2. Visually-Guided Grasping (3D)
• Other approaches for finding 3D grasps

- Analyzing complete 3D object model
  - 3D reconstruction
  - CAD model
- Object Recognition
  - Extensive training sessions

Previously known!

- Off-line Time Consuming
- Complex and Non-reactive algorithms

Towards 3D Visually-Guided Grasping with a Dexterous Hand

Grasping of previously unknown 3D objects using

- visual information (camera in hand)
- 2D features from contour
- multiple views
- as few views as possible
- Model objects with a bounding box

3D Partial Reconstruction
• Our Method

• Grasping Procedure
• Height refinement through front view

![Diagram showing height refinement through front view.](image)

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• Object Model Generation

![Diagram showing object model generation process.](image)

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• Image Processing

Grey Image → Undistortion → Binarisation/Segmentation → Contour Extraction → Object Model Generation

• Centroid and Axis of Inertia

Image \( I \) with \( N \) pixels

Object \( O \)

Moment of order \( p+q \)

\[ M_{pq} = \sum_{x} \sum_{y} [x^p \cdot y^q \cdot I(x, y)] \]

where \( I(x, y) = \begin{cases} 1 & \text{if } (x, y) \in O \\ 0 & \text{else} \end{cases} \)

Centroid

\[ C = (x_c, y_c) = \left( \frac{M_{10}}{M_{00}}, \frac{M_{01}}{M_{00}} \right) \]

Normalized central moment of order \( p+q \)

\[ \mu_{pq} = \frac{1}{M_{00}} \sum_{x} \sum_{y} [(x-x_c)^p \cdot (y-y_c)^q \cdot I(x, y)] \]

Orientation of \( I_{\min} \) towards y-axes

\[ \phi = -0.5 \cdot \arctan \left( \frac{\mu_{10}}{\mu_{01}} \right) \]

Axis of Inertia

\[ I_{\min} = \begin{pmatrix} -\sin \phi \\ \cos \phi \end{pmatrix}, \quad I_{\max} = \begin{pmatrix} \cos \phi \\ \sin \phi \end{pmatrix} \]
• Following the Centroid

Image Coordinate System

Tool Coordinate System

Center of Image

Velocity Control with Visual Servoing 2-D

$$\mathbf{v}_t^{\text{img}} = \tau^* \begin{pmatrix} dx \\ dy \\ 0 \end{pmatrix}$$

$$\mathbf{v}_t^{\text{tool}} = \text{tool} R^{\text{img}} \mathbf{v}_t^{\text{img}}$$

$$\text{tool} R_{\text{img}} = \begin{pmatrix} \cos \pi/2 & -\sin \pi/2 & 0 \\ \sin \pi/2 & \cos \pi/2 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \text{Roll}_{\pi/2}$$
• 3-D Reconstruction

Camera calibration matrix:

\[
C = \begin{pmatrix}
\frac{1}{f_x} & \tan \alpha \frac{1}{f_y} & c_x \\
0 & \frac{1}{f_y} & c_y \\
0 & 0 & 1
\end{pmatrix}
\]

From image points to rays:

\[
\text{ray} = \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix} = C^{-1} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}
\]

Rays in general skewed!

• Current Experimental Setup

- Mitsubishi Robot Arm (PA-10)
- Three-Fingered Hand (BarrettHand)
- Camera in Hand (Sony XC-333)
• Grasp Planning

3D-Object Model

Grasp Characterization
Feasible grasp regions

Grasp Synthesis
Grasp regions (GR)
- > compatible GR
- > feasible GR

Filtering for executable grasps (size)
Choosing best grasp (manually)
Generating pose and spread of hand

Grasp Control

Approaching

Grasping

• Grasp Synthesis from Top

2 Finger Grasps

3 Finger Grasps
• Grasp Synthesis from Front

\[ |\theta - \phi| \leq \text{thresh} \]
Examples of top grasps

Examples of front grasps
Characteristics of Top Grasp

- Vertical Position
- Orientated and Positioned with respect to Grasping Regions
- Precision Grasp
  - Spread if 3 finger grasp selected
  - Finger tips stay at the same z-level

Grasp Execution From Front

- Horizontal Position
- Positioned always at Height of Center of Mass
- Distance of Length/2 to Center of Bounding Box
- Power Grasp
  - No spread
  - Palm stays at object for support
Examples

Problems?
Towards Complex Tasks

Conclusions and Future Lines

• A new approach for grasping previously unknown 3D objects has been implemented and tested on a real robotic system
• Force/torque and tactile sensors are starting to use now for compensating the inaccuracies of both, grasp planning and visual perception
3. Sensor-based Control Interaction

3.1 planning of physical interaction tasks

3.2 vision-force-tactile integration for robotic physical interaction

Preliminary ideas
What is a Service Robot?

**Definition-1**

It is an intermediate state between the Industrial Robot and the Humanoid Robot

**Definition-2**

Robots working and collaborating with humans in human environments

**Properties**

- Unstructured and changing environment
- Unknown objects
- Poorly defined tasks
- Inaccuracy in the information about the environment

*Uncertainty is a main concern*
A Brief History about AI Robots

“Shakey” (SRI 1967) vs “Herbert” (MIT 1990)

Hierarchical Paradigm

Reactive Paradigm

Hierarchical Paradigm

“Shakey”

SENSE

ACT

PLAN

Task-Planner

STRIPS [Nilsson, Rosen et al., 1969]

Stanford Research Institute Problem Solver
Reactive Paradigm

Intelligence!

