

MedRob-1 - Development of Planning and Control Strategies for Safety-Constrained Surgical Task Execution and Robot Interaction

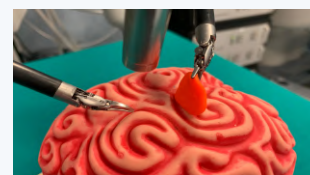
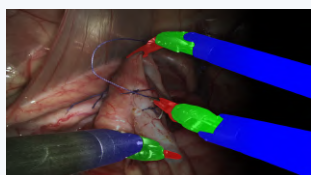
Thesis sheet · PRISMA Lab



<p><i>da Vinci Research Kit (dVRK)</i></p>	<p><i>Needle Insertion</i></p>	<p><i>Safety constraints</i></p>	<p><i>Force sensor</i></p>
<p>THESIS OVERVIEW</p> <p>The objective of the thesis is to develop safe constrained control algorithms for the da Vinci Research Kit (dVRK) surgical system, enabling autonomous execution of complex surgical tasks while enforcing strict safety constraints. The work integrates the dVRK robot dynamic model with Control Barrier Functions (CBF) formulated within a Quadratic Programming (QP) framework to enforce hard constraints on obstacle avoidance, joint velocity/torque limits, and contact forces with anatomical structures. CBF will be used to plan and control the surgical robot and as a safety filter that modify a nominal control input, ensuring constraint satisfaction without compromising task performance. Model-based and neural network-based approaches will be investigated to enable sensorless external force estimation during tissue interaction.</p>		<p>TOOLS</p> <p>Quadratic Programming solvers, PyTorch, C+, ROS 2, CoppeliaSim, da Vinci Research Kit (dVRK), Force sensors</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR</p> <p>Cristina Iacono cristina.iacono@unina.it Paolino De Risi paolino.derisi@unina.it</p> <p>KEYWORDS</p> <p>Surgical Robotics; Motion and Force Control; Optimization</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • CBF-based safety filter that modifies surgeon teleoperation nominal input in real-time, enforcing safety constraints without degrading task performance • Execution of complex a surgical tasks such as needle insertion with constrained force to prevent tissue damage and constrained insertion orientation of the needle for correct suture execution validated on dVRK hardware 			
<p>PREREQUISITES / NOTES</p> <p>Foundation of Robotics and Robot Interaction Control courses are recommended.</p> <p>Required skills: C++ programming, ROS2 framework.</p>		<p>RELATED BIBLIOGRAPHY</p> <p>Ames, A.D., Coogan, S., Egerstedt, M., Notomista, G., Sreenath, K. and Tabuada, P., 2019, June. Control barrier functions: Theory and applications. In 2019 18th European control conference (ECC) (pp. 3420-3431). Ieee.</p> <p>Argin, O.F., Moccia, R., Iacono, C. and Ficuciello, F., 2024. daVinci Research Kit Patient Side Manipulator Dynamic Model Using Augmented Lagrangian Particle Swarm Optimization. IEEE Transactions on Medical Robotics and Bionics, 6(2), pp.589-599.</p> <p>Adorno, B.V. and Marinho, M.M., 2020. Dq robotics: A library for robot modeling and control. IEEE Robotics & Automation Magazine, 28(3), pp.102-116.</p>	

MedRob-2 – Development of a Multi-Sensor Fusion Algorithm for Position and Orientation Tracking of Surgical Instruments

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da Vinci Research Kit (dVRK)

Surgical instrument segmentation

Minimally invasive robotic surgery

dVRK surgical tools and endoscopic camera

THESIS OVERVIEW

This thesis focuses on the development of marker-less tracking algorithms for surgical needles and instruments during manipulation and environmental interaction tasks. The work integrates object segmentation and real-time localization methods (e.g. CNNs, YOLO, SAM2, DINO, etc.) for instrument and needle segmentation with pose estimation techniques such as Extended Kalman Filtering (EKF). Advanced multi-sensor fusion combines visual information from endoscopic systems with robot kinematics. A measurement model will be implemented from the needle visual features extracted and the prior knowledge of the needle 3D model, to implement the needle pose estimation and tracking pipeline. Critical foundations include endoscope hand-eye calibration methods and 3D reconstruction of observed anatomical structures.

TOOLS

PyTorch/TensorFlow, Python, ROS2, dVRK

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KEYWORDS

Surgical instrument tracking; Multi-sensor fusion; Robotic surgery

EXAMPLES / POSSIBLE ACTIVITIES

- Training of localization/segmentation algorithm on da Vinci surgical video datasets
- Implementation of a multi-sensor fusion pipeline to couple visual information and robot kinematics
- Needle pose estimation model definition and tracking pipeline implementation

PREREQUISITES / NOTES

Foundation of Robotics course is recommended.
Required skills: Python programming, ROS2 framework.

RELATED BIBLIOGRAPHY

YOLOv11 Documentation:

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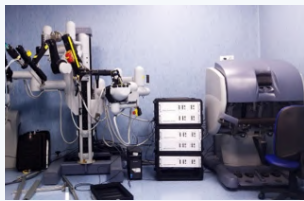
Ren, T., Chen, Y., Jiang, Q., Zeng, Z., Xiong, Y., Liu, W., Ma, Z., Shen, J., Gao, Y., Jiang, X. and Chen, X., 2024. Dino-x: A unified vision model for open-world object detection and understanding. arXiv preprint arXiv:2411.14347.

