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Whole Arm Manipulation with Effects of Static and Dynamic Friction on Body Surface

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Recently, powerful and skillful robotic systems for human power assist and cooperation have been developed. These robots should interact with humans softly and safety using not only the end-effector but also the whole-body surface in unknown environment. Although the present manipulator technologies can operate only small and light objects using a robot's hand and finger, it is still difficult to operate large and heavy objects skillfully like a human.

Several methods of the robotic whole-arm manipulation (WAM) and whole-body manipulation (WBM) have been investigated assuming the use of contact force information measured by tactile skin sensors. Knowledge acquired from research of such an advanced motion-mimetic of human is not only important in the understanding of a physical sense and the nerve control function but also indispensable in realizing the high motion more than limits of current actuator output, and skill up as the soft robot which is kind to the human. The advantages of WAM and WBM are summarized as follows.

1. By distributing the contact forces by increasing the number of the contact points between a robot and the target object, each joint actuator can reduce control force or torque when grasping a large and heavy

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object, and this leads to generating energy-efficient robot motion and increasing operating time of the battery.

2. By using the soft skin like a human, WAM and WBM can achieve safe physical interaction with external environment and humans.
3. Different from point-contact manipulation, WAM and WBM utilize surface contact skillfully and can hold or grasp large and heavy objects without injuring them.

In stable grasping and operation of a large object using the robot whole-body and whole-arm surface, modeling and the control theories in consideration of a static and dynamic friction forces on the body surface are necessary but have not been established fully due to the complexity and difficulty of the modeling. One way to easy reproduce the effect of complicated friction forces is the use of the LuGre friction model. The fascination of this model is to make it possible that the static and dynamic friction forces can be specified as a single differential equation.

Based on the observations, in this paper we discuss modeling and control of a WAM systems in consideration of a static and dynamic friction forces on the body surface specified as the LuGre friction model. First, we introduce a 2-DOF WAM system with a circular object and develop the mathematical model and apply the LuGre friction model to reproduce the friction dynamics at the contact points between the robot arm and the object. Second, we design two different controllers for trajectory tracking control in order to manipulate the position of the center of mass of the object; one is based on the inverse dynamic control (Method 1) and the other is based ob the sliding mode control (Method 2). Method 1 uses PD feedback gains but there is a risk that the control input sometimes becomes significantly large when the tracking error is large. Whereas Method 2 achieves robust control without generating a large control input even if the tracking error is large. We compare the control performance of the two methods in terms of average error norm and average input power, and analyze the fundamental motion properties of the WAM system through numerical simulations.