Passive Compliant Grasping for Unstructured Environments

Aaron M. Dollar and Robert D. Howe

Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA

GRASPER DESIGN OPTIMIZATION

In unstructured environments, where sensing uncertainties are large and target object size and location may be poorly known, compliance conveys several advantages for robotic grasping:

- Reduce contact forces
- Conform to a wide range of objects
- Allows for uncertainty in object location and properties

Passive compliance, implemented through springs in robot joints, offers additional benefits to active compliance, particularly in impacts, where control loop delays may lead to poor control of contact forces.

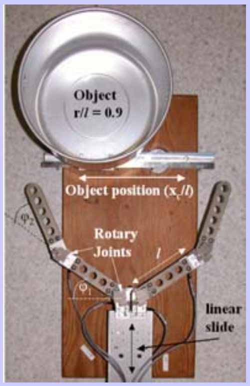


Diagram of reconfigurable gripper showing parameters varied within optimization

We examine the optimization of the design of a simple two-fingered gripper with passive springs in the joints in both simulation and hardware:

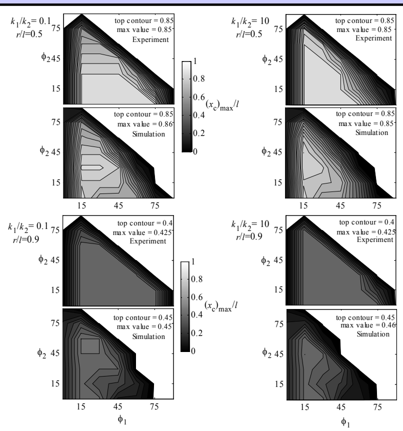
Grasper parameters varied

- Joint stiffness ratio (k_1/k_2)
- Joint rest angles (ϕ_1, ϕ_2)
  - "preshape"

Object parameters varied

- Object size (r/l)
- Object location (x_c/l)

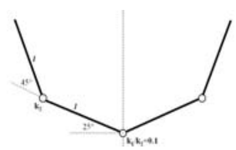
Goal: Find the combination of grasper parameters that result in the maximum allowable uncertainty in object size and location with low contact forces



(above) Successful grasp range results from both simulation and experiment for k_1/k_2={0.1,10} and r/l={0.5,0.9}. Joint angles are in degrees and countours in increments of 0.05

(right) Normalized mean contact force during object acquisition from simulation and experiment for large k_1/k_2 and r/l=0.5

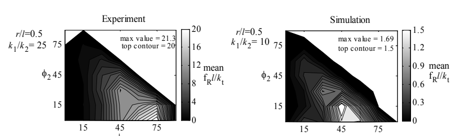
Results



The configuration of the "optimum" gripper

Results of the simulation and experiment show:

- Successful grasp range is maximized around ϕ_1=25° ϕ_2=45° and low k_1/k_2
- Contact forces are low at these same configurations



A ROBUST COMPLIANT GRASPER VIA SHAPE DEPOSITION MANUFACTURING

Robustness is a limiting factor in experimental development of multifingered robot hands: their expense and fragility precludes casual experimentation, restricting the type of experimental tasks that can be reasonably attempted and slows implementation due to the need for careful validation of programs.

We explore the benefits of using Shape Deposition Manufacturing (SDM) for constructing a gripper for use in unstructured environments. This simple process allows for spatial variation of mechanical properties and embedded sensing and actuation components.

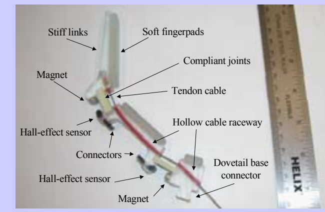
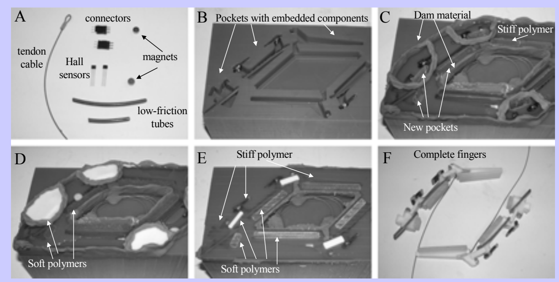


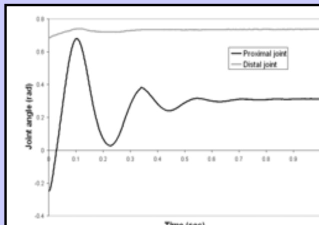
Diagram showing the components of the SDM finger



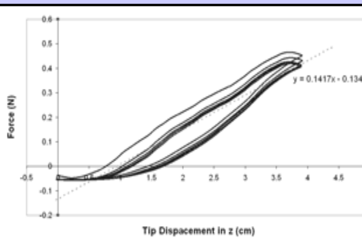
Steps of the SDM process:
- *Pockets are machined into machine wax and components (A) put into place (B).*
- *Polyurethane resin is poured, allowed to cure, and a second set of pockets is machined (C).*
- *The resins for the compliant finger joints and soft fingerpads are deposited (D).*
- *The block is faced off (E), and the completed fingers removed from the wax support.*

The entire process takes approximately 30 hours, only 4 of which require human supervision.

- Fingers are extremely robust!
  - Can successfully grasp objects under large size and position uncertainty
  - Construction can withstand large deflections and impact loads
- Fingers exist as one part – no fasteners!
- Manufacturing process allows for easy redesign and fabrication
- Preshape and stiffness of fingers is based on results of optimization study
- Hall-effect sensors paired with rare-earth magnets enable joint angle sensing
- Finger is underactuated: one tendon cable actuates both joints due to the joint compliance
- The inner joint of the fingers actuate first, increasing the chances that both links of the finger are in contact with the object for greater friction



Joint response of the SDM finger to a tip step displacement released at time=0. The viscoelastic properties of the joint material quickly damp out unwanted joint oscillations



Force-deflection behavior of the tip of the SDM finger in the out-of-plane direction (with linear trendline). The data represents five cycles of tip motion.

- SDM fingers can undergo large displacements without degradation of mechanical properties
- Approximate tip stiffness in the *x* and *y* (planar) and *z* directions are 5.85, 7.72, and 14.2 N/m
- Grasper becomes much stiffer when actuated

Funding by the Office of Naval Research grant number N00014-98-1-0669