An Integrated Solution to the Synthesis of Multifinger Grasps

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November 19, 2009

Objective

Solving the grasp synthesis problem for multifingered hands

Given a hand and an object to be grasped, the problem entails finding feasible configurations of the hand-object system that simultaneously yield a *stable* and *manipulable* grasp.

Motivation

- Hands as versatile and efficient tools for manipulation

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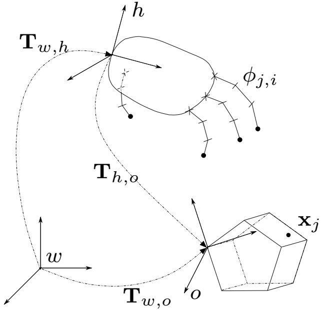

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- Hands as versatile and efficient tools for manipulation
- The grasp synthesis within dexterous manipualtion
- Partially related problems in the literature

  Problem 1 Contact Point Synthesis
  Problem 2 Fingertip Force Computation
  Problem 3 Inverse Kinematics
  Problem 4 Dexterous Manipulation

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- Further applications

  Autonomous manipulation, assisted teleoperation, dexterous prosthetic hands, and in general to any setting involving the control of multifingered manipulation devices.

Expected contributions

- An integrated and generic formulation of the problem
- A general and complete solution method for multifinger grasp synthesis

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  - *Integrated*, unify the proposed constraints
  - *General*, applicable to any hand
  - *Adequate*, use of low-degree terms (i.e. x_i, x_i^2, $x_i y_i$)
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- A general and complete solution method for multifinger grasp synthesis
  - *General*, able to solve any formulated equation system
  - *Complete*, find solutions if they exist and conlude usolvable otherwise

On the solution method

Factors affecting the dimensionality:

- Number of fingers
- Contact model

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Approaches:

- *Lower-dimensional cases:* algebraic-geometric and branch-and-prune methods
- *Higher-dimensional cases:* probabilistic methods combined with branch-and-prune methods

State of the art

- Human hand models
- Solutions to the grasp synthesis problem
- Solutions to algebraic equations