Özgüner, O., Hao, R., Jackson, R.C., Shkurti, T., Newman, W. and Cavusoglu, M.C., 2018, May. Three-dimensional surgical needle localization and tracking using stereo endoscopic image streams. In 2018 IEEE international conference on robotics and automation (ICRA) (pp. 6617-6624). IEEE.

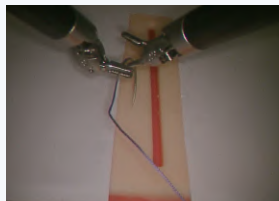
ROS 2 Documentation: <https://docs.ros.org/>

MedRob-3 – Development of control strategies for the automated execution of suturing (FF–L).

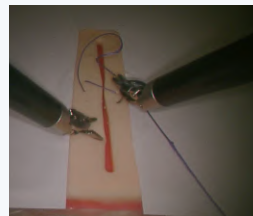
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da Vinci Research Kit



Needle grasping



Suturing

THESIS OVERVIEW

This thesis focuses on the development of an autonomous robotic suturing framework for minimally invasive surgery in deformable and uncertain environments. The suturing task can be decomposed into needle grasping, planning of insertion points along the wound, execution of the needle trajectory through soft tissue, and final needle extraction. For each of these subtasks, cost functions can be defined and minimized to achieve optimal suturing performance. Reconstruction of the environment, in particular tracking the deformation of tissue and the needle, is an open problem that is primarily addressed using vision-based methods. Force information, either measured directly or estimated through observers, is essential during interaction to minimize tissue stress. Learning from Demonstration can be incorporated into the control strategy using Dynamic Movement Primitives (DMPs), which provide an initial motion prior that can subsequently be refined using optimal control methods such as Model Predictive Control (MPC) to adapt to uncertainty and environmental changes. This work aims to develop a closed-loop framework integrating control, vision-based perception, force-aware interaction, and learning from demonstration, and to evaluate it in simulation and/or realistic robotic surgical scenarios.

TOOLS

Python, C++, MATLAB, ROS2 (Robot Operating System 2), OpenCV, SOFA Framework, Kalman filtering, DMPs, da Vinci Research Kit, stereo cameras, endoscopy

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KEYWORDS

Robotic Suturing, Optimal Control, Deformable Environments, Learning from Demonstration

EXAMPLES / POSSIBLE ACTIVITIES

- Development of an optimal control framework for robotic suturing with cost functions for accuracy, smooth motion, and force minimization
- Implementation of vision-based state estimation for tracking deformable tissue and surgical instruments
- Integration of learning from demonstrations with optimal control methods such as Model Predictive Control (MPC).

PREREQUISITES / NOTES

This thesis is aimed at Master's-level students, with recommended background in robotics, control, computer vision, and optimization. Required skills include strong Python/C++ programming and basic knowledge of robot control and vision, while experience with ROS or machine learning is a plus. The project is suitable for a 6-8 months master's thesis, and no prior surgical robotics experience is required.

RELATED BIBLIOGRAPHY

- [1] Marra, P., Hussain, S., Caianiello, M. and Ficuciello, F., 2024. Mpc for suturing stitch automation. *IEEE Transactions on Medical Robotics and Bionics*, 6(4), pp.1468-1477.
- [2] Schwaner, Kim L., et al. "Autonomous bi-manual surgical suturing based on skills learned from demonstration." 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2021.
- [3] Zhong F, Wang Y, Wang Z, Liu YH. Dual-arm robotic needle insertion with active tissue deformation for autonomous suturing. *IEEE Robotics and Automation Letters*. 2019 Apr 24;4(3):2669-76.

MedRob-4 – Hierarchical Interaction-Safe Control and Surface-Adaptive Virtual Fixtures for Multi-Tooth Robot-Aided Dental Preparation

