Università degli Studi di Napoli Federico II

itee PhD
information technology
electrical engineering

DIETI
UNINA

Cristina Iacono

Automation of robot-assisted surgical procedures

Tutor: Fanny Ficuciello

Cycle: XXXV

Year: 2nd

My background

- **MSc degree**: Automation Engineering at Università degli Studi di Napoli Federico II
- **Research group/laboratory**:
  - PRISMA LAB
  - ICAROS
- **PhD start date**: 1st November 2019
- **Scholarship type**: Unina

Research field of interest

- **Research topic**: Automation of robot-assisted surgical procedures

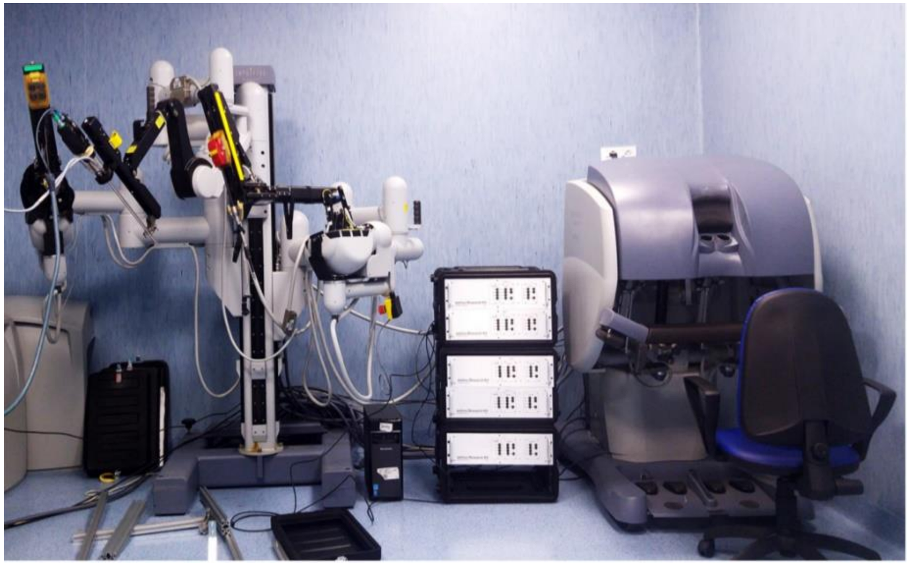


Figura 1 - dVRK presente nel laboratorio ICAROS

Summary of study activities

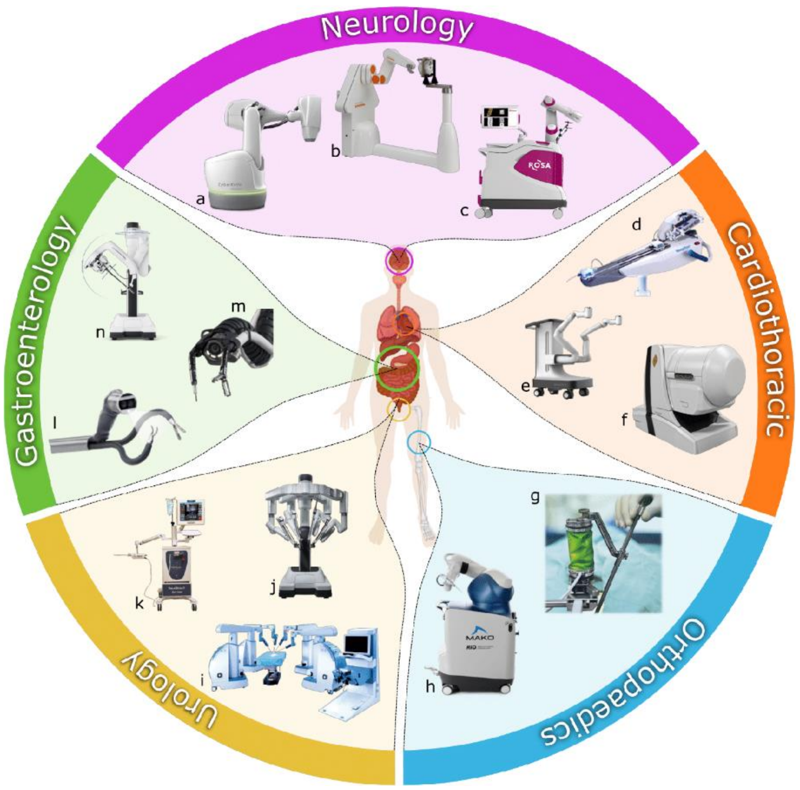
- PhD courses:
  - Statistical data analysis for science and engineering research
  - Mathematics and Statistics for Life Sciences
  - Strategic Orientation for STEM Research and Writing

