Robotica chirurgica e intelligenza artificiale: i robot al servizio delle persone

MIRANDOLA SUMMER CAMP
Tecnologie biomediche tra competitività e innovazione per una value-based healthcare
Prof.ssa Federica Ferraguti
3 Ottobre 2023
Federica Ferraguti
Assistant Professor (since 2017 @ARSControl Lab)
• Master degree in Industrial and Management Engineering
• Phd in Industrial Innovation Engineering (Mechatronics curriculum)
• Visiting Phd student at ETH Zurich (2013)
• 2017 «Fabrizio Flacco» Young Author Best Paper Award – IEEE RAS Italian Chapter
• Inventor in 4 patents
• FAR 2022 and PRIN 2022 awarded

Research topics

➤ Surgical robotics
  ▪ EU project I-SUR
  ▪ EU project SARAS
  ▪ EU project DIH-HERO

➤ Physical human-robot interaction and collaborative robotics
  ▪ EU project SYMPLEXITY
  ▪ National project ADAPTIVE MANUFACTURING (Cluster Nazionale Fabbrica Intelligente)

➤ Teleoperation
Until the end of the 80s, open surgery represented the treatment of choice for oncological and non oncological disease.

September 13, 1980 the German gynaecologist Kurt Semm performed the first laparoscopic appendectomy in history.
The turning point
Surgical robotics

Robots in Medicine start with **neurosurgery** and **orthopedics**

**NEUROMATE 1987** *(Integrated Surgical System)*

Computer-controlled, image-guided robotic system for stereotactic functional neurosurgery


*Computer-interactive stereotactic resection of deep-seated and centrally located intraaxial brain lesions.*

*Kelly PJ, Kall BA, Gowers SJ.*

Department of Neurologic Surgery, Mayo Clinic, Rochester, Minn.

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**ROBODOC 1992**

Robotic system developed for arthroplasty


*Development of a surgical robot for cementless total hip arthroplasty.*

*Paul HA, Bargar WL, Mittelstadt B, Musits B, Taylor RH, Kazanzides P, Zuhars J, Williamson B, Hanson W.*

Integrated Surgical Systems, Sacramento, CA 95834.
Surgical robotics

Until today monopoly of the da Vinci system by Intuitive
Surgical robotics

Until today monopoly of the da Vinci system by Intuitive
Surgical robotics

Intuitive has built high barriers to new entry of surgical robots by:

• Superior product offerings
• Intellectual property protection
• Multiple regulatory clearances
• Large installation base
• Strong customer relationships

BUT: Expiry of existing key patents in 2019
• Stimulate new era of robotic master-slave systems
Surgical robotics
Levels of autonomy

- **No autonomy**: Operator performs all tasks including monitoring, generating performance options, selecting the option to perform (decision-making), and executing the decision made.
- **Robot assistance**:Operator maintains continuous control of the system while the robot provides certain assistance.
- **Task autonomy**: Operator maintains discrete control of the system, and the robot can perform certain operator-initiated tasks automatically.
- **Conditional autonomy**: Operator selects and approves a surgical plan, and the robot performs the procedure automatically but with close surgical oversight by human.
- **High autonomy**: Robot is able to make decisions but under the supervision of a qualified operator.
- **Full automation**: No human needs to be in the loop, and the robot can perform an entire surgery.

**Commercially available platforms**: NO relevant examples of a fully autonomous surgical robot.

Yang et al. Sci. Robot. 2017
### Levels of autonomy

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<thead>
<tr>
<th>Level 1: robot assistance</th>
<th>Technology/application</th>
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<td>Enabling technologies</td>
<td>Tool tracking</td>
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<td>Tissue interaction sensing</td>
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<td>Practical applications</td>
<td>Assisted planning</td>
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<th>Level 2: task automation</th>
<th>Technology/application</th>
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<td>Gesture classification</td>
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<td>Practical applications</td>
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<td>Knot tying</td>
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<td>Supervised suturing</td>
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<td>Tissue retraction</td>
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<td>Stiffness mapping</td>
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<td>Ablation</td>
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<th>Level 3: conditional autonomy</th>
<th>Technology/application</th>
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<td>Tissue modeling</td>
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<td>High-level feature tracking</td>
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<td>Practical applications</td>
<td>Navigation of continuum surgical devices</td>
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<td>Advanced suturing</td>
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<th>Level 4: high autonomy</th>
<th>Technology/application</th>
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<tr>
<td>Enabling technology</td>
<td>Organ and tumor segmentation</td>
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<tr>
<td>Practical application</td>
<td>Debridement and tumor resection</td>
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Surgical robotics

2012-2015
FP7 project

Development of a robotic assistant for laparoscopic surgery

2018-2020
H2020 projects

Automation of needle insertion (cryoablation) and suturing (anastomosis)

Pan European Network of DIH

UNIMORE projects
I-SUR – Intelligent Surgical Robotics

Goal:
Development of advanced technologies for autonomously performing simple surgical procedures (i.e. US-guided needle insertion, suturing of planar wounds).
CRYOABLATION OF KIDNEY TUMORS

Computation of the number of needles to be inserted and the optimal position in order to:

- Assure a complete ablation of the tumor
- Minimize the damage to other organs
- Avoid forbidden regions (e.g. ribs, veins, etc.)
Surgical procedure planning

- Environment (MRI+CT)
- Constraints
- Iceball dimensions and shape

Torricelli et al. EMBC 2013
Surgical procedure execution
US-guided multiple needle insertion
Handling unexpected events

Teleoperated Mode

2017 Young Author Best Paper Award (IEEE IRAS) to Federica Ferraguti
Goal: Development of the next-generation of surgical robotic systems that will allow a single surgeon to execute Robotic Minimally Invasive Surgery (R-MIS) without the need of an expert assistant surgeon.
The SARAS scenario

1. MULTIROBOTS-SURGERY

2. SOLO-SURGERY

3. LAPARO2.0-SURGERY
MULTIROBOTS-SURGERY platform

**MASTER SIDE**

**SLAVE SIDE**

**ASSISTANT SURGEON**

**MAIN SURGEON**

Data recording as shown in Figure 19.
MULTIROBOTS-SURGERY platform
1. Recognize the action of the main surgeon
2. Make decisions on the autonomous task
3. Plan collisions-free trajectories
SOLO-SURGERY platform
Urology

- AR and robotic-assisted PCNL – FAR 2022 Mission oriented

Pre-operative

(a) CT / MRI

(b) 3D reconstruction

(c) Pre-operative planning

Intra-operative

(d) Real-time registration

(e) AR visualization

(f) Robotic Assistance
➢ Urology

• AR and robotic-assisted PCNL – FAR 2022 Mission oriented
• Tool segmentation, tip estimation and surgical phase recognition
➢ Urology

- AR and robotic-assisted PCNL – FAR 2022 Mission oriented
- Tool segmentation, tip estimation and surgical phase recognition
➢ Urology

• AR and robotic-assisted PCNL – FAR 2022 Mission oriented
• Tool segmentation, tip estimation and surgical phase recognition
• Selective clamping
Orthopedics

• AR visualization for helping surgeons in hip and knee surgery
➢ Ophthalmology

• Robot-assisted intra-vitreal injections
➢ Ophthalmology
• Robot-assisted intra-vitreal injections
➢ Action recognition for robot-assisted procedures
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