synchrony is conductive to smooth communication. However, these researches only focus on two people talking in disciplined experimental environments, none of them has done research about the body motions in social networks. Here, we provide a method to analysis the body motion of people embedded in social networks.

As networks are always consisted of many small communities, and people from different communities always have different backgrounds, we can compare the synchrony phenomena of people in the same communities to that of people from different communities to figure whether the synchrony phenomenon is dependent on the

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Fig. 1 Face-to-face network

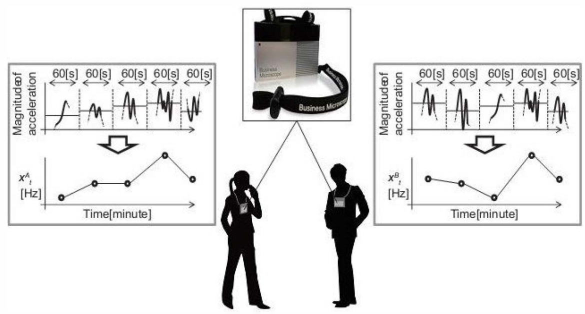

Fig. 2 The wearable sensors(Business Microscope). The equipment is attached on the upper torso of a participant.

backgrounds of communication. We can also reflect the smoothness of communication in each community by comparing the synchrony phenomenon of communities, the smoothness of communication in each community. In addition, community separation in organization is totally different from different viewpoints. From the functional viewpoint, organization could be separated into some departments like human resource, finance. While, when considering the interaction among people, we can obtain another community separation in organization different from the above viewpoint. In this paper, different community separation methods are also compared by body motions in face-to-face communication.

In the present paper, we provide a method to look at the synchrony phenomenon of body motions in face-to-face communication in communities (in the same communities) and between communities (between different communities). Moreover, we also make comparison on the result based on two different communication detection methods.

2. METHOD

2.1 Measurement device

In this study, we use the Hitachi business microscope which uses an acceleration sensor and an infrared sensor to measure time series body motion data and people's interaction [6, 7]. This device was advocated to workers in each organization. The workers wore the device as in Fig. 2 at work and took off it after work. The device can measure people's body motion rhythm and interaction information [6]. For body motion data, three axis acceleration signals are captured for 2 seconds every 10 seconds at 50 Hz. The unique motion rhythm during those 10 seconds is then calculated by the frequency of wave zero-crossing after some band-path filtering. For instance, if four zero crossings are found in the 2 seconds, we determine that the unique motion rhythm of those 10 seconds is 2.0 Hz. In the study x_t^i [HZ] is the motion rhythm. Here, i is the sensor wearer's label, t is the time.

For face to face interaction data, it is measured by the infrared sensor every 10 seconds. The valid zoom for the sensor is 120 angles in horizontal position and 60 angles in vertical position. If two people wearing the sensor meet, and their distance is less than 2 meters (Fig. 2), their IDs will be recorded. Here, 2 meters is based on Hall [8]. They have showed business communications are often take in a distance from 1.2 meters to 3.6 meters. From the interaction data, we can figure out every person meet how many people and whom were they meet in a specified time.

In the present study, the body motion rhythm data and interaction information data was all added up to minute for analysis.

2.2 Data

People in 6 organizations participated into this study. Here, an organization means one part in a company or a company. Table 1 shows the type of each organization, the number of research objects, and the duration of days for research. The research objects are the people who had wear the device at least one time. The valid days are the days that the number of people who wear device is above 10% of the total population of the organization. These data is provided and controlled by world signal center (Hitachi).

2.3 Body motion synchrony

We focus on people's body motion synchrony phenomenon in communities and between communities. Especially, we pay attention to the synchrony phenomenon between communication pairs. Here body motion synchrony is showed by the difference of body motion rhythm. If the body motion rhythms of two people are close, in other words, the difference of their body motion rhythm is closer to zero, they are regarded to be synchronize easier. In order to show the difference clearly, we display the distribution of the difference of body motion rhythm in communities and between communities, and we use the standard deviation and kurtosis to discuss the difference of distributions. For data manipulating, we only extract people's body motion rhythm data when they communicate with others. There are two things to be noted. First, we only focus on communication between two people, that is to say, if communication is conducted in a group of people, we separate them into pairs. For

Table 1 Summary of organizations. "Type" expresses the category of organization. "Department" shows the community information of each organization. "Participants" is the number of research objects (people). "Days" is the total duration for analysis. Organizations A, B are different companies. Organizations D, E, F are different divisions of the same company

