学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（工学）　　氏名　呉 孟鴻

学　位　論　文　題　名

Cooperative Object Transportation With Multiple Humanoid Robots
（複数ヒューマノイドロボットによる協調物体搬送）

There are more and more robots appearing in factory or our daily life due to development of recent technology. Among all types of robots, humanoid robots have the potential to perform multiple tasks and walk on uneven terrain like human beings. Hence, it is expected that humanoid robots work instead of human beings at dangerous zones such as plant facilities. In such dangerous zones, humanoid robots must cooperate with each other in order to carry heavy and large objects.

Although there is a large amount of ongoing research about multiple robot cooperation, most of them focus on multiple manipulators or wheeled robots, and there is almost no research about cooperative object transportation by multiple humanoid robots. A few attempts have been made to achieve cooperation between a humanoid robot and human. However, such cooperation will not be possible in disaster zones or dangerous areas.

In this thesis, two frameworks of cooperative object transportation by multiple humanoid robots are proposed and evaluated. Multiple robot cooperation can be classified into two types in general: leader-follower type and symmetry type. Both types of cooperation control are implemented in real humanoid robots and experimentally evaluated in this thesis.

Two humanoid robots HRP-2 were used in experiments. In Chapter 2, the details of software and hardware system used in this research are described.

When a humanoid walks around a real environment, walking pattern must be generated online. In Chapter 3, an online walking pattern generation method used in this research is described.

In Chapter 4, a leader-follower type cooperation control is proposed. In leader-follower type control, the leader robot controls the position and attitude of the object, while the follower robot follows the leader robot based on the force sensor information measured on its hands. In this type of cooperation, the follower robots start planning after the leader robot moves, and hence this time-lag may cause excessive internal forces. The generated excessive internal force acts as disturbance for stabilizing controller of robots. Hence such excessive internal force may result in low responsiveness and unexpected tilting of the humanoid robots. There are two ways to suppress the internal force: by changing the relative position of robots or by changing the position of their hands. By combining position-based impedance control with online walking pattern generation, it is possible to generate walking command according to the displacement of the hands. This method is implemented in the follower robot. The proposed leader-follower type control is verified by experiments with two humanoid robots HRP-2 along a sagittal axis.

In Chapter5, a symmetry type cooperation control for arbitrary numbers of humanoid robots is proposed. In symmetry type cooperation control, all robots synchronously move, which achieves high

responsiveness and safety when transporting an object. A method to define the external and internal force of an arbitrary number of humanoid robots is proposed. Furthermore, a symmetric hybrid position/force control law is derived. In order to achieve stable object transportation, external position and internal force are controlled. Internal forces are eased by adjusting the positions of all hands. The proposed symmetry type control is validated both in steady state (without walking) and in object transportation (with walking). In steady state, the reference object position is set as initial position, and reference internal forces are given online. The robots can track the reference internal forces while keeping in initial position. In cooperative object transportation experiments, the humanoid robots are able to generate its whole body motion to transport an object and to control the internal force. The cooperative object transportation among four HRP-2 humanoid robots is simulated and the cooperation between two HRP-2 humanoid robots is experimented. Both results show the effectiveness of the proposed symmetry cooperation control.

This work is summarized in Chapter 6.