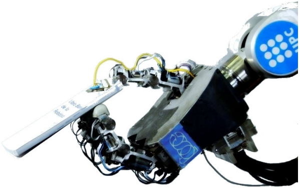
Human hand models

robot hands

3-finger hands

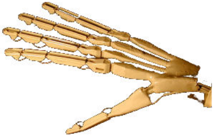
Townsend 2000

4-finger hands



Suarez and Grosch 2005

5-finger hands



Lotti et al. 2005

Human hand models

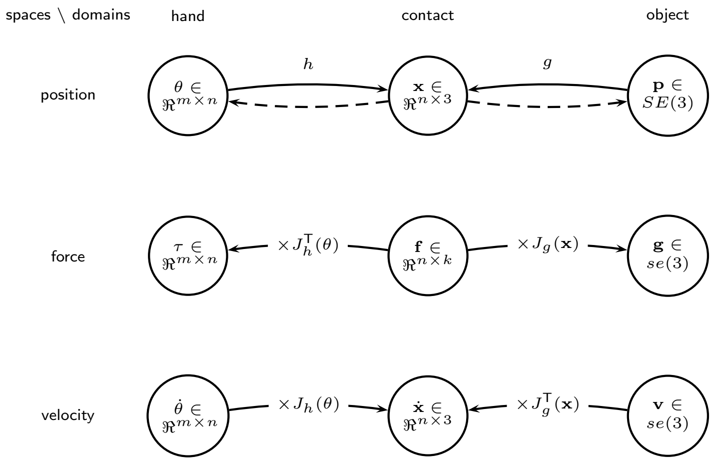
prosthetic hands

Touch Bionics 2004

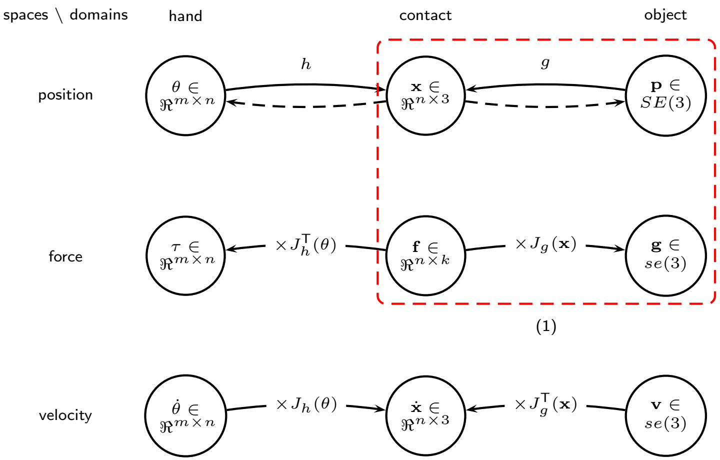
virtual hands

Peña et al. 2005

Solutions to the grasp synthesis problem



Problem 1 Contact Point Synthesis



Problem 1 Contact Point Synthesis

1876, Reuleaux introduces force and form closure, conludes 4 as minimum number fingers for 2D objects

1900, Somov states that 7 is the required fingers for 3D objects

1983, Salisbury and Roth introduce the wrench space for analysis

1987, Mishra *et al.* set upper bounds for required fingers:12 and 6 for piecewise smooth objects in 3D and 2D, respectively

1988, Nguyen introduces independent contact regions in 2D in the construction of grasps

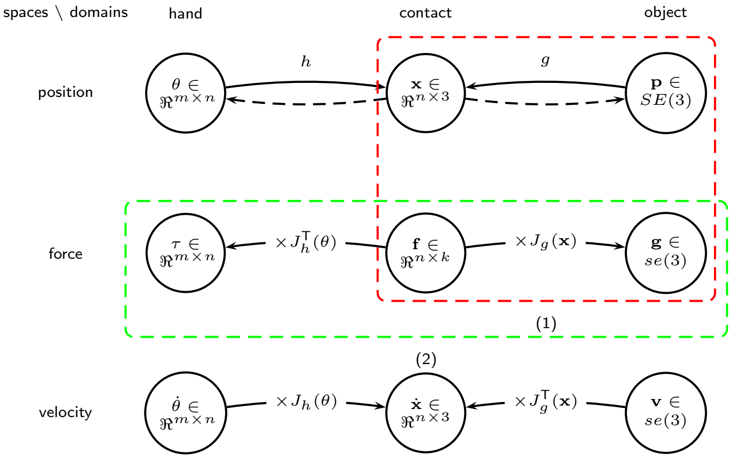
1992, Ferrari and Canny introduce a quantative measure in wrench space

1998, Liu provides an approach for n-finger grasps synthesis in 2D objects

2003, Li *et al.* provide a general method for 3-finger grasps synthesis in 2D and 3D objects

2007, Roa and Suárez provide a geometric approach for n-finger grasps synthesis in 3D objects

Problem 2 Fingertip Force Computation



Problem 2 Fingertip Force Computation

1986, Kerr and Roth linearize the friction cone with planar faces to include torque constraints

1989, Kumar and Waldron provide suboptimal algorithms, and introduces the finger force decomposition

1991, Cheng and Orin provide optimal solutions using linearized model

1991, Yoshikawa and Nagai reformulate the finger force decomposition into

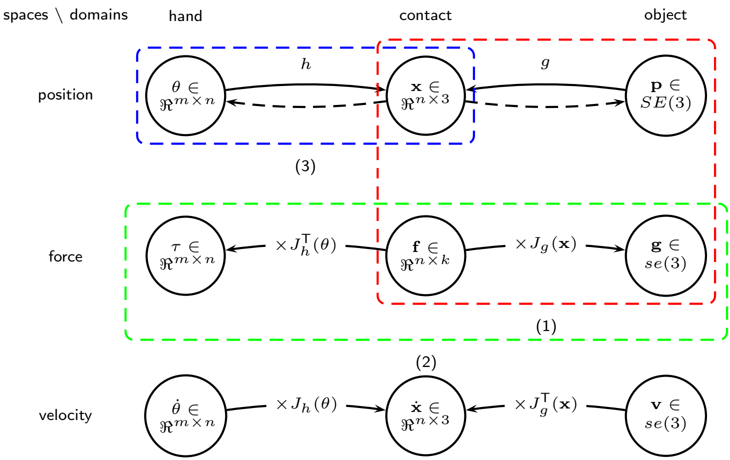
1996, Buss *et al.* formulate the non-linear friction constraints as positive-definiteness of a matrix

2000, Zuo and Quian solve the problem using dynamic programming techniques

2006, Carloni formulates the problem using the dual theorem of non-linear programming

