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Modeling and Control of 3-D pinching in Full Variables by Soft Fingers under Non-holonomic Constraints

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ABSTRACT

Hands have many joints in comparison with other parts of the human body. In the motor area of cerebral cortices related directly to sensation and movement, the area related to hands occupies a large part. This implies that dexterity of hands contributes to the development of the human brain. By virtue of the dexterity, hands have evolved to make tools and write pictures and characters. Especially, the primatologist Napier [1] claims that most of important movements of hands are based upon finger-thumb opposition that has contributed to the progress of humanity. This enlightened a great number of researchers on robot hands, who designed and actually made mechanical multi-fingered hands to investigate or unravel the hand dexterity of human. However, most of the researches in robotics remain in kinematics or motion planning establishing a force/torque closure grasp in a static sense. On the other hand, rolling geometry between a finger tip and a pinched object is investigated in detail [2]. However, the researches that take into account the rolling constraints have also remained in a kinematic or semi-dynamic sense without elucidating how the constraint forces affect the stability of pinching motion. In other words, physical interactions of rollings of the finger ends on the object surfaces were not explicitly expressed and incorporated in the overall equations of motion. Around the year of 2000, Arimoto *et al.*[3] disclosed a possibility of stable grasping in a dynamic sense by using a pair of robot fingers with hemispherical ends and incorporating rolling constraint forces in the fingers-object dynamics, in a two dimensional case. In the paper, the equations of motion of the object are expressed explicitly in the wrench space with the aid of Lagrange's multipliers associated with rolling contact constraints. In particular, it is shown that rolling constraints that exert tangential forces upon the object play an essential role stabilizing motion of the finger-object system. In the year of 2006, Arimoto *et al.* [4] extended the works to 3D object grasping and derived a mathematical model as a set of equations of motion of the fingers-object system under Pfaffian constraints due to rolling constraints and another nonholonomic constraint due to the cease of spinning motion around the opposition axis connecting two contact points between a left or right finger tip and an object surface respectively. In a dynamic sense, a constructive method of a 3D object grasping simulator, which considers that the instantaneous axis of the 3D object

is time varying, was proposed firstly in the paper [5]. In the year of 2007, a mathematical model of 3D object grasping in full variables, which allows the spinning motion, was derived in the 6-dimensional wrench space [6]. However, it is assumed in the paper that the tip material of the robot fingers grasping an object is rigid. In this paper, we formulate the overall fingers-object dynamics with soft finger tips as a full variables model depicted in Figure 1 under the assumption that spinning around the opposition is possible but it accompanies viscous friction around the x-axis in the frame coordinates. Simulations are carried out to verify the validity of modeling of the system and the effectiveness of the proposed control signal called " blind grasping " which is the same as that of the 3D object grasping with rigid finger tips [6]. Finally, we show that any solution of the closed loop dynamics converges to an equilibrium state satisfying force/torque balance as time tends to infinity.

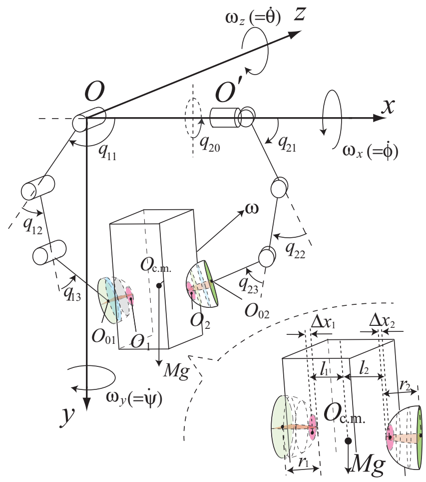

Figure 1: Two robot fingers pinching an object with parallel flat surfaces under the gravity effect

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