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<p><i>Experimental Setup</i></p>	<p><i>Manual Guidance</i></p>	<p><i>Dental bur grinding for crown preparation</i></p>	<p><i>Dental turbine with round drilling burr</i></p>
<p>THESIS OVERVIEW</p> <p>This thesis aims to extend the current semi-autonomous robotic system for tooth preparation toward safer, more adaptive, and more task-aware multi-tooth procedures. The work will investigate a hierarchical control architecture that integrates task-level planning, surface-aware motion guidance, force-aware interaction control, and safety supervision. At the high level, a task manager will coordinate the workflow across different preparation phases, such as free motion, surface approach, cutting, fixture exit, transition to another surface, and movement to the next tooth. At the lower level, the interaction controller will adapt virtual fixtures to the local curved geometry of the tooth and regulate the physical interaction between the dental bur and the tooth during cutting.</p> <p>A central objective is to combine geometric guidance from Virtual Fixtures with force-aware control. The virtual fixtures will define the admissible motion of the dental bur according to the planned preparation geometry and anatomical safety constraints. Meanwhile, force/torque information will be used to manage contact-rich interaction with the tooth, for example by combining tangential guidance along the preparation surface with normal-direction compliance or force regulation. This would allow the bur to follow the desired preparation geometry while reducing excessive contact forces, abrupt impacts, and unsafe tool motions.</p>		<p>TOOLS</p> <p>KUKA LBR Med 14; ROS 2; Python/C++; RGB-D camera or optical tracking system; phantom head; 3D tooth models.</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR:</p> <p>Fan Shao fan.shao@unina.it Paolino De Risi paolino.derisi@unina.it</p> <p>KEYWORDS</p> <p>virtual fixtures; force control; variable impedance control;</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • Design a hierarchical task-control layer for multi-surface and multi-tooth preparation, including state transitions between free motion, surface approach, cutting, fixture exit, and next-surface/tooth selection. • Develop surface-adaptive virtual fixtures based on tooth geometry, replacing simple bounding-box constraints with curved-surface-aware guidance and forbidden regions. • Integrate force control with virtual fixtures, allowing the desired cutting/contact force to be regulated while limiting impact forces and unsafe force peaks. • Validate the system on dental phantom experiments. 			
<p>PREREQUISITES / NOTES</p> <p>Robotics, control theory, ROS 2, robot kinematics and dynamics, human-robot interaction. Knowledge of impedance control, force control, point-cloud or mesh processing, and C++/Python programming.</p> <p>Note: This project builds directly on an existing robotic platform for dental prosthesis preparation, where manual guidance, variable impedance control, and torque control have already been developed. Therefore, students can quickly get started with the project and focus on advanced research topics such as hierarchical task control, force-safe interaction, and surface-adaptive virtual fixtures.</p>		<p>RELATED BIBLIOGRAPHY</p> <p>Master's thesis: Semi-Autonomous System for Robot-Aided Tooth Preparation for Dental Prosthesis.</p> <p>Alqutaibi, A. Y., et al. "Practical applications of robots in prosthodontics for tooth preparation and denture tooth arrangement: A scoping review." The Journal of Prosthetic Dentistry, 2024.</p> <p>Robotic tooth preparation video: https://www.youtube.com/watch?v=TTxCYNKMcnk&list=PLWk4y64S95tKJ3PxpQUf3N91qFMI-xsZ3 Yomi robot: https://www.youtube.com/watch?v=B1frwNoztzg&list=PLWk4y64S95tKJ3PxpQUf3N91qFMI-xsZ3 https://www.youtube.com/watch?v=UdYUSUnk9dIlxO9QHq7XI</p>	

MedRob-5 – Surgical gesture recognition, task classification, and performance evaluation (FF/LM - T)

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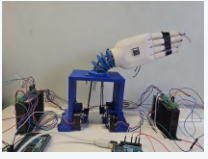
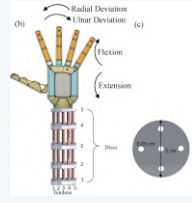


<i>da Vinci Research Kit</i>	<i>Suturing Task</i>	<i>Sensors</i>
THESIS OVERVIEW <p>This thesis focuses on the application of machine learning techniques to automatically segment surgical activities performed during teleoperation in robot-assisted minimally invasive surgery. The integration of sensory information, including force, vision and biological signals, will be used to recognize surgical gestures and classify elementary tasks during the execution of complex tasks. Machine learning approaches such as Gaussian Mixture Models (GMMs) and Hidden Markov Models (HMMs) will be investigated for modeling and segmenting surgical workflows. An extensive analysis of individual surgical tasks will be conducted in collaboration with surgeons from ICAROS. The classification of robotic surgical procedures will be based on demonstrations provided by expert surgeons. Additionally, biosignals, gesture recognition, and task classification methods will be used to develop quantitative metrics to evaluate surgical performance.</p>		TOOLS <p>da Vinci Research Kit, force sensors, vision sensors, machine learning, ROS2, C++, Python, OpenCV</p> SUPERVISOR <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> TECHNICAL SUPERVISOR <p>Marcella Piacentino marcella.piacentino@unina.it Theodora Kastritsi theodora.kastritsi@unina.it</p> KEYWORDS <p>Robot-assisted minimally invasive surgery, Machine learning, Surgical activity segmentation</p>
EXAMPLES / POSSIBLE ACTIVITIES <ul style="list-style-type: none">• Development of machine learning models (e.g., GMM, HMM, or deep learning methods) for surgical gesture recognition and task segmentation.• Integration of sensory information, such as force and video data, to improve the accuracy of surgical activity classification in teleoperated robotic surgery.• Evaluation of surgical performance among users with different levels of experience.		
PREREQUISITES / NOTES <p>Required areas of knowledge include basic robotics, machine learning, data analysis, probability, and linear algebra, along with basic programming in C++ or Python. Familiarity with processing sensor data is a plus. This is a bachelor-level thesis with a typical duration of about 6-8 months.</p>	RELATED BIBLIOGRAPHY <p>[1] Zappella L, Béjar B, Hager G, Vidal R. Surgical gesture classification from video and kinematic data. Medical image analysis. 2013 Oct 1;17(7):732-45. [2] Selvaggio M, Villani L, Siciliano B, Ficuciello F. Physics-based task classification of da vinci robot surgical procedures. InProc. 6th Nat. Congr. Bioeng. 2018.</p>	

MedRob-6 – Lightweight Hybrid Tendon-Driven Soft Wrist for Dexterous Prosthetic Hands

