Optimization-based control for dual-arm manipulation

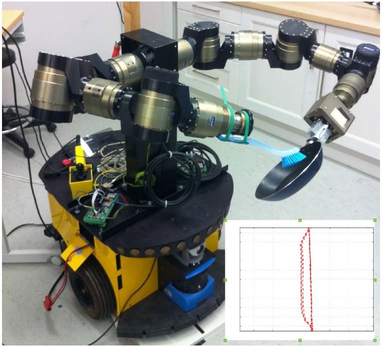
Yuquan Wang, Francisco Viña, Yiannis Karayiannidis, Christian Smith and Petter Ögren

KTH, Center for Autonomous Systems (CAS)

June 5, 2014

Background: Why constraint-based programming?

Problem:

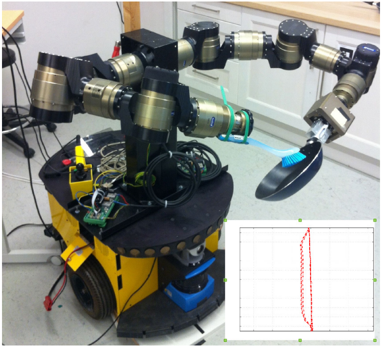


Candidate solution: Trajectory planing

- Pan&brush trajectories $e(t)$
- Joint trajectories $q(t)$

Background: Why constraint-based programming?

Problem:



Candidate solution: Trajectory planing

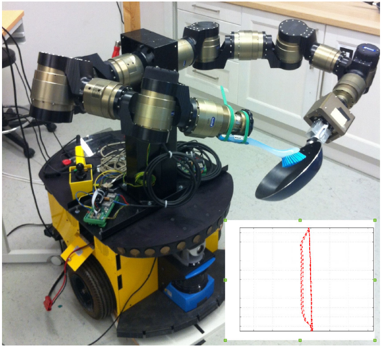
- Pan&brush trajectories $e(t)$
- Joint trajectories $q(t)$

Drawbacks:

- Not reactive
- Hard to extend

Background: Why constraint-based programming?

Problem:



Candidate solution: Trajectory planing

- Pan&brush trajectories $e(t)$
- Joint trajectories $q(t)$

Drawbacks:

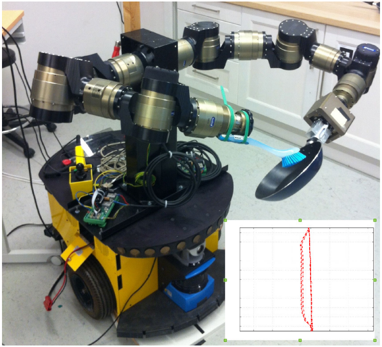
- Not reactive
- Hard to extend

Alternative:

- Constraint-based programming

How to use constraint-based programming?

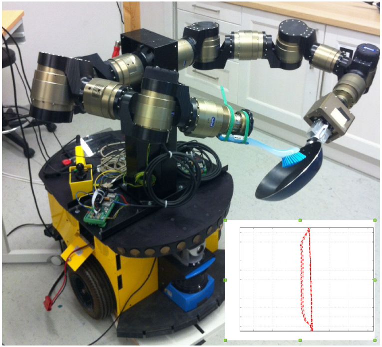
Example:



- Specifing constraints:
- Combining constraints.

How to use constraint-based programming?

Example:

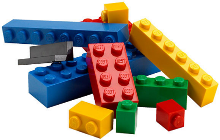


- Specifing constraints:

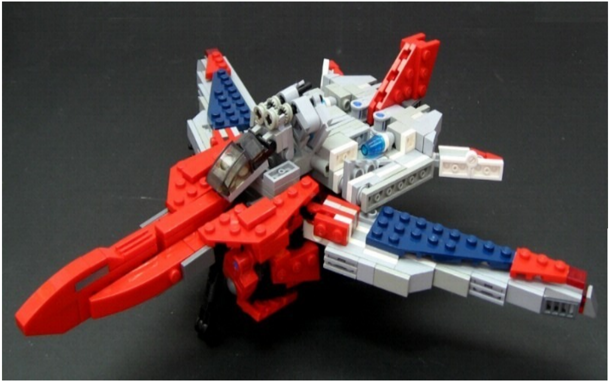
  { Relative position
  Brush orientation
  Contact force
  Obstacle avoidance
  Singularity avoidance

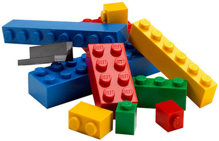
- Combining constraints.