2007, Al-Gallaf gives a neuro-kinematic based approach for this problem

Problem 3 Inverse Kinematics



Problem 3 Inverse Kinematics

1991, Hunt *et al.* present a kinematic study of multifinger grippers defining special configurations

1995, Bicchi defines force-closure grasps considering the hand

1997, Pollard synthesizes whole-hand grasps based on the geometry of the contacting bodies

2002, Borst *et al.* formulate the kinematic constraints as an unconstrained optimization problem

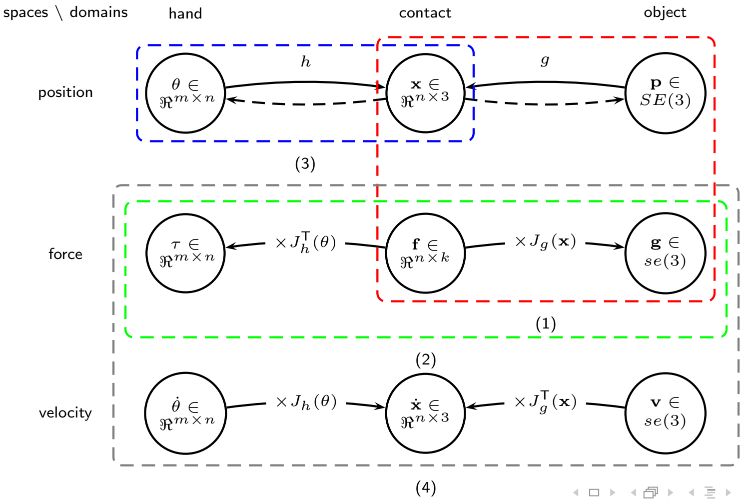
2005, Gorce and Rezzoug rely on neural network and reinforcement learning to obtaing hand configurations

2005, Rosell *et al.* use optimization to compute joint values using fingertip distance to contact point

2007, Ciocarlie *et al.* introduce eigengrasps and use random sampling to preconfigure the hand

2008, Rosales *et al.* provide a general and complete method for finding hand configurations

Problem 4 Dexterous Manipulation



Problem 4 Dexterous Manipulation

1989, Li *et al.* propose a control algorithm considering the dynamics of the object and the hand, for position trajectory and desired internal force

1990, Murray *et al.* present a mathematical framework for the formulation of the kinematics, dynamics and control of robot hands

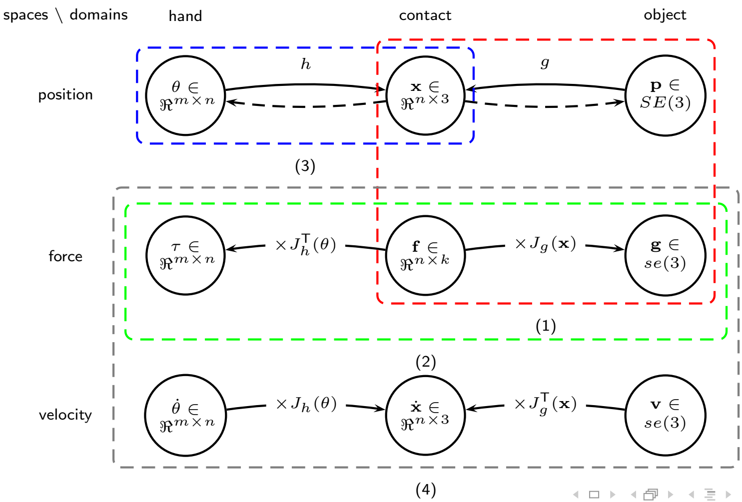
1996, Shimoga resumes grasp synthesis methods in generalized algorithms within a control scheme

2000, Okamura *et al.* propose three control level framworks for dexterous manipulation

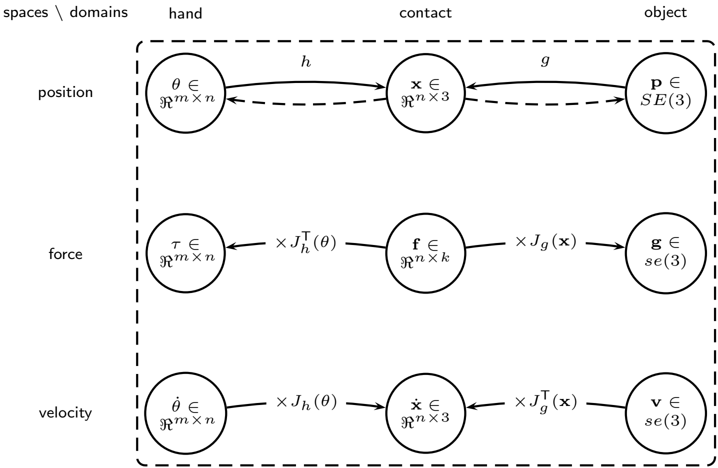
2007, Arimoto provides control algorithms considering rolling constraints and introduces the concept of blind grasping (no need of object surface information)