Thesis sheet · PRISMA Lab



			
<p>Wrist section CAD</p>	<p>Fabricated wrist section</p>	<p>Wrist module Setup</p>	<p>Conceptual model of wrist section</p>

THESIS OVERVIEW

This thesis aims to redesign the PRISMA soft continuum wrist for integration with a new prosthetic hand. Starting from the existing disc-spring-tendon architecture, the student will develop a lighter, more stable and higher-payload hybrid soft wrist while preserving continuum compliance and tendon-driven actuation. The target is a compact wrist module with mass below 500 g, increased payload capability, improved posture stability, higher dexterity and the minimum feasible number of tendons. The work will investigate alternative compliant backbones, optimized soft-rigid interfaces, lightweight disc/flange geometries and tendon routings for multi-DOF motion. Activities will include requirements definition, CAD design, FEM-based structural optimization, Cosserat/GVS modelling, actuator and tendon selection, prototype fabrication and experimental validation with the new hand.

TOOLS

CAD software, e.g. SolidWorks / Fusion 360 / Creo; MATLAB/Simulink; SoRoSim or GVS-based modelling tools; FEM software, e.g. ANSYS / Abaqus / COMSOL; Python; 3D printing; elastomers / TPU / PLA / nylon / composite inserts; tendons, motors, encoders, load cells, ArUco/camera-based tracking.

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KEYWORDS

soft continuum wrist; tendon-driven actuation; hybrid soft-rigid design; prosthetic hand; payload optimization; Cosserat/GVS modelling; dexterous manipulation

EXAMPLES / POSSIBLE ACTIVITIES





- Analyse the current PRISMA soft wrist and define new design requirements: mass \leq 500 g, higher payload, stability with the new hand, workspace and DOF targets.
- Design and compare hybrid compliant architectures, such as a central elastic backbone, soft lattice support, optimized disc spacing, 3-tendon spatial bending, 4-tendon differential routing or helical tendon paths for additional dexterity.
- Build and validate a prototype through FEM, GVS/Cosserat modelling and experiments measuring workspace, payload capacity, posture stability, repeatability and manipulation performance.

PREREQUISITES / NOTES

Recommended for a Master thesis in robotics, mechanical/mechatronic engineering or related areas. Useful skills include CAD design, basic robot kinematics, FEM simulation, MATLAB/Python and rapid prototyping. The thesis can focus mainly on mechanical redesign or be extended to modelling and control depending on the student background. The design must remain a soft wrist and tendon-actuated, with a hybrid structure only used to improve load support, stability and integration with the new prosthetic hand.

RELATED BIBLIOGRAPHY

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- H. Liu, P. Ferrentino, S. Pirozzi, B. Siciliano, F. Ficuciello, "The PRISMA Hand II: a sensorized robust hand for adaptive grasp and in-hand manipulation," ISRR, 2019.
- F. Renda et al., "A geometric variable-strain approach for static modeling of soft manipulators with tendon and fluidic actuation," IEEE Robotics and Automation Letters, 2020.
- A. T. Mathew et al., "A MATLAB toolbox for hybrid rigid-soft robots based on the geometric variable strain approach," 2021.
- W. R. Wockenfuß et al., "Design, modeling and validation of a tendon-driven soft continuum robot for planar motion based on variable stiffness structures," IEEE Robotics and Automation Letters, 2022.

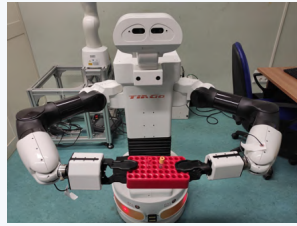
			
<p><i>KUKA MED LBR</i></p>	<p><i>Ultrasound Probe</i></p>	<p><i>Sciatic Nerve Phantom</i></p>	<p><i>Nerve Detection with Yolo</i></p>
<p>THESIS OVERVIEW</p> <p>This thesis is based on a shared control system that enables teleoperation, utilizing impedance control, along the transverse visualization axis of the sciatic nerve. Furthermore, it automatically adjusts the position along the axis perpendicular to the nerve to keep it centered during the ultrasound scan. Future objectives will include developing and defining force control along the robot's z-axis, which interacts with the environment (the phantom), and subsequently automating the rotation around the transverse axis of movement relative to the nerve. This ensures correct visualization of the nerve, regardless of the anatomical structure of the human leg or phantom.</p>		<p>TOOLS</p> <p>ROS2, C++, Python, KUKA MED LBR, KDL Library, OpenCV, YOLO, PyTorch, Autodesk Fusion 360, Echo Wave, Ultrasound Probe, Sciatic Nerve Phantom</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello Fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR</p> <p>Antonio Fabio Pannuto fabiopannuto@hotmail.it</p> <p>KEYWORDS</p> <p>Shared Control; Robotic Ultrasound; Nerve Tracking</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • Implementation of Force Control along the z-axis • Adaptment of the pressure between the patients using Machine Learning 			
<p>PREREQUISITES / NOTES</p> <p>Recommended courses: Medical Robotics, Robotics Lab, Computer Vision</p> <p>Required Skills: C++ and Python programming, KDL Library, Robotics Dynamic Control, ROS2 Architecture, Visual Servoing, Computer Vision (OpenCV, PyTorch, YOLO)</p>		<p>RELATED BIBLIOGRAPHY</p> <p>[1] «Robotica - Siciliano Bruno; Sciavicco Lorenzo; Villani Luigi; Oriolo Giuseppe.</p>	

MedRob-8 – Learning-Driven Control Strategies for Bimanual Assistance using TIAGo Pro

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Tiago++ [1] opening a box



Tiago++ holding a tube rack



Allegro Hand V4 [2], equipped on TiagoPro [3]



TiagoPro

THESIS OVERVIEW

The objective of the thesis is the development of a control system for a wheeled robot for bimanual manipulation in domestic or hospital assistance tasks. The control system utilizes force and vision feedback and will be integrated with learning techniques to improve efficiency and autonomy.