Organization	A	B	C	D	E	F
Type	R&D	Wholesale	Development	Development	Development	Development
Department	A-B	A-E	C1-C10	P1-P10	Q1-Q6	U1-U6
Participants	163	211	219	144	109	124
Days	41	48	56	58	57	59

instance, if A, B, C had conversation, we consider that A and B, B and C, A and C had conversation. Second, we consider that communication is established between people who had continuous (above 3 minute) face to face interaction. We therefore cut the first minute and last minute from their interaction time. After these preprocessing, we can obtain a set of people's communication data. Using these data as index, we extract the body motion rhythm data when people have face-to-face interaction. Then we calculate the difference of communication pairs' body motion rhythm. Y is the set of the difference of body motion rhythm, described as

$$Y = \{x_t^i - x_t^j \mid t \in T_{ij}, (i,j) \in E\} \quad (1)$$

where T_{ij} means the time people i and j had face to face interaction, E is the set of users' labels after data preprocessing.

2.4 Community detection

We use two methods to separate the organizations into communities. The first method is based on real department information (information of each person belong to which department). The second method, called Newman's method, is based on real interaction information (information of interaction between two person) [9]. These two methods look at organizations from different viewpoints. One is from the communities' occupational function and spatial position viewpoint, the other one is from the people's interaction (or connection) in organizations. The real department information has been showed in table 1, every organization is composed of some departments and every people belongs to one department. We directly use this relation to detect communities in organizations.

We also use network analysis to show the relationship of people in a network. In it we regard the people as nodes, and their interaction (say encounter) as edges, wherein the weight of an edge shows the length of time people meet. Thus the weights in the network represent the strengths of connection from one people to another. The network G subjected to this study is undirected and symmetric because the communication in this study is defined as communication between two people. The real interaction information includes betweenness of an edge in a network. The edge betweenness in a network is defined as the number of shortest paths between vertex pairs i, j on the network that run along that edge, summed overall i and j. The community detection algorithm of Newman's method is as follows:

- Calculate edge betweenness of network G, ignoring the weight
- Divide each edge betweenness by the weight of corresponding edge
- Remove the edge with the highest betweenness/weight
- Calculate the modularity[9] which shows the separation quality
- Loop this calculation
- Choose the separation which has the highest modularity score.

In order to treat every objects' weights in the network equally, we normalized the weights. Specifically, we add all the days' data together to generate the adjacency matrix of the network. Then we calculate every people's sensor wearing time by minute. Dividing each row of the adjacency matrix by the corresponding time, we symmetrize the matrix by comparing symmetric pairs and choose the bigger one.

3. RESULT

Fig. 3 shows the result of community detection by two different methods. Fig. 4 shows the distribution of body motion rhythm difference in communities and between communities. We will discuss the result by conventional statistic analysis.

3.1 Result of community detection

Firstly, let us see the result of community detection. Figs. 3(a1) and 3(a2) depict the network of organization A having the same configuration of nodes and edges. Fig. 3(a1) show the result of communication detection using the real department information, and Fig. 3(a2) show the result using the real interaction information. Likewise, Figs. 3(b1) and 3(b2) depict the network of organization C having the same configuration of nodes and edges. Fig. 3(b1) show the result of communication detection using the real department information, and Fig. 3(b2) show the result using the real interaction information. These figures are color-coded according to community. It is easy to see that the result of two community detection methods is totally different. First of all, the number of communities is different. For instance, organization A is divided into two departments by the real department information, while it has almost 8 communities in terms of the real interaction information. Second, the same person

