論文の要旨

題　目 A Study on Wheeled Inverted Pendulum Robots Capable of Climbing Stairs

（階段を昇降できる車輪型倒立振子ロボットに関する研究）

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The mobility of indoor robots remains a challenge. Most indoor robots are unable for proper locomotion in a human environment, which typically includes stairs, narrow passages, and objects commonly located on desks. Therefore, it is essential to improve the design and mobility of such robots. Many robots were designed and developed to address stairs and narrow-passage issues, such as multiped walking robots, wheel-leg robots, crawler-type rescue robots, transformable tracked robots, and hopping robots. However, most of them have a short structure. Thus, they cannot reach objects that are typically located on desks. Humanoid robots that resemble a human being can effectively climb stairs and can move through narrow passages. The tall body of such humanoid robots is helpful for their convenient interaction with humans and other objects, such as desks or tables. Despite the many advantages offered by humanoid robots, their design is complex and expensive because it requires many actuators and other electronic components.

Self-balancing inverted pendulum mobile robots are uniquely suitable for working in a human environment. They can have a tall body. Thus, they can conveniently interact with humans and other objects. Given that most of them require only one or two contact points to touch the ground, the robots can have a slim structure to move through congested human environments. Recently, a growing interest in the development of stair-climbing inverted pendulum robots emerged. However, most of them require complex structures.

The developed two-wheeled stair-climbing inverted pendulum robot has a simple structure. The robot uses a wheel and an intermediate arm to move its center of gravity when climbing stairs; thus, the robot can climb stairs without losing its balance. Although the robot had already been developed, the control method and its parameters were determined by trial and error. Therefore, we developed a method for adjusting the control parameters to achieve stair climbing based on the analysis of two behaviors: motion of the robot on a flat surface and motion on a step. In the initial step, the control parameter is determined according to a linearized dynamic model of the robot on a flat surface. Subsequently, the compatibility of the control parameter is checked to ensure that it satisfies the condition for climbing.

Although the developed two-wheeled stair-climbing inverted pendulum robot is suitable for operation in a human environment, the robot may fall in a lateral direction when it moves on a side slope or when turning on a slanted terrain. To address this problem, we developed a single-wheeled inverted pendulum robot capable of climbing stairs. The robot has an active lateral balance controller. Thus, the robot can maintain its stability when moving on a side slope. The robot also uses a wheel and an intermediate arm to climb stairs, similar to the developed two-wheeled stair-climbing inverted pendulum robot.

The second robot is a single-wheeled inverted pendulum platform. This robot has an advantage with respect to the first robot when traversing side slopes because its lateral balance is actively controlled. Despite this advantage, studies addressing the improvement of the mobility of single-wheeled robots on uneven terrains are lacking. Therefore, we propose a new configuration of climbing mechanism for such single-wheeled inverted pendulum robot. This robot uses an

intermediate arm to move its center of gravity to climb stairs. To simplify its structure, we propose the use of a differential mechanism to drive an intermediate arm by using a single actuator that drives the wheel of the robot. With this mechanism, the robot can distribute the torque to itself, both on the wheel and the intermediate arm, according to the topography of the ground. Thus, this robot does not require a dedicated sensor to detect stairs because it can automatically move its intermediate arm when stairs are encountered.

This thesis is organized into four chapters. Chapter 1 introduces the background of the study and summarizes the related works on an inverted pendulum robot and a robot capable of climbing stairs. In chapter 2, a two-wheeled stair-climbing robot is discussed. The discussion includes the concept of the developed robot, the control method employed for the robot, and some models used for control parameter adjustment. The effectiveness of the robot on climbing stairs is shown by checking the stability using a limit cycle method and experiments on climbing the stairs with riser height of 12 cm. In chapter 3, the design of a single-wheeled robot capable of climbing stairs is discussed. The discussion includes the concept and design of the single-wheeled robot, and control method used in the robot for climbing stairs. The effectiveness of the robot is shown by experiments on climbing several steps with different height and climbing a staircase with a riser height of 12 to 13 cm. Chapter 6 concludes this study and discusses future works.