- PhD Schools: SIDRA 2021
  - Game Theory and Network Systems
  - Soft Robots

- Attended
  - Italian Institute of Robotics and Intelligent Machines (I-RIM) 3D 2020
  - Italian Institute of Robotics and Intelligent Machines (I-RIM) 3D 2021

I-RIM
Istituto di Robotica e Macchine Intelligenti

Research activity: Overview



- **Problem**:

Surgical robotics still strongly depends on surgeon's abilities

Limitations:

  - *limited vision on the surgical site*
  - *surgical procedures are comprised of a series of kinematically complex and repetitive tasks*

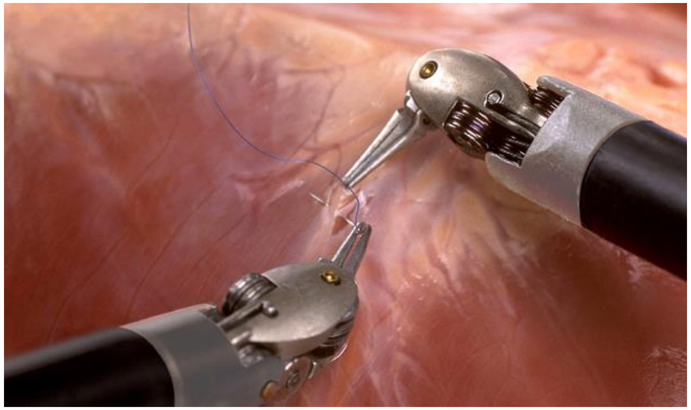
Research activity: Overview

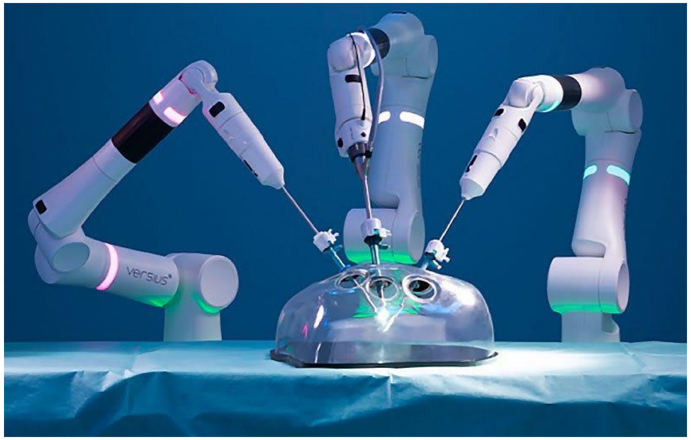
- **Objective:**

  *A*utomation of surgical tasks in order to reduce surgeon errors, duration of procedures, trauma, and expense.

  Two principal aspects necessary for the automation of surgical robot-assisted procedures:

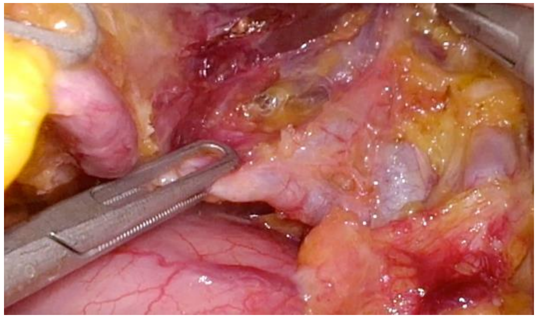
  - Vision perception for robotics systems
  - Force feedback during robotic procedures

