「論文の内容の要旨」

Development of a Variable Viscoelastic Handshake Manipulator Based on the Analysis of Viscoelastic Property of Human Elbow Joint in Handshake Movement

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This paper is a research focused on utilizing the variable viscoelasticity control method to develop a compliant robot arm for human-robot interaction. The robot arm was developed based on the data analysis of real human movements, and soft actuators were applied.

Chapter 1 explained the situation that more and more robots are starting to work for and with human beings. Conventional industrial robots are usually shielded from humans, however, in the foreseeable future, robots might need to physically interact with a human in everyday life. Safe and smooth interaction between humans and robots may become an important concern in future robot developments. Whereas, motor-driven robots are not good at physical interaction due to the lack of back-drivability. Therefore, this research attempted to propose a new soft actuator design to fulfill the purpose.

In chapter 2, the detailed concepts of stiffness and viscosity of human arms are explained with an introduction of how these concepts were developed throughout the history and the attempts made in previous researches to measure them. Then stiffness and viscosity of human arms are measured and analyzed under different handshake conditions. The result of the prerequisite experiment proved the effectiveness of the stiffness and viscosity estimation methods proposed in this paper. And in the following human-human handshake experiment, significant difference were found in joint stiffness which indicated that joint stiffness plays a very important role in the handshake movements. Based on the collected data, and ANN (artificial neural network) model was trained and tested, 85% correct predicting rate was achieved, which proved the effectiveness of the measurement methods proposed in this paper.

Chapter 3 first explored the existing research field of handshake robots explained the problems with the existing robots and then proposed a new design for handshake robots. The majority of the existing handshake robots focused on the planning of the shaking motion of the robotic arm. To achieve high precision of position and speed control, most of the handshake robots are driven by motors and reduction gears. However, this type of structure lacks back-drivability and compliancy, therefore, we proposed a new kind of handshake manipulator which is soft, safe, and with high back-drivability. The joint of the manipulator was comprised of artificial muscles and MR-brakes, which has a similar structure with a real human arm. And the joint also possesses the variable viscoelasticity property like a real human arm.

Chapter 4 explained the upgraded handshake manipulator prototype, which has been made capable of generating a wider range of stiffness for the human-robot experiments. Then applied the stiffness and viscosity measured in the previous human handshake experiments as the target value for the handshake manipulator. Next, human-robot handshake experiments were performed, subjective evaluations were taken and physiological data of the experimenter were compared when he shook hands with human subjects. Finally, a subjective evaluation experiment was conducted to evaluate the performance of the manipulator, and the result indicated that by controlling the viscoelasticity it is possible for the manipulator to generate handshake movements with different feelings.

Chapter 5 summarised the overall conclusion of this research and discussed the application of the proposed actuator in real-world applications.

「論文審査の結果の要旨」

Ⅰ. 論文の主題

Development of a Variable Viscoelastic Handshake Manipulator Based on the Analysis of Viscoelastic Property of Human Elbow Joint in Handshake Movement

Ⅱ. 当該研究分野における位置づけ

In recent years, industrial robots are in an explosion, hundreds of thousands of robots in different shapes and sizes are working to replace human labor in manufactory lines. Also, with the development of social robots in recent years, robots are purposely put in contact with humans for interaction, such as rehabilitation or supporting for hard physical work. Therefore, social and physical interaction between robots and humans is foreseeably to extend in the future. The physical interaction between human and robots are gaining more attention every day.

The actuator comprised of artificial muscles and MR-brakes proposed by this paper is a new attempt for human-robot physical interaction. It provided a complaint and safe structure which also resembles the real human joint. This paper is a research focused on utilizing the variable viscoelasticity control method to develop a compliant robot arm for human-robot interaction. The robot arm was developed based on the data analysis of real human movements, and the evaluation experiments have proved the effectiveness of the proposed handshake manipulator.

Ⅲ. 論文の構成（目次と各章の概要）

■Chapter 1: Introduction　In recent years more and more robots started to work for and with human beings. Conventional industrial robots are usually shielded from humans, however, in the foreseeable future, robots might need to physically interact with a human in everyday life. Safe and smooth interaction between humans and robots may become an important concern in future robot developments. Therefore, this research attempted to propose a new soft actuator design to fulfill the purpose.

■Chapter 2: Human handshake analysis　The detailed concepts of stiffness and viscosity of human arms are explained with an introduction of how these concepts were developed throughout the history and the attempts made in previous researches to measure them. Then stiffness and viscosity of human arms are measured and analyzed under different handshake conditions. In the following human-human handshake experiment, significant differences were found in joint stiffness which indicated that joint stiffness plays a very important role in the handshake movements. Based on the collected data, and ANN model was trained and tested, 85% correct predicting rate was achieved, which proved the effectiveness of the measurement methods proposed in this paper.

■Chapter 3: Variable viscoelastic handshake manipulator　The existing research field of handshake robots was explained and the problems with the existing robots were discussed. Then the author proposed

a new design for handshake robots. a new kind of handshake manipulator which is soft, safe, and with high back-drivability. The joint of the manipulator was comprised of artificial muscles and MR-brakes, which has a similar structure with a real human arm. And the joint also possesses the variable viscoelasticity property like a real human arm.

■Chapter 4: Human-robot handshake experiments The stiffness and viscosity measured in the previous human handshake experiments was used as the target value for the handshake manipulator. Then, human-robot handshake experiments were performed, subjective evaluations were taken and physiological data of the experimenter were compared when he shook hands with human subjects. Finally, a subjective evaluation experiment was conducted to evaluate the performance of the manipulator, and the result indicated that by controlling the viscoelasticity it is possible for the manipulator to generate handshake movements with different feelings.

■Chapter 5: Conclusions Summarized the overall conclusion of this research and discussed the application of the proposed actuator in real-world applications.

Ⅳ. 論文の独自性や成果

Novelty and achievements of this paper can be listed as follows.

- The research of handshake from joint viscoelasticity point of view is a new angle in the handshake research, there was no viscoelasticity data collected in handshake movements.
- This research attempted to categorize a “good” handshake and a “bad” handshake by physical properties, and the proposed measurement methods were proved to be effective.
- A new actuator was proposed for the purpose of human-robot interaction research and its effectiveness was evaluated.

Ⅴ. 論文の課題

The size and durability should be discussed in the future for the real-world application of the proposed actuator and control strategy.

Ⅵ. 論文の評価

This paper proposed a new handshake manipulator design based on the analysis of human elbow joint in a handshake movement. In order to acquire the necessary data a measurement method was proposed. And subjective evaluation experiments were conducted to test the performance of the manipulator. A very thorough research has been done regarding analyzing and reproduce human handshake movements.

Based on the above, this paper is considered to have reached the level to confer a Ph.D. (engineering) degree.