Build a monster from something simple



Build a monster from something simple

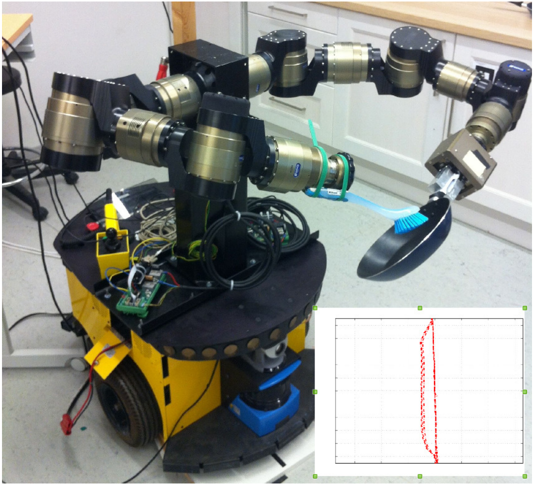




Seminal earlier works in constraint-based programming

- Additional tasks (Seraji 1989)
- User defined objective functions (Peng and Adachi 1993)
- Stack of Tasks (Mansard and Chaumette 2007)
- iTaSC (De Schutter 2007)
- Sub-tasks (Tatlicioglu 2008)
- Prioritizing linear equality and inequality systems (Kanoun 2009)

Dual arm manipulation



Dual arm manipulation using constraint based programming

Our formulation of constraint-based programming

Quadratic optimization problem:

- 2014 IFAC:
  Dual arm manipulation using constraint-based programming.
- 2012 Syroco:
  A multi objective control approach to online dual arm manipulation.

Our formulation of constraint-based programming

Quadratic optimization problem:

$$\min_{u} \quad \dot{f}_j(\boldsymbol{q}(t), \boldsymbol{u}, t) + \boldsymbol{u}^T Q \boldsymbol{u},\ j \in I$$

Q is a diagonal positive definite matrix.

Our formulation of constraint-based programming

Quadratic optimization problem:

$$\begin{aligned} \min_{u} \quad & \dot{f}_j(\boldsymbol{q}(t), \boldsymbol{u}, t) + \boldsymbol{u}^T Q \boldsymbol{u},\ j \in I \\ \text{(s.t.)} \quad & \dot{f}_m(\boldsymbol{q}, \boldsymbol{u}, t) \leq b_m,\ \forall m \in I_{ie}, \end{aligned}$$

where b_m, b_n are positive scalars and Q is a diagonal positive definite matrix.

Our formulation of constraint-based programming

Quadratic optimization problem:

$$\begin{aligned} \min_{u} \quad & \dot{f}_j(\boldsymbol{q}(t), \boldsymbol{u}, t) + \boldsymbol{u}^T Q \boldsymbol{u}, \ j \in I \\ \text{(s.t.)} \quad & \dot{f}_m(\boldsymbol{q}, \boldsymbol{u}, t) \leq b_m, \ \forall m \in I_{ie}, \\ & \dot{f}_n(\boldsymbol{q}, \boldsymbol{u}, t) = b_n, \ \forall n \in I_e, \end{aligned}$$

where b_m, b_n are positive scalars and Q is a diagonal positive definite matrix.

Explicitly parameterize the convergence of each constraint:

$$\dot{f}_m(\boldsymbol{q}, t) \leq b_m, \ \forall m \in I_{ie},$$
$$\dot{f}_n(\boldsymbol{q}, t) = b_n, \ \forall n \in I_e,$$

Explicitly parameterize the convergence of each constraint:

$$\dot{f}_m(\boldsymbol{q}, t) \leq -k_m e_m, \ \forall m \in I_{ie},$$
$$\dot{f}_n(\boldsymbol{q}, t) = -k_n e_n, \ \forall n \in I_e,$$

Explicitly parameterize the convergence of each constraint:

$$\dot{f}_m(\boldsymbol{q}, t) \leq -k_m(f_m(\boldsymbol{q}, t) - b_m), \ \forall m \in I_{ie},$$
$$\dot{f}_n(\boldsymbol{q}, t) = -k_n(f_n(\boldsymbol{q}, t) - b_n), \ \forall n \in I_e,$$

Time-forward terms:

$$\begin{aligned} \dot{f}_m(\boldsymbol{q}, t) &\leq -k_m(f_m(\boldsymbol{q}, t) - b_m), \ \forall m \in I_{ie}, \\ \dot{f}_n(\boldsymbol{q}, t) &= -k_n(f_n(\boldsymbol{q}, t) - b_n), \ \forall n \in I_e, \end{aligned}$$