TOOLS

TiagoPro, ROS, ROS2, Python, OpenCV, C++, Mujoco

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KEYWORDS

Bimanual Manipulation, Impedance Control, Reinforcement Learning, Human-Robot Interaction

EXAMPLES / POSSIBLE ACTIVITIES

- The use of learning techniques to acquire manipulation skills from human demonstration, specifically grasping, manipulation, and the management of multiple tasks.
- The development of a control strategy that dynamically manages priority among multiple tasks, starting from the learned motion primitives and the force and vision information.
- The investigation of reinforcement learning techniques for grasping and manipulation tasks. Dimensionality reduction techniques for the robotic system's configuration space (motor synergies) will be adopted to optimize the learning of new tasks. This requires the use of a high-level vision sensor for object recognition and force sensors for grip control.
- The development of shared control techniques in which the human and the machine share the task and cooperate in its execution with variable levels of autonomy based on the current state of the task

PREREQUISITES / NOTES

Medium/Advanced knowledge of ROS, ROS2, Python, OpenCV, C++, Machine Learning, Impedance Control is required


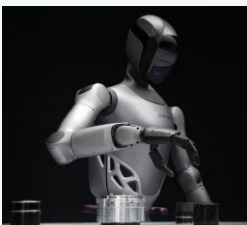


RELATED BIBLIOGRAPHY

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- [2] <https://www.allegrohand.com/sub/tech/t.php?id=2>
- [3] <https://pal-robotics.com/robot/tiago-pro/>

MedRob-9 – Control Strategies for Bimanual Manipulation in Humanoid Robots for Assistive Tasks

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<p><i>Fourier GR2 [1]</i></p>	<p><i>Fourier GR2 grasping some objects</i></p>	<p><i>Photo of Fourier GR2 in our lab</i></p>	<p><i>Fourier GR2 grasping some objects</i></p>

THESIS OVERVIEW

This thesis aims to develop advanced control architectures for humanoids, placing a primary focus on the integration of Control frameworks and Machine Learning methodologies to achieve dexterous fine manipulation while keeping the balance

TOOLS

Fourier GR2, Python, OpenCV, C++, Mujoco, NVIDIA Isaac Sim

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KEYWORDS

Bimanual Manipulation, Humanoid Robot, Reinforcement Learning, Whole-Body Control

EXAMPLES / POSSIBLE ACTIVITIES

- The use of learning techniques to acquire manipulation skills from human demonstration, specifically grasping, manipulation, and the management of multiple tasks.
- The development of a Whole-Body Control (WBC) strategy to ensure dynamic balance during fine manipulation, allowing the robot's posture and legs to automatically compensate for physical disturbances caused by rapid arm movements or load variations.
- The integration of force sensors on the robotic hands to enable reactive and dexterous manipulation. This tactile feedback will be coupled with variable impedance control and learning policies to safely absorb impacts and execute highly dynamic tasks.

PREREQUISITES / NOTES

Medium/Advanced knowledge of Python, OpenCV, C++, Machine Learning, Impedance Control is required


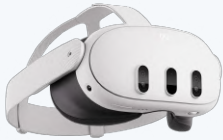


RELATED BIBLIOGRAPHY

[1] <https://www.fftai.com/products-gr2>

MedRob-10 – Teleoperation Frameworks for Humanoid Robots in Healthcare and Domestic Assistance

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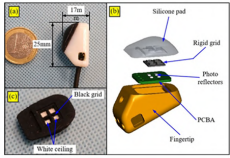


			
<p><i>Fourier GR2</i> [1]</p>	<p><i>Meta Quest 3 device</i> [2]</p>	<p><i>Photo of Fourier GR2 in our lab</i></p>	<p><i>Teleoperation example</i></p>
<p>THESIS OVERVIEW</p> <p>This thesis aims to develop advanced teleoperation systems for humanoid platforms, placing a primary focus on translating operator movements into precise robot actions to achieve highly dexterous manipulation during complex domestic or healthcare tasks.</p>		<p>TOOLS</p> <p>Fourier GR2, Python, OpenCV, C++, Mujoco, Meta Quest 3, EMG sensors</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR</p> <p>Paolino De Risi paolino.derisi@unina.it Domenico Tuccillo domenico.tuccillo@unina.it</p> <p>KEYWORDS</p> <p>Bimanual Manipulation, Humanoid Robot, Imitation Learning, Teleoperation</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none">• The use of teleoperation frameworks to collect high-quality human demonstrations for Imitation Learning, enabling the robot to autonomously acquire and reproduce complex, dexterous manipulation techniques• The implementation of tele-impedance control strategies, utilizing wearable sensors (e.g., electromyography or force myography) to measure the operator's muscle contraction and dynamically adjust the robot's stiffness, ensuring safe physical interactions• The development of a whole-body teleoperation architecture that translates human input into coordinated movements across the robot's entire kinematic chain, seamlessly coupling arm manipulation with torso and base adjustments			
<p>PREREQUISITES / NOTES</p> <p>Medium/Advanced knowledge of Python, OpenCV, C++, Machine Learning, Impedance Control is required</p>		<p>RELATED BIBLIOGRAPHY</p> <p>[1]https://www.fftai.com/products-gr2 [2]https://www.meta.com/it/quest/quest-3/</p>	