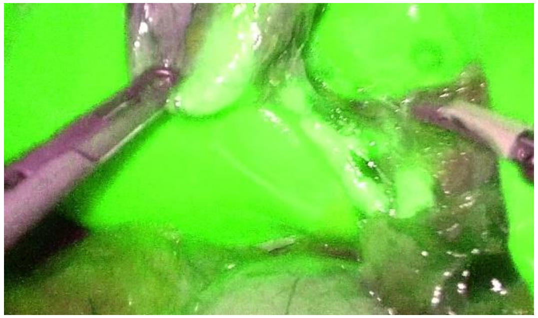




Localization of the biliary tract in laparoscopic images

- **Laparoscopic Cholecystectomy**
  - Advantages: faster recovery and better cosmetic results,
  - Disadvantages: higher risk of bile duct injury
- **Indocyanine green (ICG)**
  - Imaging method to enhance intraoperative visualization of the bile duct
  - Disadvantage: it makes it challenging to see all the other anatomical structures
- **Aim**
  - help the surgeon to better visualize the biliary tract without the use of ICG



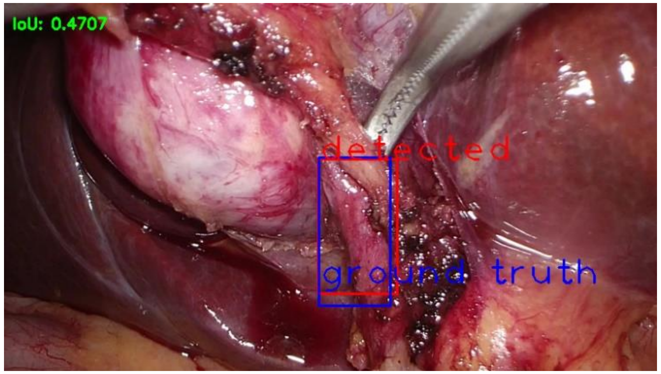


Localization of the biliary tract in laparoscopic images

- **Proposed Solution**
  - Deep learning-based algorithm for localization of the biliary tract from white-light images
  - Construction and annotation of an image database to train the deep learning algorithm.

- The method uses You Only Look Once (YOLO) on laparoscopic images to localize the biliary duct.

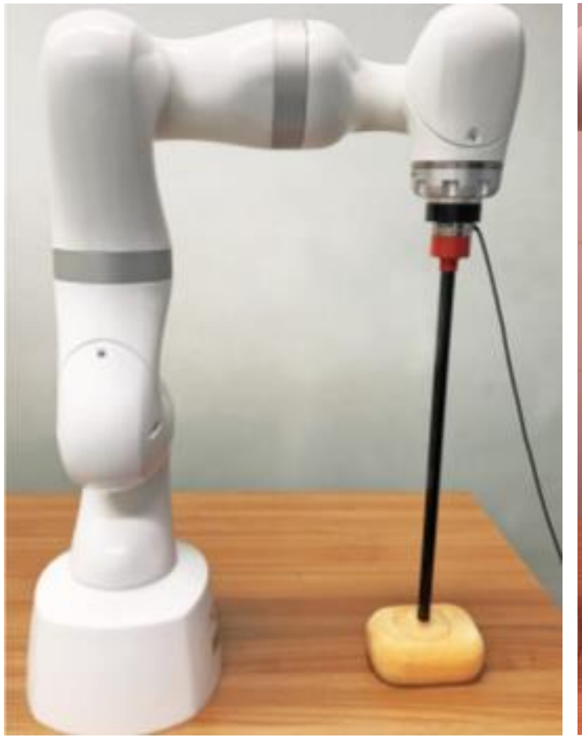
	Total Frames	*Training*	*Test*
Patient 1	142	15	15
Patient 2	171	34	14
Patient 3	219	-	39
Patient 4	152	74	20
Patient 5	48	5	5
Patient 6	144	-	29
Patient 7	168	14	10
Patient 8	89	18	10
Patient 9	153	14	10
Patient 10	73	20	10
Patient 11	27	14	10
Patient 12	135	-	19



Control framework for human-robot interaction in medical robotic applications

- Several medical robotics applications require and **RCM constraint:**
  - passive (mechanically)
  - active (software)