Time-forward terms:

$$\frac{\partial f_m(\boldsymbol{q},t)}{\partial \boldsymbol{q}}\dot{\boldsymbol{q}} \leq -k_m\left(f_m(\boldsymbol{q},t)-b_m\right)-\frac{\partial f_m(\boldsymbol{q},t)}{\partial t},\ \forall m \in I_{ie},$$

$$\frac{\partial f_n(\boldsymbol{q},t)}{\partial \boldsymbol{q}}\dot{\boldsymbol{q}} = -k_n\left(f_n(\boldsymbol{q},t)-b_n\right)-\frac{\partial f_n(\boldsymbol{q},t)}{\partial t},\ \forall n \in I_{e},$$

Prioritizing the constaints:

$$\begin{aligned} \min_{u} \quad & \dot{f}_j(\boldsymbol{q}(t), \boldsymbol{u}, t) + \boldsymbol{u}^T Q \boldsymbol{u}, \ j \in I \\ \text{(s.t.)} \quad & \dot{f}_m(\boldsymbol{q}, \boldsymbol{u}, t) \leq -k_m(f_m(\boldsymbol{q}, t) - b_m), \ \forall m \in I_{ie}, \\ & \dot{f}_n(\boldsymbol{q}, \boldsymbol{u}, t) = -k_n(f_n(\boldsymbol{q}, t) - b_n), \ \forall n \in I_e, \end{aligned}$$

where k_m, b_m are positive scalars and Q is a diagonal positive definite matrix.

Prioritizing the constaints:

$$\begin{aligned} \min_{u} \quad & \dot{f}_j(\boldsymbol{q}(t), \boldsymbol{u}, t) + \boldsymbol{u}^T Q \boldsymbol{u} + \boldsymbol{\mu}^T W \boldsymbol{\mu}, \ j \in I \\ \text{(s.t.)} \quad & \dot{f}_m(\boldsymbol{q}, \boldsymbol{u}, t) + \mu_m \leq -k_m(f_m(\boldsymbol{q}, t) - b_m), \ \forall m \in I_{ie}, \\ & \dot{f}_n(\boldsymbol{q}, \boldsymbol{u}, t) + \mu_n = -k_n(f_n(\boldsymbol{q}, t) - b_n), \ \forall n \in I_e, \end{aligned}$$

where k_m, b_m are positive scalars and Q, W are diagonal positive definite matries.

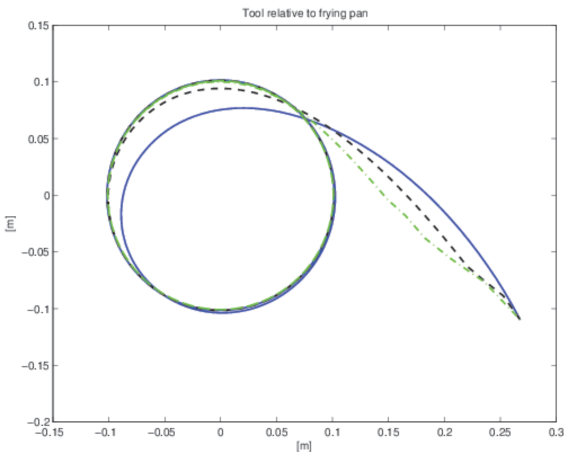
Our formulation of constraint-based programming

Advantages:

- Compact formulation of a QP including equalities and inequalities.
- Time feed-forward terms.
- Parameterize the convergence rate.

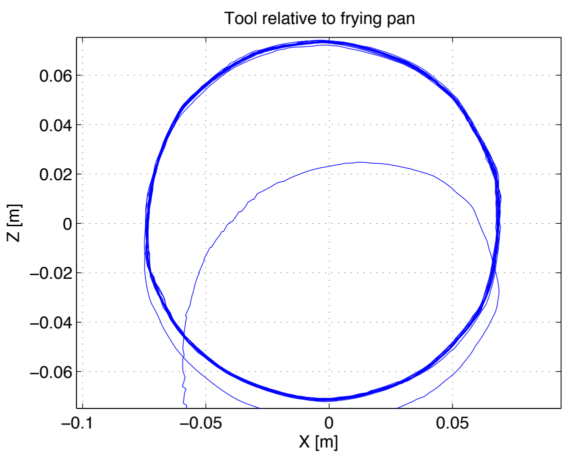
Circular trajectory in the pan cleaning task

Different convergence rate in simulation:



