Convertible Frictionless to Frictional Fingertips to Improve Robot Grasp Robustness

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Abstract

When a multi-finger robot gripper forms an initial cage on a planar object, then retracts the fingers inward, the end result will be some form of grasp. If the fingers are frictionless, the grasp will be automation immobilizing. However a frictional grasp would be a jamming or frictional equilibrium grasp in most cases. Unfortunately, both are sensitive to wrenches applied to the object. In the frictionless case, wrenches may cause sliding of the fingers along the object’s edges, from their grasping positions, removing them from the initial immobilizing grasp. In the frictional case, perturbations may disengage the finger jam, causing the object to move freely within the cage limits, requiring further retraction to regain equilibrium and stability.

The optimally secure grasp is a frictional grasp that is also immobilizing. For such grasps, small external forces would be counter-balanced by the frictional forces, without exposure to a loss of the frictional grasp and detachment from the object. We are currently developing novel finger mechanisms that will be able to accomplish this behavior by being both frictionless and frictional. Once frictionless fingers reach an immobilizing grasp, we have no further need for the frictionless contacts and would instead prefer the fingers to be frictional, as much as possible even. Our design was established on that very idea- fingers that are frictionless until they no longer need to be, at which time they become high-friction fingers.

Basically, our fingertips possess imbedded rollers that roll along the object’s boundary until enough loading force is exerted on them by finger-object interaction. This force activates a passively compliant locking mechanism that wedges the rollers, preventing further rolling and turning the fingertips into frictional static cylinders.

The loading force required to switch between the frictionless and frictional modes is different for each class of objects. Light, delicate objects need little force applied to reach immobilization grasping, while robust, heavy objects require larger finger forces to overcome the object’s friction with the surface it lies upon. For this reason, our novel design implements a method of simple force threshold adjustment. With a turn of a bolt, the force required to switch to a frictional grasp can be vastly modified. Another issue we deal with is the uncertainty of the angle at which the finger will contact the object. This requires an ingenious mechanism that will lock the roller using the same force regardless of its direction.

We have developed several variable friction finger mechanism prototypes that show promising results. Our current research seeks to incorporate the fingers in a fully-functional robot gripper and test the grasping capabilities compared to solely frictional and frictionless fingers. Future research will also consider the use of this concept for grasping 3D objects.

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**ABSTRACT**

A design of mechanical fingers that are frictionless while retracting upon a two-dimensional object, once the fingers are in an immobilizing grasp and enough force is applied, the fingers convert into high-friction entities that improve the grasp’s robustness to wrenches applied to the object. This combination of frictionless and frictional fingers grants “the best of both worlds”, ending in an immobilizing friction grasp without exposure to jamming issues. The fingers possess a locking system that stops the movement of a roller when enough force from any direction is applied. We incorporate a mechanism that allows easy adjustment of the force threshold required to activate locking with a turn of a bolt. The locking mechanism is slightly offset from the finger’s center and can pivot around it, giving it the ability to align itself normal to the contact surface and not be affected by its orientation.

**CONCEPT**

Blindly retracting frictionless fingers from a caged position guarantees a resulting immobilizing grasp, however the fingers may slide from the grasping position due to external wrenches. Frictional grasps are less susceptible to dislocation from wrenches, however retracting frictional fingers from a caged position may result in a jamming grasp instead of an immobilizing one. This type of grasp can be unhinged by wrenches, detaching the fingers from the object entirely. Our fingers passively allow transition between the two states. A simple contact sensor can be used to determine if the mechanism is locked, and a potentiometer can be used to determine the contact angle. Several prototypes show promising results and more robust grasps than their frictional or frictionless counterparts.

**Grasping Process**

1. Any number of fingers retract from a caged position
2. Finger contacts the object, alignment to the contact surface occurs
3. Object/Hand moves from retraction, fingers roll along object surface
4. Fingers reach immobilizing grasp, no more movement occurs
5. Fingers continue to retract, force exerted on object and fingers grows
6. Force exceeds threshold, locking mechanism activates, friction added
7. Sensors detect locking in all fingers, user may apply more force or stop.

**Contact Normal Alignment**

The rotating locking mechanism is slightly offset to the finger center, so when the roller comes in contact with a surface, it aligns itself normal to the contact plane. This way, the spring locking mechanism always requires the same force to activate. Our design allows normality to surfaces within a 45 degree tolerance (90 altogether), however slight modification can allow omnidirectional contact alignment.

**Finger Design**

Left to right: 3D printed working prototype, 3D model, Section view of 3D model

**Adjustable Force Threshold**

We use a spring that is pre-compressed against the moving part, creating a “preload” force that must be overcome to start moving. The remainder of force required to lock the mechanism is the product of the spring’s stiffness and the small distance the moving part travels. This value of force is small and constant. The preloading force can be adjusted by pre-compressing the spring:

\[
F_{\text{Lock}} = F_{\text{pre}} + F_{\text{dis}} \\
F_{\text{pre}} = k\Delta b \\
F_{\text{dis}} = k\Delta x
\]

Where \( x \) is the distance traveled, \( k \) is the spring stiffness, and \( b \) is an adjustable parameter.

**Future Work**

- Small improvements to design, reduce size and increase versatility
- Incorporate additional sensors for better feedback control
- Implementation of concept to 3D fingers

Image: A simple three fingered hand using a single actuator that utilizes the passive finger mechanism to grasp assorted objects.