[MedRob-11] – Shared EMG–Force Control of the PRISMA Hand III with Synergy-Based Grasping and Stiffness Modulation

Thesis sheet · PRISMA Lab



			
<p>EMG Sensor-Delsys</p>	<p>Prisma Hand III</p>	<p>VS system</p>	<p>Force sensor</p>

THESIS OVERVIEW

This thesis aims to develop a shared-control framework for the PRISMA Hand III prosthetic hand, combining surface EMG signals and fingertip force/tactile feedback to achieve robust, intuitive and adaptive grasping. The user intention will be decoded from EMG signals to command hand opening/closing, grasp initiation and possibly grasp type selection. At the same time, force sensors will provide autonomous feedback to detect object contact, regulate grasp force, avoid excessive squeezing and improve grasp stability. The control strategy will exploit postural synergies to reduce the dimensionality of the hand control problem and generate optimal grasp postures for different object shapes and tasks. A specific focus will be given to the fourth motor of the PRISMA Hand III, which modulates the stiffness of thumb, index and middle fingers. The controller will decide when to increase stiffness for stable grasping and load holding, and when to decrease stiffness for safe interaction, compliance and object release. The expected outcome is a real-time shared-control architecture validated on grasping tasks with objects of different size, shape, stiffness and weight.

TOOLS

PRISMA Hand III; surface EMG sensors; fingertip force/tactile sensors; motor drivers and embedded controller; ROS / ROS 2; MATLAB/Simulink; Python; Arduino / STM32 / microcontroller environment; signal processing tools; machine learning libraries, e.g. scikit-learn / PyTorch; experimental objects for ADL grasping; data acquisition board; load cells or external force sensors for validation.

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KEYWORDS

shared control; EMG control; force feedback; prosthetic hand; postural synergies; variable stiffness; adaptive grasping; tendon-driven hand

EXAMPLES / POSSIBLE ACTIVITIES

- Develop an EMG interface to estimate user intention, including hand opening/closing, grasp activation, release command and possibly grasp type selection through classification or regression methods.
- Implement a synergy-based controller that maps low-dimensional commands into coordinated postures of the PRISMA Hand III for power grasp, pinch grasp, tripod grasp and adaptive grasping of unknown objects.
- Design a force-feedback shared-control strategy that automatically detects contact, regulates grip force and commands the fourth motor to increase or decrease the stiffness of thumb, index and middle fingers according to object stability, slip risk and safety constraints.
- Validate the controller through experiments on daily-life objects, measuring grasp success rate, contact force regulation, stiffness modulation timing, slip events, EMG effort, response time and user workload.

PREREQUISITES / NOTES

Recommended for a Master thesis in robotics, biomedical engineering, automation, mechatronics or related areas. Useful skills include robot control, signal processing, basic machine learning, Python/MATLAB and experimental robotics. Knowledge of EMG processing, impedance/stiffness control and tactile sensing is appreciated but not mandatory. The thesis can be tuned toward either control and signal processing, or toward experimental validation with the real prosthetic hand. The key idea is to keep the user in the loop through EMG commands while letting the hand autonomously manage contact, force and stiffness for safer and more stable grasping.

RELATED BIBLIOGRAPHY

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- H. Liu, P. Ferrentino, S. Pirozzi, B. Siciliano, F. Ficuciello, "The PRISMA Hand II: a sensorized robust hand for adaptive grasp and in-hand manipulation," ISRR, 2019.
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- M. Santello, M. Flanders, J. F. Soechting, "Postural hand synergies for tool use," Journal of Neuroscience, 1998.
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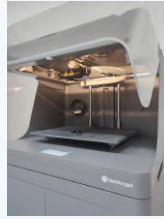
			