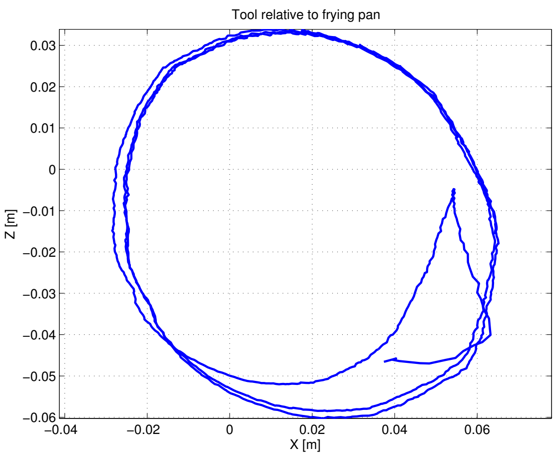
Circular trajectory in the pan cleaning task

Experiment on a dual-arm robot:

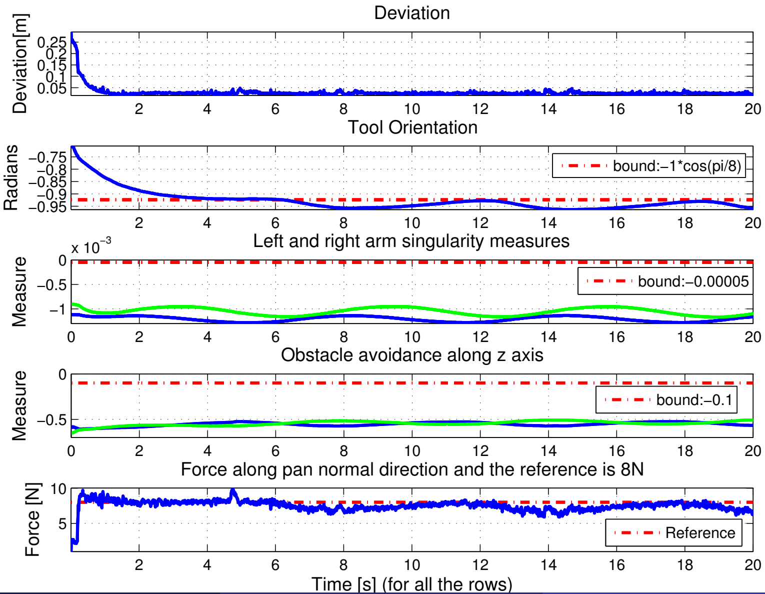


Circular trajectory in the pan cleaning task

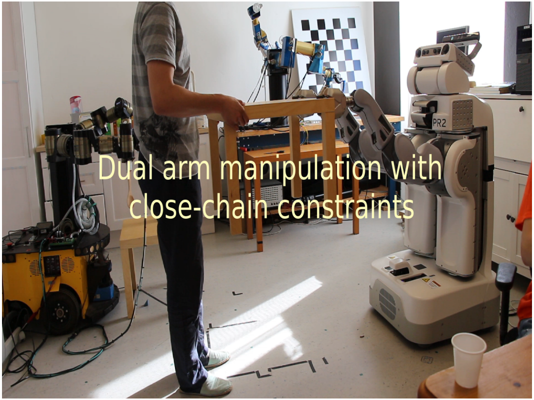
Experiment with contact force control:



Performance indices

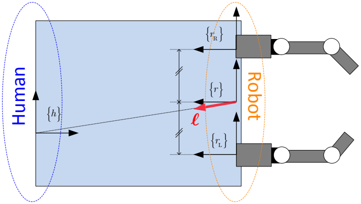


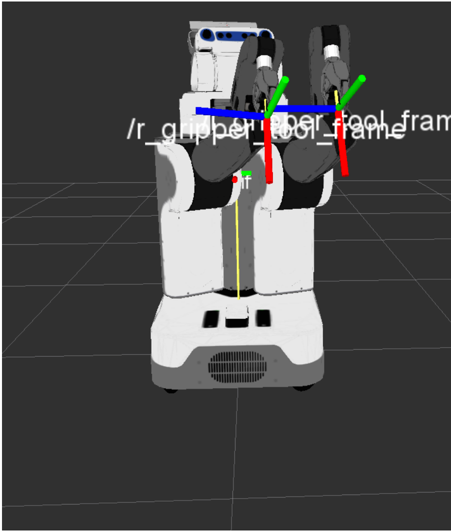
Human robot co-manipulation



Human robot co-manipulation

Human robot co-manipulation





Acknowledgement and questions

Acknowledgement:

- Swedish Foundation for Strategic Research (SSF)
- Swedish Research Council (VR)
- EU FP7 project RoboHow.Cog

Acknowledgement and questions

Acknowledgement:

- Swedish Foundation for Strategic Research (SSF)
- Swedish Research Council (VR)
- EU FP7 project RoboHow.Cog

Questions?