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【論文の内容の要旨】

Entrainment has been studied for many years, which is a kind of lubricating oil in human-human interaction. A good interaction needs entrainment, which includes speech entrainment, body movements entrainment, and even entrainment between heart rates or brainwaves. Movements and speeches, which have been used for monitoring entrainment in conventional research, are self-controllable. However, these are unsuitable for monitoring the internal state of humans. Hence, this dissertation employs heart rate and brainwaves as physiological signals to assess the entrainment of humans. There are many occasions that need entrainment, such as group learning on educational occasions and group work on work occasions; these occasions need intermediaries for realizing smooth collaboration, such as a teaching assistant, a moderator, and a coordinator. However, intermediaries are difficult to find in many cases because of the shortage of human resources. Therefore, this dissertation proposes entrainment promoting robots as assistants to improve human-human interaction and increase their cooperative performance.

This dissertation proposes to utilize robots to assist the corporation among humans. The proposed “entrainment promoting robot” promotes interpersonal entrainment and

assists cooperation and smooth communication among humans by participating as an intermediary. The dissertation has three contributions; first, it is confirmed that the heart rate and brainwaves have the same entrainment phenomenon; second, it is confirmed that a robot can affects the internal state of humans through communication with expressions and dialogue; third, an assessment method of physiological signal entrainment considering a delay in physiological signal is proposed.

First, an experiment is conducted to investigate the relation of entrainment between heart rate and brainwave. In the experimental condition, the experimenter imitates the subject's actions, articulation, and voice volume when talking about a common interesting topic. On the other hand, in the control condition, the experimenter behaves opposite to the subject's actions, articulation, and voice volume. Their heart rate and brainwave are collected during the experiments and analyzed by Pearson Correlation Coefficient (PCC) as the assessment method. The results show the delay of the physiological signal from heart rate (LF/HF ratio) to brainwave (Beta/Alpha ratio) is around 40-60 seconds, and the brainwave response speed is faster and more sensitive than the heart rate. However, there is no significant difference between the result with imitation behavior and that in the control condition, which implies simply imitating a partner is not enough for promoting entrainment.

Based on the result of the first experiment, the second experiment is conducted to verify whether a robot affects the internal state of a human through the robot's movement and expressions. In this experiment, subjects wear a heart rate sensor and a brainwave sensor, and asked to answer true or false to math questions given by the robot. After the subject answers the questions, the robot expresses happiness or worried behavior according to whether their answer is right or wrong. A worried expression is used to give a proper pressure so that they can think questions seriously. The results show the robot affects the internal state of a human through its movement and expressions.

Finally, the entrainment promoting robot that encourages interpersonal entrainment through dialogue is developed. This dissertation also proposes an assessment method of entrainment that employs Dynamic Time Warping (DTW) and PCC to analyze Power Spectral Density (PSD) data from heart rate and brainwaves. This experiment was conducted with two subjects in each experimental group. One subject holds a clue and the other fills a grid of a crossword respectively, and they communicate and cooperate to complete the crossword in a limited time. In the experimental condition, the robot tells the subjects the time with different dialogues and expressions of anxiety. The control

condition is conducted without the robot. The experimental results show that the average completion rate of tasks was 92% with the robot and 82% without the robot, respectively. It was also observed the subject tended to talk more frequently in the experiment with the robot than in the control condition, which indicates using the robot as an intermediator is helpful for human communication and for improving the performance of cooperation. In terms of the entrainment assessment, DTW is found to be more suitable than PCC. It was also confirmed that different from regular synchronization that is the phenomenon observed at the same time, the physiological entrainment between humans observed in the experiment had a "time delay": the entrainment of partners (collaborators) was observed in the same time segment, but not at the same time. This finding is expected to be examined by subsequent studies in the future.

The dissertation is composed of 6 chapters. Chapter 1 introduces the background and motivation. Chapter 2 describes the concept of entrainment promoting robots and the entrainment assessment method. The experiment for investigating the relation of entrainment between heart rate and brainwave is described in Chapter 3. The second experiment to confirm the effectiveness of a robot for affecting the internal state of a human is described in Chapter 4. The third experiment using the entrainment promoting robot and the result of assessing the entrainment are described in Chapter 5. Chapter 6 presents the conclusion and discusses the future direction of the research based on the findings of the dissertation.