Sensory feedback for dynamic stable pinching and orientation control of an object by means of a pair of robot fingers

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Human hand is said to be an agent of the brain. Human swiftly pinches an object in a natural way and manipulate it smoothly in daily life. However, it is very difficult for a robot to do the same motion. For example, human can sense by fusion of various information transmitted from sharp sensory organs such as visual sensing and tactile sensing. However, ability of sensing in robotics such as visual sensing, tactile sensing, and so on, are inferior to human. In addition, the manufacturing cost of multi-fingered robot hands that can move dexterously like a human hand is by far high. Another important reason is that pinching motion is not logically and rigorously analyzed in a strict sense. In the past literature, stable pinching has been analyzed on the basis of only kinematics viewpoint. Moreover, it lacks the viewpoint of "Sensory-Motor Coordination" that must exist and be essential in human motion of object manipulation. In fact, multi-fingered robot hands are so far used only in open-loop control and the importance of sensory feedback has not yet been discussed extensively and precisely in the past literature.

This paper derives Lagrange's equation of a pair of robot fingers with hemispherical tips pinching a rigid object under geometric rolling constraints. In derivation of the equation, it is assumed that the rigid object has two parallel flat surfaces. It is then shown that there exists a sensory feedback signal realizing not only secure pinching with the desired contact force but also control of the object orientation at a specified rotational angle. In addition, to prove the convergence of closed-loop dynamics, "stability on a manifold" is defined accordingly to the fact that the trajectory of any solution to the closed-loop dynamics lies on a manifold with lower dimension than that of the original state space caused by holonomic constraints and converges asymptotically to another manifold with smaller dimension that is a set of states expressing a target task. A method of computer simulation based on the non-linear differential equation with four geometric constraints is discussed together with presenting some computational results. Moreover, some experimental results are obtained by constructing a pair of robot fingers with hemispherical finger ends. Finally, usefulness of the proposed control method is discussed from the practical viewpoint.