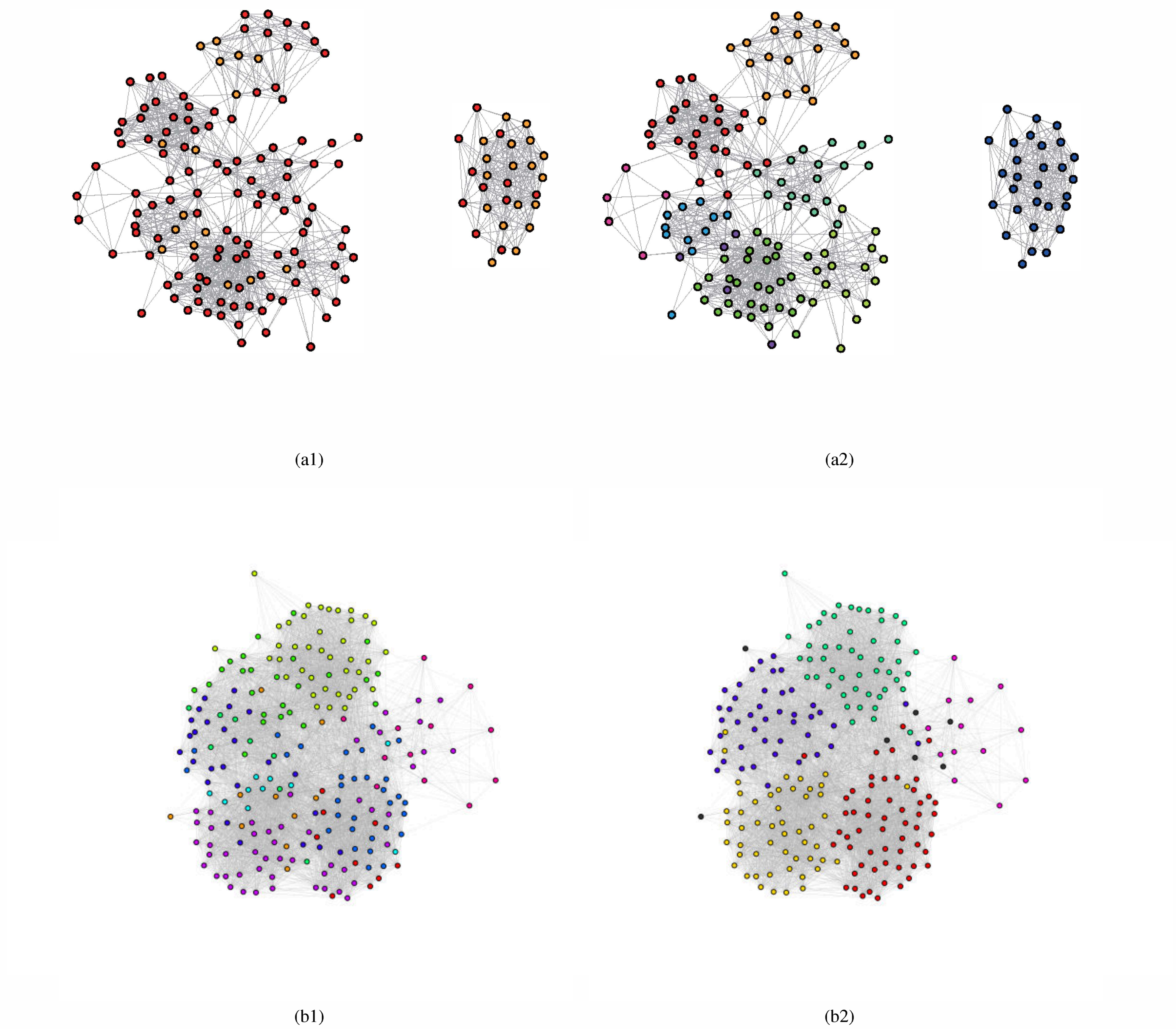

Fig. 3 Community detection result. Fig. 3(a1) and 3(a2) show the result of organization A, Fig. 3(b1) and 3(b2) show the result of organization C. Figs. 3(a1) and (b1) are the result of community detection by the real department information, Fig. 3(a2) and 3(b2) are the result of community detection by the real interaction information.

could belong to different communities based on different viewpoints. Specifically, one can belong to community A from the viewpoint of the real department information and he/she can also belong to community B form the viewpoint of the real interaction information. Third, we can see that people from different communities in Figs. 3(a1) and 3(b1) can form a new community in Figs. 3(a2) and 3(b2).

3.2 Comparison on body motion synchrony

Secondly, let us compare the body motion synchrony of two people in communities and between communities. We focus on the body motion rhythm difference between two people nearby 0[Hz] to compare the body motion synchrony in communities and between communities. Figs. 4(a1), 4(b1), 4(c1), 4(d1), 4(e1) and 4(f1) show the distribution of the body motion rhythm difference of two peoples in communities and between communities detected by the real department information. Figs. 4(a2), 4(b2), 4(c2), 4(d2), 4(e2) and 4(f2) show the distribution of the body motion rhythm difference of two peoples in communities and between communities detected by the real interaction information. Here small "a" to "f" denote organizations A to F, respectively. First, from Figs. 4(a1) to 4(f1), we cannot see obvious difference between distributions in communities and that between commu-