<p>Fourier Intelligence ExoMotus M4 lower-limb exoskeleton</p>	<p>Delsys Trigno wireless EMG acquisition system</p>	<p>Brain Products LiveAmp wireless EEG system</p>	<p>Human gait cycle with the main kinematic events</p>
<p>THESIS OVERVIEW</p> <p>This thesis aims to develop a hierarchical control framework for the Fourier Intelligence ExoMotus M4 lower-limb rehabilitation exoskeleton. The objective is to make robot-assisted gait training more patient-cooperative by combining bio-signal-based intention estimation with adaptive assist-as-needed control. The work will be organized around two complementary control layers. The high-level layer will estimate the user’s walking intention and gait phase by fusing EMG, EEG and exoskeleton sensor data. EMG signals will provide information about residual muscle activation and movement onset, while EEG signals will be explored to detect motor intention, gait-related motor imagery and cognitive engagement. The mid-level layer will use this information to adapt the robotic assistance during gait training. In order to optimize the activation of selected target muscles according to a desired rehabilitation profile. Depending on the therapeutic goal, the controller may reduce the user’s effort to avoid fatigue and abnormal compensations or increase the user’s active contribution by reducing assistance or applying controlled resistance. The expected outcome is a real-time bio-signal-driven assist-as-needed controller validated on gait rehabilitation tasks with the ExoMotus M4.</p>		<p>TOOLS</p> <p>Fourier Intelligence ExoMotus M4; surface EMG sensors; EEG cap; ExoMotus onboard sensors; optional IMUs; Python; MATLAB/Simulink; ROS 2; signal processing tools; real-time data acquisition system; gait analysis tools; statistical analysis tools.</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR</p> <p>Raffaella Mancino raffaella.mancino@unina.it</p> <p>KEYWORDS</p> <p>lower-limb exoskeleton; gait rehabilitation; assist-as-needed control; EEG–EMG fusion; intention estimation; gait-phase recognition; adaptive impedance; muscle effort regulation</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • Develop a multimodal intention-estimation module using EMG, EEG and exoskeleton data to detect gait initiation, walking continuation, stopping intention and possibly sit-to-stand or marching tasks. • Implement gait-phase recognition, for example stance/swing or heel strike, foot flat, heel off and swing, using EMG features, EEG features and robot sensor feedback. • Define target muscle-effort curves for selected muscles, such as tibialis anterior, gastrocnemius/soleus, rectus femoris, vastus lateralis, biceps femoris or gluteus medius. • Develop an assist-as-needed controller that adapts the assistance provided by the ExoMotus M4 according to the user’s estimated voluntary contribution, gait phase and rehabilitation goal. 			
<p>PREREQUISITES / NOTES</p> <p>Useful skills include robot control, signal processing, Python/MATLAB. Knowledge of EMG/EEG processing, gait analysis, is useful but not mandatory. The thesis can be split into two independent projects: one focused on high-level EEG–EMG intention and gait-phase estimation, and one focused on mid-level assist-as-needed control based on muscle-effort regulation.</p>		<p>RELATED BIBLIOGRAPHY</p> <p>W. Meng et al., “Recent Development of Mechanisms and Control Strategies for Robot-Assisted Lower Limb Rehabilitation,” <i>Mechatronics</i>, 2015.</p> <p>S. Tortora et al., “Hybrid Human–Machine Interface for Gait Decoding Through Bayesian Fusion of EEG and EMG Classifiers,” <i>Frontiers in Neurobotics</i>, 2020.</p> <p>R. Baud et al., “Review of Control Strategies for Lower-Limb Exoskeletons to Assist Gait,” <i>Journal of NeuroEngineering and Rehabilitation</i>, 2021.</p> <p>Y. Zhang et al., “A Multi-Information Fusion Method for Gait Phase Classification in Lower Limb Rehabilitation Exoskeleton,” <i>Frontiers in Neurobotics</i>, 2021.</p>	

MedRob-13 – Redesign and Control of the Auxivo EduExo Pro Upper-Limb Exoskeleton

Thesis sheet · PRISMA Lab



Original Auxivo EduExo Pro upper-limb exoskeleton



Markforged X7 3D printer



Logitech C920e webcam



Representative setup for testing a vision-based upper-limb assistance

THESIS OVERVIEW

This thesis aims to develop a complete design-and-control framework for a modified Auxivo EduExo Pro upper-limb exoskeleton. The mechanical part focuses on transforming the platform into an active shoulder-elbow device by integrating a shoulder motor, designing a torso/shoulder-back support structure, and optimizing materials, load paths and human interfaces to minimize weight and maximize comfort. The mechatronic redesign will also compact the battery, motor drivers, controller, sensors and cable routing into the support frame to reduce distal mass and improve wearability. The control part focuses on the development of hierarchical control to assist the user for activities of daily living. The high-level controller will be vision-based. The mid-level controller will implement an impedance-control strategy that converts the high-level task plan into safe and adaptive shoulder–elbow assistance. The low-level controller will implement PID-based joint control for the shoulder and elbow motors.

TOOLS

Auxivo EduExo Pro; CAD software, e.g. SolidWorks / Fusion 360 / Creo; MATLAB / Simulink; Python; Arduino / Raspberry Pi; 3D printing; IMU / encoders / force sensors, ROS 2; OpenCV; YOLO / object-detection networks; MediaPipe or hand/pose tracking tools.

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KEYWORDS

Upper-limb exoskeleton; shoulder actuation; lightweight design; wearable robotics; ergonomic support; material optimization; compact electronics; EduExo Pro.

EXAMPLES / POSSIBLE ACTIVITIES

- Design and optimization: design and optimize an active shoulder module and a lightweight support structure to stabilize the exoskeleton on the user while preserving comfort and safety.
- Mechatronic integration: integrate actuators, sensors, battery, motor drivers and cable routing into a compact wearable layout, minimizing distal mass and improving donning/doffing.
- Hierarchical control: develop and validate a hierarchical controller combining vision-based task estimation, impedance-based assistance and low-level PID joint tracking for ADL tasks.

