Computer Assisted Medical Interventions

Force control, collaborative manipulation and telemanipulation

Project: Robot-Assisted Procedures in Interventional Radiology

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Joint course
University of Strasbourg, University of Houston, Telecom Paris Tech

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Interventional Radiology (IR) procedures

A long list of minimally invasive image guided procedures

Balloon angioplasty, biliary drainage and stenting, central venous access, chemoembolization, cryoablation, infection and abscess drainage, needle biopsy, radiofrequency ablation, thrombolysis, urinary tract obstruction, vertebroplasty, ...
Interventional Radiology: access

Percutaneous access: focus on procedures with needles or probes

- Catheters: angioplasty, drainage, stenting, venous access, ...
- Needles: biopsies, injections, radiofrequency ablation, cryoablation, vertebroplasty, ...

![Image of catheters and needles]
## Treatment schedule

1. Diagnosis and intervention planning
Interventional Radiology: manual procedure schedule

Treatment schedule

1. Diagnosis and intervention planning
2. Entry point registration
Interventional Radiology : manual procedure schedule

Treatment schedule

1. Diagnosis and intervention planning
2. Entry point registration
3. Patient preparation: sterilization, anaesthesia, etc.
Interventional Radiology: manual procedure schedule

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<td>1</td>
<td>Diagnosis and intervention planning</td>
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<td>2</td>
<td>Entry point registration</td>
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<td>3</td>
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<td>4</td>
<td>Incision at the entry point</td>
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Interventional Radiology: manual procedure schedule

**Treatment schedule**

1. Diagnosis and intervention planning
2. Entry point registration
3. Patient preparation: sterilization, anaesthesia, etc.
4. Incision at the entry point
5. Insertion, treatment and needle removal
Imaging for IR

US

Availability ++
Price ++
Radiations ++
Imaging quality -
Variety of targets -
Imaging for IR

- **Availability**: +
- **Price**: +
- **Radiations**: - -
- **Imaging quality**: -
- **Variety of targets**: –
<table>
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<th>CT</th>
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<td><strong>CT</strong></td>
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<td>Variety of targets ++</td>
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Imaging for IR

MRI

Availability - -
Price - -
Radiations ++
Imaging quality ++
Variety of targets ++

US

CT

MRI
Needle insertion

Haptics
- Basic requirement in the absence of real-time imaging
- Nonlinear, non homogeneous, patient variability
- Forces up to $6 - 10 \text{ N} \ (\text{max. } \simeq 20 \text{ N bones})$

![Graph showing force vs. time](image)
Why robots for IR?
Why robots for IR?

- US
- Motions in the image plane
- Realtime image guidance
Why robots for IR?
Why robots for IR?

CT MRI

X-rays protection
Registration
Planning
Limited realtime imaging
Necessary force feedback
Why robots for IR?
Why robots for IR?

- Registration/planning
- Realtime image guidance
- Tunnel access
- Operator
- Guidance modality?
Project: Robotic Specifications

Step 1
Definition on the medical task: general case, limitations, incompatibilities?

Step 2
Definition of the robotic task.

Step 3
Robotic specifications for this task.
Step 1 : Medical Specifications

- image acquisition
- registration needle/image
- incision and local insertion
- image acquisition
- orientation correction (needle bevel, bending)
- image acquisition
- needle insertion
- image acquisition (checking)
- ...
- medical treatment
- needle removal
Step 2: Robotic task

- image acquisition
- registration needle (or robot)/image
- entry point position and needle orientation computation
- insertion
- image acquisition (checking)
- ...
- medical treatment
- needle removal
Step 3: Robotic Specifications

- Automatic robot and/or tool registration in the imaging device
- Positioning device with 5 or 6 DOF (insertion decoupling?)
- Operator interaction to be chosen: automatic, collaborative manipulation, telemanipulation
- Force feedback
- Position measurement with/without model
Step 4 : Your Solution
Existing systems

Table mounted systems
Existing systems

Table mounted systems

Patient mounted systems
# Telerobotic needle insertion system for CT

## Features

- Teleoperation: staff protection
- Automatic registration tool/image
- Perceptual feedback (force, vision)
- Ergonomics

## Issues

- Technology
- Planning, control, image registration
- Safety, sterilization
- Performances

<table>
<thead>
<tr>
<th>Features</th>
<th>Constraints</th>
<th>Solution</th>
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<tr>
<td><strong>Safety</strong></td>
<td>Motion compensation</td>
<td>Patient-mounted robot.</td>
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<td>Failsafe behavior</td>
<td>Quick removal of the robot from its base.</td>
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<td></td>
<td>Joints locked in case of power failure. Release of the needle.</td>
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<tr>
<td><strong>Environmental compatibility</strong></td>
<td>CT-scan compatibility</td>
<td>No metal in the CT-plane to avoid image artifacts.</td>
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<td>Sterilization</td>
<td>Protective bags, autoclavable distal parts, and one use parts.</td>
</tr>
<tr>
<td><strong>Mechanical features</strong></td>
<td>Dimensions</td>
<td>$\approx 200$ mm side cube (remaining space in the scanner ring for a stout patient).</td>
</tr>
<tr>
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<td>Weight</td>
<td>$&lt; 3$ kg for the patient comfort.</td>
</tr>
<tr>
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<td>Mobility</td>
<td>$5$ DOF according to physicians requirements; optional DOF for the needle self rotation (trajectory bending).</td>
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<td>Angular limits</td>
<td>$-10$ to $65$ deg in the CT-plane, $\pm 25$ deg in the orthogonal plane, to give access to various organs under various incidences.</td>
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<tr>
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<td>Accuracy</td>
<td>$5$ mm max position error at the tip of a $200$ mm long needle ($\approx 10$ mm for a manual procedure).</td>
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<td>Forces</td>
<td>$20$ N max. force along the axis of the needle</td>
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CT-Bot insertion unit  [IJRR special issue 2009]

Specifications

- Needle insertion and bevel orientation
- Needle manipulation and release
- Adapted the CT-Bot platform (small/stroke)
- X-rays compatible
- Force measurement
CT-Bot insertion unit [IJRR special issue 2009]

### Driving mechanism

1. Casing (CT-Bot platform)
2. Transmission and actuator for translational displacement
3. Actuator for the grasp/release of the needle
4. Force sensor

- Flexible shaft
- Compression latch
- Connecting rod

### Insertion mechanism

1. Casing
2. Carriage B
3. Grasping device

- Needle
- 130 mm
- 150 mm
CT-Bot insertion unit  [IJRR special issue 2009]

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