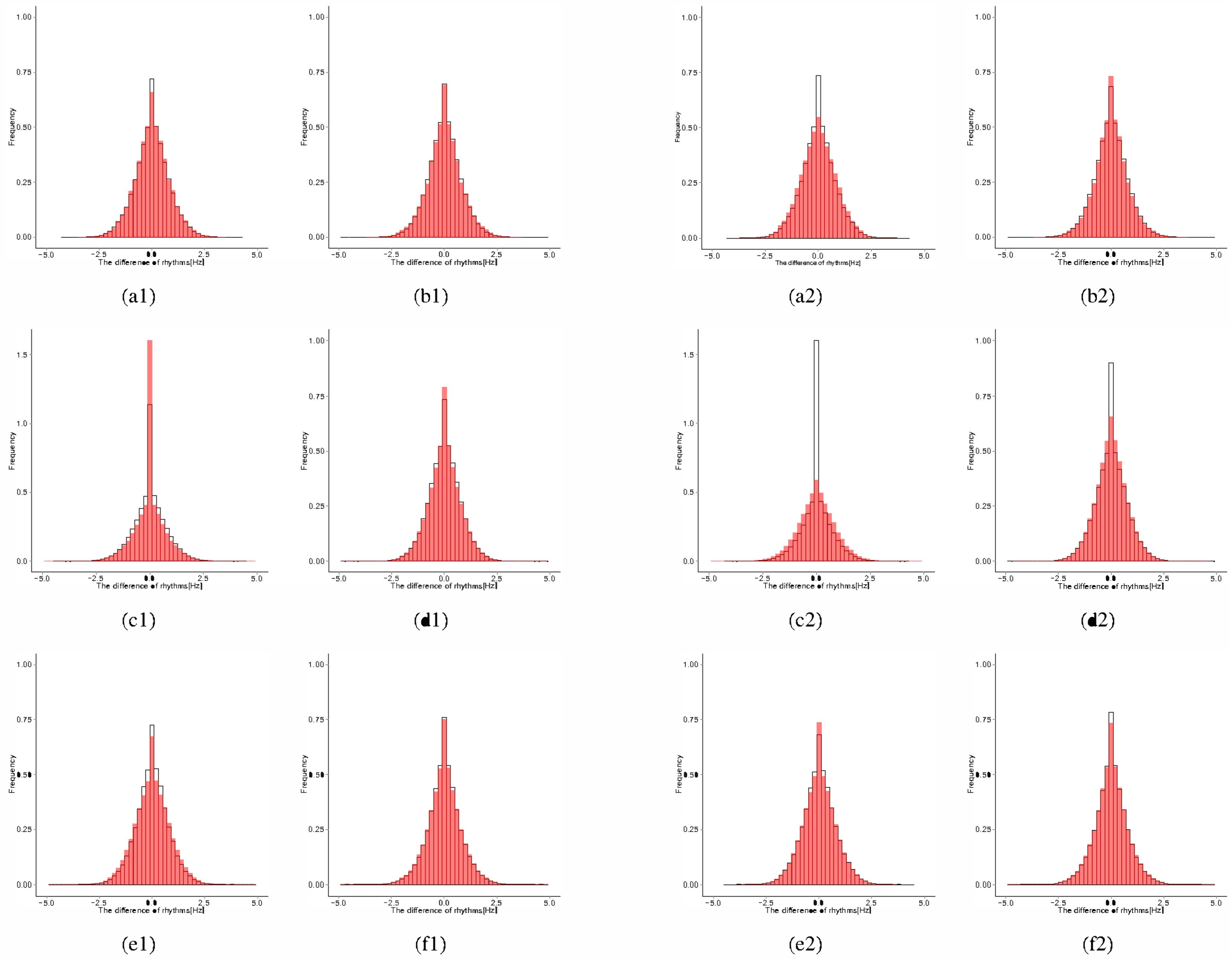

Fig. 4 Distribution of body motion rhythm difference. Figs. 4(a1), 4(b1), 4(c1), 4(d1), 4(e1) and 4(f1) show the distribution of the body motion rhythm difference of two people distribution in communities and between communities (communities are extracted through real department information). Figs. 4(a2), 4(b2), 4(c2), 4(d2), 4(e2) and 4(f2) show the same distribution but communities is extracted through the real interaction information. Small "a", "b", "c", "d", "e" and "f" correspond to the organization A, B, C, D, E, F. The blank part shows the distribution in communities, and red part shows the distribution between communities

nities. While, from Fig. 4(a2) to 4(f2), we can see that half of the 6 organizations show the distribution of body motion rhythm difference is sharper in communities than between communities.

