DESIGN, MODELING AND MOTION PLANNING OF UNDERACTUATED SPHERICAL ROBOTS

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論 文 名　：DESIGN, MODELING AND MOTION PLANNING OF UNDERACTUATED SPHERICAL ROBOTS
（劣駆動球型ロボットの設計とモデリングおよび動作計画）

区　　分　：　甲

論 文 内 容 の 要 旨

This dissertation investigates underactuated spherical robots. The underactuated systems have models that their control inputs are fewer than the states variables. Although this characteristic might be seen as a drawback due to control and application challenges, it has been observed that they are part of nature in the dynamical model of animals and humans including their locomotion. A living example in nature for an underactuated mechanism is the bird's wing that the elastic ligament connection between feathers and skeleton creates a direct control of wing by using wrist and finger motion of the bird. In robotics, underactuated mechanisms can save the actuator's space and power. In addition, they can result in complex motions, which are well-known theoretical challenges in the field of control and robotics. These models can be seen in large numbers of problems. The object manipulation with fingertips, the rolling robots with rotational mass actuators, certain motions of the legged robots, and even in simple car parking problems are some of these examples.

This dissertation mainly focuses on the underactuated rolling robots, however, certain studies aim for broader applications in the field of robotics and control. Part of this study focuses on a novel fluid-actuated rolling robot. The proposed rolling robot works by rotating spherical cores inside the pipes. In order to push the core, the fluid-actuated mechanism circulates the fluid inside the considered pipe model. After the analytical and performance studies for the underactuated rolling robot, we propose a motion control strategy by using the inverse dynamics of the system.

The fluid-actuated mechanism requires to have a motion tracking of the rotating spherical masses (cores) in pipes. Therefore, a general complementary filter is designed to do the motion tracking of the core by inertial measurement unit under the ferromagnetic effects. Experimental studies take place by comparing the performance of the proposed filter to the well-known quest filter. More importantly, this work shows a new and general observation that using onboard permanent magnets of motors can shield different magnetic disturbances with proper filter design in robots and actuators.

This study continues with a focus on the control problems related to inertial-coupling at underactuated robots. General solution is presented to prevent singularities that exist in the inverse of inertial matrices. The method is applying small-amplitude waves on the rotating mass trajectories. After deriving inverse nonlinear dynamics with combined wave kinematics, conditions for the wave parameters are designed to avoid these configuration singularities. Furthermore, the configuration singularities in the mass-rotating rolling systems due to inertial-coupling are presented for the first time. The singular-free model is analyzed for the underactuated rolling system and planar manipulators.

Finally, a novel geometric-based motion planning is introduced for the spin-rolling sphere with three rotational degrees-of-freedom on a plane. This particular problem has an underactuated model. The study uses the Darboux frame kinematics and develop an arc-length-based control strategy. The aim is to create smooth and realizable trajectories for converging the full-configuration of the overall system. In addition, the motion of the spin-rolling sphere is planned by following the shortest optimal trajectory on the plane. Proposed motion planning strategy illustrates in certain simulation studies.