2007, Saut *et al.* use probablisitc techniques for dexterous manipulation and re-grasping sequences

Current state



Proposal


spaces \ domains
hand
contact
object
position
force
velocity
$\theta \in \Re^{m \times n}$
$\mathbf{x} \in \Re^{n \times 3}$
$\mathbf{p} \in SE(3)$
h
g
$\tau \in \Re^{m \times n}$
$\mathbf{f} \in \Re^{n \times k}$
$\mathbf{g} \in se(3)$
$\times J_h^{\mathsf{T}}(\theta)$
$\times J_g(\mathbf{x})$
$\dot{\theta} \in \Re^{m \times n}$
$\dot{\mathbf{x}} \in \Re^{n \times 3}$
$\mathbf{v} \in se(3)$
$\times J_h(\theta)$
$\times J_g^{\mathsf{T}}(\mathbf{x})$

Solutions to algebraic equations

Algebraic-geometric methods

- Reduce the initial system to an univariate polynomial
- Used for inverse kinematics of general 6R manipulators (Manocha and Canny 1994; Raghavan and Roth 1993), and the forward analysis of general Stewart-Gough platforms (T.-Y. Lee and J.-K. Shim 2001).
- Recent progress on sparse resultant theory qualifies them as promising techniques (Dickenstein and Emiris 2005)

Solutions to algebraic equations

Continuation methods

- Gradually transform a system with known solutions to a system whose solutions are sought, tracking the solution path along the way
- It was first showed that the inverse kinematics of the general 6R manipulator has up to sixteen solutions (L. -W. Tsai and Morgan 1985), and the direct kinematics of the general Stewart-Gough platform can have at most forty solutions (Raghavan 1993)
- Currently, it is well studied and developed (Sommese and Wampler 2005; H.-J. Su et al. 2006)

Solutions to algebraic equations

Branch-and-prune methods

- Use approximate bounds of the solution set in order to rule out portions of the search space that contain no solution
- It has been used for under and over constrained systems, position analysis of complex kinematic closed loops such as molecular structures and multifinger grasps.
- Current state include two families: bounding via Taylor expansions (J.-P. Merlet 2001b, Gavriliu 2005) and via polytopes (Lebbah et al. 2005, Porta 2008).

Tasks

Task 0
Literature review.

Task 1
Definition of a generic hand model.

Task 2
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Identification of problem classes.

Task 7
Development of a solution method for lower-dimensional problems.

Task 8
Development of a solution method for higher-dimensional problems.

Task 9
Proposition of a set of objects to test the procedures.

Task 10
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Gantt chart (I)

tasks \ time	2007				2008			
	T1	T2	T3	T4	T1	T2	T3	T4
literature review	●	●	●	●	●			
hand model			●	●				
contact models			●	●				
kinematic constraints				●	●			
stability constraints					●			
manipulability constraints								
problem classes								
lower-dimensional problems								
higher-dimensional problems								
object set and testing			●					
thesis writing								

Gantt chart (II)

tasks \ time	2009				2010			
	T1	T2	T3	T4	T1	T2	T3	T4
literature review		■						
hand model								
contact models								
kinematic constraints								
stability constraints								
manipulability constraints								
problem classes								
lower-dimensional problems	■	■	■					
higher-dimensional problems		■	■	■	■			
object set and testing		■						
thesis writing					■	■	■	■

Resources

Resource	Status	Purpose
Multi-processor computer	64-processor grid at IRI	To increase the computational capacity to carry out the experiments
Mechanical robot hand	SAHand and MA-I at IOC	To demonstrate the approach using a real robotic hand
Robot arm	Stäubli at IOC	To move the real robotic hand
Programming software	C++ tools, Matlab, Maple.	To implement and test of the algorithms
Access to bibliography	UPC and others	To determine the state of the art

Thanks for your attention

Feel free to ask questions, I will do my best to answer them!