In order to compare the distributions more carefully, we calculate the SD (standard deviation) and kurtosis (kurt for short) of each distribution. SD shows how much the rhythm difference dispersion exists. Kurt measures the "peakedness" of the distributions. The bigger the SD is, the more dispersed the rhythm difference is. The bigger the kurtosis is, the more the near 0 part of rhythm difference has. That means more communication pairs are synchronized in their body motion. Thus, if SD in communities is smaller than that between communities, and the kurtosis in communities is bigger than that between communities, we can state that people in communities are more easily to synchrony than people between communities, and vice versa. Especially, if the two distributions have the same SD, and the distribution in communities have bigger kurtosis, we can also state that people in communities are easier to synchrony. SD and Kurt are defined as follows:

$$SD = \sqrt{\frac{\sum_{k=1}^{n}(y_k - \bar{y})^2}{n}}, \quad (2)$$

$$Kurt = n\frac{\sum_{k=1}^{n}(y_k - \bar{y})^4}{\left(\sum_{k=1}^{n}(y_k - \bar{y})^2\right)^2} - 3. \quad (3)$$

Here, n is the c of set Y. As set Y is symmetric by 0, the mean $\bar{y}$ equals 0. The result is presented in table 2 and table 3. Table 2 shows the standard deviation and kurtosis of the rhythm difference in communities and between communities. The communities are detected by real department information. Table 3 shows the standard deviation and kurtosis of the rhythm difference in communities and between communities. The communities are detected by real interaction information. In table 2, we can see that different organizations have different results. In organizations B, E, F people in communities have bigger SDs and smaller kurtosis than people between communities. However, organization C has the opposite result. In organizations B, E, F, people in communities are easier

Table 2 The standard deviation and kurtosis of the rhythm difference in communities and between communities. The communities are detected by real department information.

Organization	SD_{in}	SD_{btw}	$Kurt_{in}$	$Kurt_{btw}$
A	0.797	0.789	0.509	0.536
B	0.774	0.781	0.658	0.657
C	0.750	0.692	1.060	1.706
D	0.747	0.753	0.580	0.881
E	0.763	0.786	0.607	0.526
F	0.777	0.775	1.137	1.195

Table 3 The standard deviation and kurtosis of the rhythm difference in communities and between communities. The communities are detected by real interaction information.

Organization	SD_{in}	SD_{btw}	$Kurt_{in}$	$Kurt_{btw}$
A	0.789	0.838	0.536	0.164
B	0.781	0.838	0.657	0.659
C	0.692	0.852	1.706	0.533
D	0.753	0.756	0.881	0.576
E	0.786	0.786	0.526	0.415
F	0.775	0.786	1.195	0.919

to synchrony than people between communities. While in organization C, people from different communities are easier to synchrony than people from the same communities.

In table 3, we can see that all organizations except organization B show the tendency that people in the same communities are easier to synchrony than people from different communities. Also, we cannot tell big difference between people in the same communities and from different communities in organization B. It is to be noted that the above tendency in table 3 is easier to synchrony than people from different communities are stronger than the result in table 2.

4. CONCLUSION AND DISCUSSION

As people in the same communities are more familiar than people from different communities, the former people tend to have more communication compared to the latter ones. It is therefore expected that people in the same communities are easier to synchrony than people from different communities. In fact, from the result of statistical analysis, we can see that most organizations show that people in the same communities are easier to synchrony. However, in the result of community detection based on the real interaction information (Newman's method), the tendency is much stronger. At first sight, it may seem strange. Since people in the same communities (based on the real department information) share the same spatial space and occupational function, it appears that they have more similar background and have more chance to communicate with each other. Hence they ought to be easier to synchrony. Nevertheless, the result is on the opposite. However, deeply considering the result, we can accept it. The real interaction information reflects people's connection based on communication in organizations. According to the community detection based on the real interaction information, people who have more communication tend to be in the same communities. Further, it has been reported that the body motion rhythms of two people tend to be synchronized when they have face-to-face communication. So, it is reasonable that people in the same communities (based on the real interaction information) show stronger tendency to synchrony than people in the same communities (based on the real department information).

In addition, we pay attention to one organization. Organization C shows that people from different communities (based on the real department information) are easier to synchrony, while people from the same communities (based on the real interaction information) are easier to synchrony. For the interesting result, we can give one explanation. From the viewpoint of the real department information, every department is in an open environment, everyone is free to have connection with the outside. Therefore, there may be strong connection between different departments. In contrast, from the viewpoint of the real interaction information, most people may have regular communication groups or partners because of the type of organization C (development). This means that the communities detected by the real interaction information are almost like closed environment, their connection to other communities are relatively weak. Hence, the result suggests that people in the same communities, which are detected by the real interaction information, are easier to synchrony.

In fact, almost all companies are separated into departments and each department executes its own function. However, not all departments in companies function well. Poor department separation may lead to a less productive company. Therefore, how to set department properly is an urgent issue in business world. The present study assumes that body motion synchrony can evaluate the quality of departments. Our result of this study creates a new path to evaluate companies detected in different community detection methods in terms of body motion synchrony and find out the most suitable department separation for each company.

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