- Reduced workspace to avoid touching dangerous areas



Control framework for human-robot interaction in medical robotics applications

- **Proposed solution:**

RCM constraint

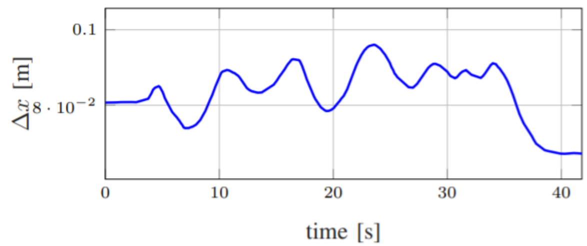
$$\dot{\mathbf{p}}_{RCM} = \mathbf{J}_{RCM}(\mathbf{q},\lambda)\begin{bmatrix}\dot{\mathbf{q}}\\ \dot{\lambda}\end{bmatrix}$$

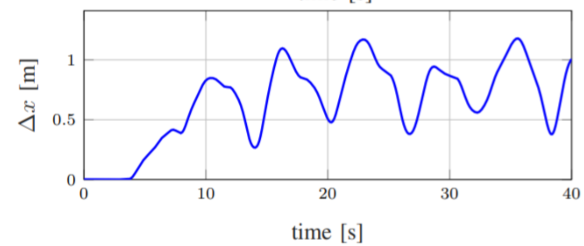
$$\dot{\mathbf{t}}_{EXT} = \begin{bmatrix}\dot{\mathbf{t}}\\ \mathbf{0}_{3\times1}\end{bmatrix} = \begin{bmatrix}\mathbf{J}_t & \mathbf{0}_{n_t\times1}\\ \multicolumn{2}{c}{\mathbf{J}_{RCM}}\end{bmatrix}\begin{bmatrix}\dot{\mathbf{q}}\\ \dot{\lambda}\end{bmatrix} = \mathbf{J}_{EXT}\begin{bmatrix}\dot{\mathbf{q}}\\ \dot{\lambda}\end{bmatrix}$$

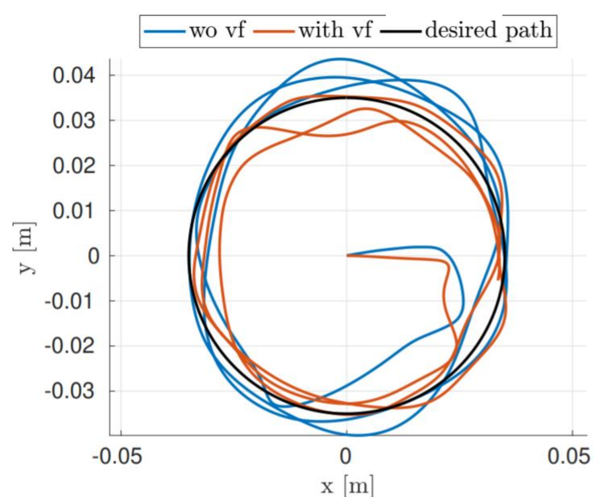
Manual guidance and Virtual Fixtures

$$\mathbf{f}_{VF} = \mathbf{K}_{VF}\mathbf{d} + \mathbf{D}_{VF}\dot{\mathbf{d}}$$

$$\mathbf{M}\ddot{\mathbf{p}} + \mathbf{D}\dot{\mathbf{p}} + \mathbf{K}\mathbf{p} = \mathbf{f} - \mathbf{f}_{VF}$$