Environment

SENSE  ACT

“Herbert”
[Connell, 1990]

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Behavior-Based Robotics

Visually-Guided Grasping
Robot control system spectrum
Adapted from [Arkin & Grupen, 93]

SPEED OF RESPONSE

DELIBERATIVE
Purely Symbolic
Representation-dependent
Slower response
High-level intelligence (cognitive)

REACTIVE
Reflex Response
Representation-free
Real-time response
Low-level intelligence

PREDICTIVES CAPABILITIES

DEPENDENCE ON ACCURATE, COMPLETE WORLD MODELS

Which are our expectations for this kind of robots?
Human attendance in museums, hospitals, etc.

Attending elderly and disabled people
Are Autonomous Actions Necessary?

3.1 Planning of physical interaction tasks
Preliminary concepts

- the contact-level approach vs the knowledge-based approach
- Task-oriented grasps and grasp-oriented tasks

The concept of physical interaction

“… is introduced to refer indistinctly to the grasp (prehensile and non-prehensile) and to the task”
The Questions to Answer

• How can everyday physical interaction be specified in a common framework, including both the grasp and the task, and supporting sensor-based control?

• How can a robot autonomously plan a physical interaction task, making use of this framework?

• What sensors are necessary, and how can a robot combine those sensors and control its motors for performing physical interaction tasks in a robust manner?

Grasp preshapes and shape primitives

The six basic prehensile patterns defined by Schlesinger (1919), adapted from (Taylor & Schwarz, 1955)

- Cylindrical Grasp
- Tip
- Hook or Snap
- Palmar
- Spherical Grasp
- Lateral
The physical interaction frames

(left): the object frame \( O \), the end-effector frame \( E \), the task frame \( T \), the hand frame \( H \) and the grasp frame \( G \).

The task motion must be transformed into robot coordinates through the kinematics chain formed by \( T, G, H \) and \( E \) (right).

The grasp link is the relative pose between frames \( H \) and \( G \), and represents the bridge between the task and the grasp.

Sensor-based tracking of the physical interaction frames

The use of sensor feedback is specially important for the estimation of the grasp link.
Example: Use of tools

The use of tools consists of two different instances of physical interaction tasks: one, involving a grasp for a transport task, and another one, involving the actual use of the tool.

- Grasping the tool
- Reaching for the object
- Using the tool

Task-oriented hand preshapes

The ideal task-oriented hand preshapes considered by the physical interaction task planner:

<table>
<thead>
<tr>
<th>NON-PREHENSILE</th>
<th>PREHENSILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook power</td>
<td>Cylindrical power</td>
</tr>
<tr>
<td>Hook precision</td>
<td>Cylindrical precision</td>
</tr>
<tr>
<td>One-finger frontal</td>
<td>Pinch</td>
</tr>
<tr>
<td>One-finger precision</td>
<td>Lateral</td>
</tr>
</tbody>
</table>
Mapping to the Barrett Hand

The Barrett Hand task-oriented hand preshapes

Mapping to a Parallel Jaw gripper

The parallel jaw gripper task-oriented hand preshapes
Object representation
(e.g. Structural model of a cabinet)

Classification of object parts
Task description

Robot knowledge
Object representation
Physical interaction planner

Object tasks
(e.g: increase volume)

Object actions
(e.g: turn knob)

Robot actions
(e.g: lateral preshape, physical interaction frames)

Planning

Some examples of the grasp frame specification according to the task description and selected preshapes
3.2 vision-force-tactile integration for robotic physical interaction

AN EXPERIMENT

The experimental environment consists of a mobile manipulator, an external camera and a cabinet with a sliding door that must be pushed open to the left.
4. The UJI Service Robot: A Case Study

International Cooperation

The UMass Torso (USA)
Prof. Grupen

LASMEA
Le Laboratoire Sciences Matériaux l’Electronique ‘Automatique
Prof. Martinet

Prof. Melchiorri
Italy
International Cooperation

Prof. Dillman
Germany

Prof. Färber
Germany

Looking for Books in a Library

University of Tsukuba
“Remote book browsing system using a mobile manipulator”
Tomizawa
http://www.roboken.esys.tsukuba.ac.jp/
ICRA’03

Johns Hopkins University
“Comprehensive Access to Printed Materials (CAPM)”
Choudhury
http://dke.jhu.edu/CAPM/
ICRA’02
Looking for Books in a Library

"The UJI Librarian Robot"

Main Steps

1. User Input
2. Scanning Mechanism
3. Success? not
   yes
4. Grasping module

Labels based on Library of Congress Classification (USA)
Identification, Localization and Extraction
The System in Action

Grasping Sketch

Force Feedback
Evolution of the Project

ICRA’05

ICRA’07

IROS’06

From “Jaume” to “Jaume-2”
The Software Architecture

The Task Frame Formalism (TFF)
The Task Frame Formalism (TFF)

Example 1: “the robot turning the door handle”

Example 2: “the UJI Librarian Robot”
Tactile Sensing for Grasping a Book

Robotic Intelligence Lab
Universitat Jaume I
Mario Prats. 30-11-2006
“Jaume-2” in Action

Our new platform
Questions?