Dual-arm Manipulation Planning

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Today’s Talk

• Whole Body Manipulation

• Dual-arm Manipulation Planning (Recent Work)
Whole Body Manipulation by Humanoid Robots

- Performing Tasks
  - Utilization of Hand Reaction Force
    - Pushing
    - Lifting up

- Enhancing its Mobility
- Motion Planning
- Real-time Gait Planning
- Extending ZMP

ZMP Based Biped Gait
Pushing Manipulation by Humanoid Robots

Generation of Biped Gait in Real-time According to the Result of Arm Force Control

Harada et al., IEEE/ASME TMECH ’07, ICRA’04
Modification of Waist Position According to the Hand Reaction Force

Harada et al. ICRA ’05
Stabile Gait Based on ZMP (Zero Moment Point)

Enhancing Humanoid Robot’s Mobility

Stable Motion including Hand Contact

Waling with Pushing
Supporting its Weight using Hands

Climbing up a Big Gap with Grasping Hand Rail
Extension of ZMP Theory to Manipulation Tasks

Definition of Stability using 3D Convex Polyhedron

Harada et al., IEEE TRO ’06, ISER ’06
Stability of Humanoid Robot Considering the Grasping Force

Strong Grasping Force ↔ Stable

Harada et al., IROS ’04
Mobility \sim \text{Contact Wrench Sum (CWS)}

Hirukawa et al. ICRA '07

Contact Wrench Sum (CWS)
(Gravity and Inertia Wrench)

\[ f_G = M(g - \ddot{p}_G), \]
\[ \tau_G = p_G \times M(g - \dot{p}_G) - \dot{\mathbf{L}} \]

\( p_G \) : Center of mass
\( \mathbf{L} \) : Angular momentum around COG

Contact Wrench Cone (CWC)

\[ f_C = \sum_{k=1}^{K} \sum_{l=1}^{L} \epsilon_k^l (n_k + \mu_k t_k^l) \]
\[ \tau_C = \sum_{k=1}^{K} \sum_{l=1}^{L} \epsilon_k^l p_k \times (n_k + \mu_k t_k^l) \]

\( \Rightarrow \) Polyhedral Convex Cone
Motion Planning for Humanoid Robots

- Whole Body Motion Planning
- Grasp Planning
- Gait Planning
Whole-body Motion Planning +
Dynamic Walking Pattern Generator

Harda et al. IEEE/ASME TMECH ’10, IROS ’07
Simultaneous Foot-Place/Upper-Body Motion Planning

- Using Real-time walking pattern generator for offline kinodynamic motion planning
Motion Planning for Humanoid Robots

- Whole Body Motion Planning
- Grasp Planning
- Gait Planning
Several Regrasping Styles by a Dual-Arm Manipulator

- Right Pick - Right Place
- Right Pick - Regrasp - Left Place
- Right Pick - Right Place - Left Pick - Left Place
- Right Pick - Right Place - Right Pick - Right Place

Etc..

Harada et al. (ICRA ‘12)
Configuration Space for Dual-Arm Manipulator

\[ CS = CS_r \times CS_l \times CS_o \]

Harada et al. ICRA ’14
Basic Structure

\[ CS = CS_r \times CS_l \times CS_o \]

Initial Grasp (Left)

Initial Grasp (Right)

Intermediate place (Grasped by right)

Intermediate place (Grasped by left)

Target place (Grasped by right)

Target place (Grasped by left)

\[ CG_R \]

\[ CG_L \]

Bimanual grasp
Manipulation Graph

Harada et al. ICRA ’14
Place Object on Table
Regrasp between Right and Left

Regrasp between Right and Left
Implementation of Dual-arm Manipulation

Randomized Bin-picking with Regrasp

- Use of Parallel Computation for IK Calculation

Harada et al. IEEE SII ’14
Development and Comparing Single-arm and Dual-arm Regrasps

Wan and Harada, Submitted for RA-L
The regrasp graph for single-arm regrasp

- Grasp planning component
  - Clustering and sampling
  - Evaluating

- Placement planning component
  - Convex hull and clustering
  - Placements & Stability
  - Association

- Regrasp graph component
  - Transit edges
  - Transfer edges
  - Regrasp graph

Using regrasp graph to do single and dual-arm regrasp
Using regrasp graph to do single and dual-arm regrasp

The regrasp graph for dual-arm regrasp

Grasp planning component

- Clustering and sampling
- Evaluating

Handover planning component

- Optimize position using manipulability and approachability → Fig.4
- Sampling rotation
- Association

Regrasp graph component

- Transit edges
- Transfer edges
- Regrasp graph
Using regrasp graph to do single and dual-arm regrasp

Searching and updating the regrasp graph
Using regrasp graph to do single and dual-arm regrasp

Compare Single-arm and Dual-arm reorientation

Developing and Comparing Single-arm and Dual-arm Regrasp

The Manipulation Research Group
National Institute of AIST
Weiwei Wan and Kensuke Harada
Base Position Planning for Dual-arm Mobile Manipulators Performing a Sequence of Pick-and-place Tasks

Collect multiple objects from using Dual-arm manipulator

Determine a sequence of the base position

Selective Use of Two Hands

Can Reduce the Number of Sequence

Harada et al., Humanoids 2015
OVERVIEW OF PROPOSED METHOD

Minimize : Number of Sequence and Travel Distance

Common Area of Base position:
- Left Hand Picks an Object in the Box 1
- Right Hand Pick an Object in the Box 2
Assembly Planning of Elastic Parts
(Ramirez-Alpizar, Harada, and Yoshida, Humanoids ’14)

Assembly of Elastic O-ring to Cylindrical Part

Use of Optimization Based Motion Planner (CHOMP Planner)

Consideration of Elastic Energy Term to the Index Function

CHOMP Planner
Index Function: Collision Avoidance Smoothness Elastic Potential Energy
Conclusions

• This talk introduced the whole body manipulation and the dual-arm manipulation by humanoid robots