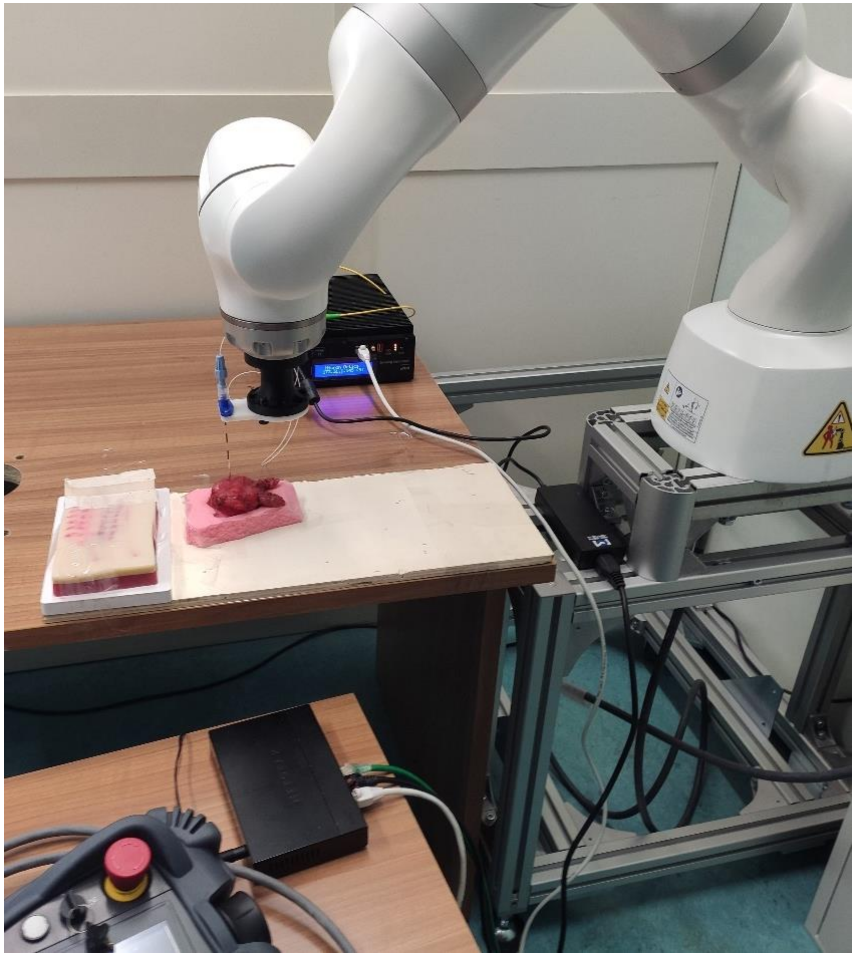






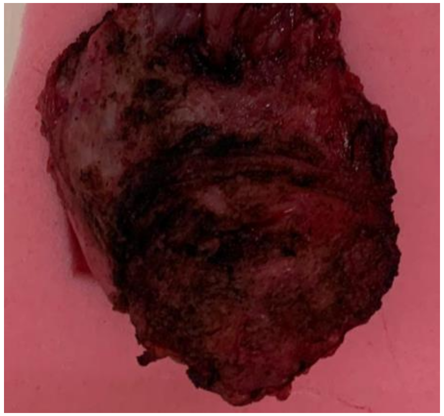
Ex vivo testing of a miniaturized probe for prostate tissue characterization

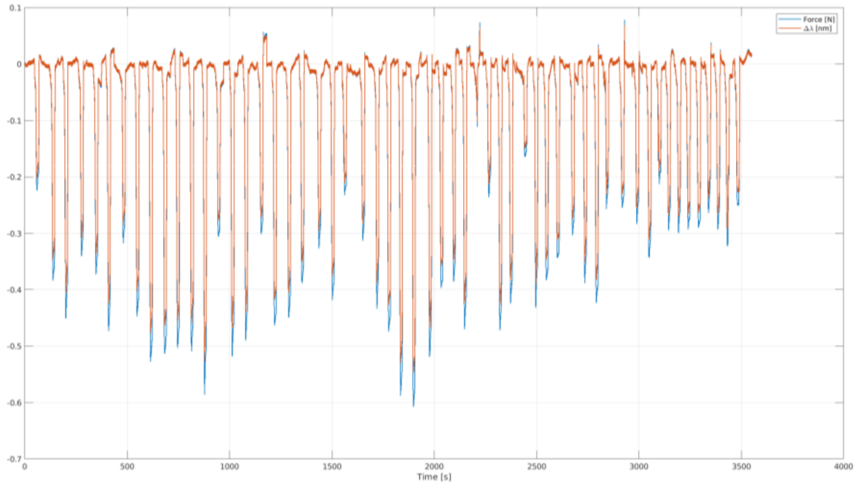
- **Problem**
  - Characterizeation of mechanical properties of insane and healthy prostate tissues
- **Aim**
  - Testing on phantom tissues and ex-vivo tissues a miniaturized probe based on optical fiber sensor technology

