論文の内容の要旨

論文題目
Learning from Observation Paradigm: Leg Task Models for Reproducing Human Dance Motions on Biped Humanoid Robots

（観察学習パラダイム：脚タスクモデルを用いた二足歩行ヒューマノイドロボットによる人の舞踊動作の再現）

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The development of biped humanoid robots has recently been active. Those robots have a potential to perform human-like motions that make full use of their human-like body. If robots can learn such motions from humans, the use of those robots will greatly increase.

This thesis describes a method that enables a biped humanoid robot to learn and reproduce human dance motions using its whole body. We achieve this goal on the basis of the Learning from Observation (LFO) paradigm. In this study, a robot uses its own legs to support its body during a dance performance. To reproduce such performances from human motions is a novel attempt. This thesis especially focuses on how to reproduce leg motions.

LFO is a paradigm of teaching a certain task to a robot. It consists of three processes: observation, recognition, and execution. First, a human instructor demonstrates a task and a robot observes the demonstration. Then the robot recognizes what is done in the demonstration. After that, the robot can execute the task according to the recognition results. For teaching a dance, all humans have to do is just to demonstrate the dance with their body. This is a great advantage in dance reproduction because it can eliminate the work of editing complex motions by human operators. This also means that a reproduced performance directly reflects the original human motions.

In the observation process, motion captures can be used for obtaining motion trajectories of human body parts. However, captured motion trajectories cannot be directly executed by a robot because of various constraints caused by differences between the human body and the body of the robot.

Constraints of leg motions are especially severe because legs must maintain stable contact of the soles to the floor and maintain the dynamic body balance so that the body does not fall down. A robot must satisfy these conditions using its own body. The way of contacting the soles is severely constrained because the soles are not flexible like human soles. The weight distribution of the body is different from that of humans; this causes different dynamic balance. As well as these leg-specific factors, robots are under general constraints caused by its joint mechanism and body shape. Furthermore, dances require a robot to preserve essential characteristics in expression. These complex factors make reproducing leg motions a challenging problem.

Under these severe conditions, details of human motion trajectories must necessarily be modified on the robot. However, the modification itself is not a problem as long as the essence of the original motions is preserved. This consideration leads to the idea that the robot generates motions for its body by concentrating on achieving the original essence. Other factors are generated so that the motions satisfy the constraints of the robot. This approach is more reasonable than the approach in which the robot tries to modify the original motion trajectories for its body.

The recognition process of LFO plays a key role in the generative approach. In the recognition process, a robot obtains the essence of observed human motions. To be precise, the robot extracts elements of task models from the motions, so that human demonstrations are described by the task models. In the LFO paradigm, task models are provided by humans from the top down for a particular task domain. In this thesis, we define leg task models, which represent the essence of leg performances. Four basic leg motions are modeled as tasks by focusing on the state of contact between soles and the floor and the state of the waist. The essential characteristics of each task are described by its skill parameters. Leg motions in a performance are described as a sequence of a number of tasks that have their own values of the skill parameters. In the execution process of LFO, a robot generates leg motions for itself according to a recognized task sequence, considering its constraints and stability.

This thesis describes a series of methods that enables the reproduction of human motion on the basis of leg task models. For the recognition process, we developed a method for extracting a sequence of leg tasks from captured motion data. For the execution process, we developed a method for generating leg motions of a robot from a given sequence of leg tasks. This method can generate motion data that satisfy the constrained condition of the robot. The method also supports various kinds of biped humanoid robots. Upper body motions are processed independently of the leg task models. We also implemented a method for converting human motion trajectories of the upper body into that executable on a robot.

We carried out experiments of our method on an actual dance and robot, using a biped humanoid robot HRP-2, which has human-like size and weight. We attempted to reproduce a Japanese folk dance called "Aizu-Bandaisan," which uses a whole body and includes characteristic leg motions. Motion data of several dancers were obtained by using a motion capture. For these items of motion data, our methods automatically extracted correct sequences of leg tasks and generated motion data that was executable on HRP-2. The generated data was input into the robot, and the robot successfully performed the dance motions stably. This has been a novel achievement of biped humanoid robots.

Through the experiments, we proved the validity of our method. This also means that the LFO paradigm is valid for the problem of teaching whole body performances to biped humanoid robots.

This technology enables biped humanoid robots to be used as an impressive, effective "medium" for presenting human body motions. As one useful application, this technology can produce digital dance archives in which a wide audience can appreciate actual performances of valuable dances.