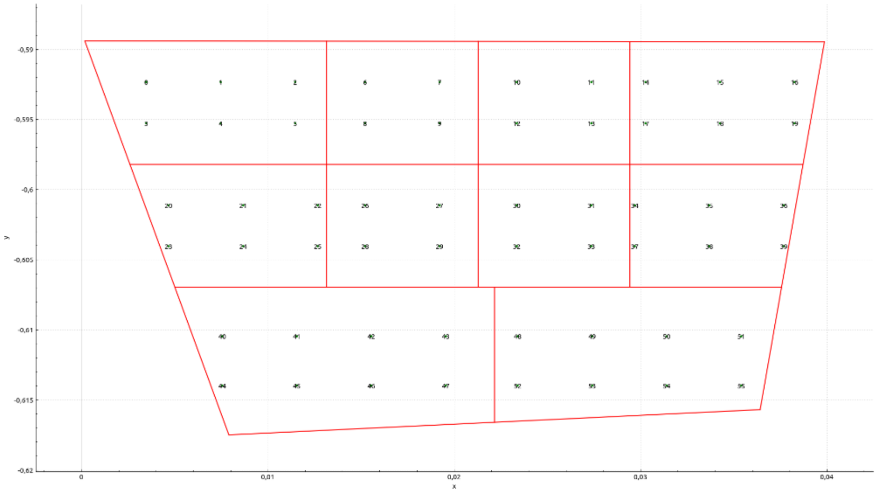


Ex vivo testing of a miniaturized probe for prostate tissue characterization

- **Results**
  - Creation of a dataset of elasticity measurements of prostate





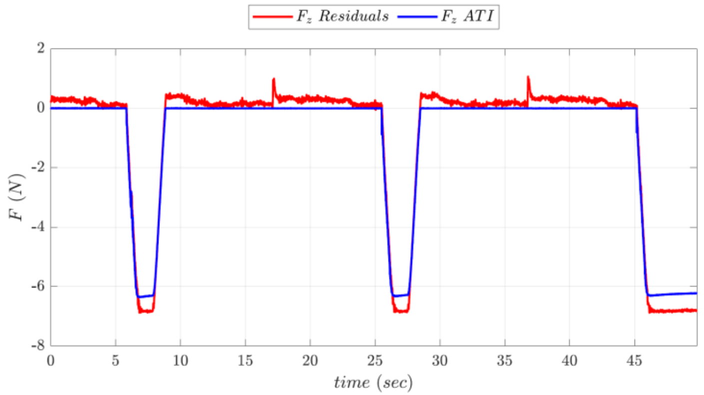


DVRK Dynamic Model Identification for sensor-less force estimation

- **Problem:** need for accurate movements in safety-critical site
- **Solution:** autonomous tasks using Da Vinci robot
- **Method:**
  - dVRK dynamic model definition
  - Sensor-less contact force estimation

$$\boldsymbol{r} = \boldsymbol{K_I}\left(\boldsymbol{p} - \int_0^t (\boldsymbol{\tau} + \boldsymbol{C}^T(\boldsymbol{q},\dot{\boldsymbol{q}})\dot{\boldsymbol{q}} - \boldsymbol{g}(\boldsymbol{q}) + \boldsymbol{r})\, ds\right)$$

$$\hat{\boldsymbol{F}}_c = (\boldsymbol{J}_c^T(\boldsymbol{q}))^* \boldsymbol{r}$$



Products

J1	*Rocco Moccia, Cristina Iacono, Bruno Siciliano and Fanny Ficuciello, "Vision-based dynamic virtual fixtures for tools collision avoidance in robotic surgery". IEEE Robotics and Automation Letters. 2020 Jan 28;5(2):1650-5.*
C1	*Cristina Iacono, Sara Moccia, Aldo Marzullo, Elena De Momi, Umberto Bracale and Fanny Ficuciello, "Deep learning-based localization of the biliary tract in laparoscopic images acquired during surgical robotic procedures", Italian Institute of Robotics and Intelligent Machines (I-RIM) 3D 2021, October 8-9,2021*