PREREQUISITES / NOTES

Useful skills include CAD design, mechanical dimensioning, FEM analysis, basic electronics packaging, 3D printing, Python/C++, ROS, OpenCV. The thesis can be split into four subprojects: high-level vision-based ADL recognition and task planning; mid-level impedance control for compliant arm assistance; and low-level PID motor control for the shoulder and elbow joints.





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- S. Crea et al., “Feasibility and safety of shared EEG/EOG and vision-guided autonomous whole-arm exoskeleton control to perform activities of daily living,” *Scientific Reports*, 2018.
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MedRob-14 – Multimodal Dataset and Gait Quality Index for Assessing UAN.GO-Assisted Walking in ALS Patients

Thesis sheet · PRISMA Lab



			
<p><i>UAN.GO powered lower-limb exoskeleton for robotic gait training</i></p>	<p><i>Delsys Trigno wireless EMG acquisition system</i></p>	<p><i>Brain Products LiveAmp wireless EEG system</i></p>	<p><i>BITalino Revolution board for multimodal biosignal acquisition</i></p>

THESIS OVERVIEW

This thesis aims to acquire and analyse a multimodal dataset for the quantitative assessment of UAN.GO-assisted gait in patients with amyotrophic lateral sclerosis (ALS). The dataset will combine biomechanical, neuromuscular and physiological information, including EMG, EEG, ECG, wearable sensors and exoskeleton data, during walking tasks performed with and without robotic assistance when clinically feasible. The first objective is to evaluate the effects of the UAN.GO lower-limb exoskeleton on gait performance, muscle activation, physiological workload and walking stability. The second objective is to identify compensatory strategies adopted by ALS patients compared with healthy subjects, focusing on spatiotemporal parameters, joint kinematics, muscle coordination, asymmetry, fatigue and abnormal recruitment patterns. The final objective is to develop a multimodal gait quality index that summarizes the patient's walking performance and deviation from healthy reference patterns. This index could later be used as an input for personalized exoskeleton control strategies, adapting robotic assistance according to the patient's biomechanical impairment, residual muscle activity and rehabilitation needs.

TOOLS

UAN.GO lower-limb exoskeleton; surface EMG sensors; EEG headset or EEG cap; ECG sensor or chest belt; IMUs; force plates; UAN.GO; OpenSim; MATLAB; Python.

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KEYWORDS

ALS; lower-limb exoskeleton; UAN.GO; multimodal dataset; EEG; EMG; ECG; gait analysis; compensatory strategies; gait quality index.

EXAMPLES / POSSIBLE ACTIVITIES

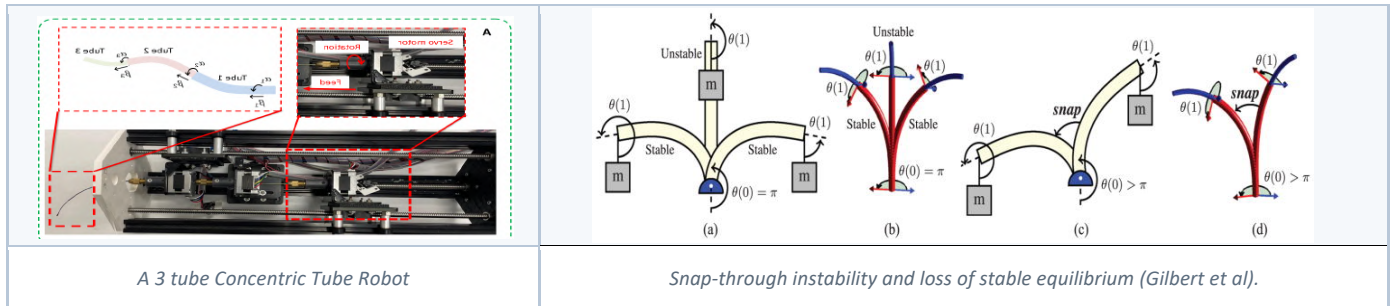
- Multimodal dataset acquisition: design and execute an experimental protocol for collecting synchronized EEG, EMG, ECG, wearable-sensor and exoskeleton data from ALS patients and healthy subjects during gait tasks with and without UAN.GO assistance.
- Biomechanical and neuromuscular analysis: compare ALS patients and healthy controls to identify compensatory strategies, altered muscle activation patterns, gait asymmetries, fatigue indicators and changes induced by exoskeleton-assisted walking.
- Gait quality index development: develop a multimodal gait quality index combining spatiotemporal, kinematic, EMG, EEG and ECG-derived features, with the long-term goal of using it for personalized rehabilitation and adaptive exoskeleton control.

PREREQUISITES / NOTES

Useful skills include signal processing, gait analysis, Python/MATLAB, statistics, and experimental protocol design. Knowledge of EMG, EEG, ECG, OpenSim and clinical gait analysis is useful but not mandatory. The thesis requires close collaboration with clinicians and therapists.

RELATED BIBLIOGRAPHY

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A 3 tube Concentric Tube Robot

Snap-through instability and loss of stable equilibrium (Gilbert et al).

THESIS OVERVIEW

Concentric tube robots (CTRs) are continuum manipulators made from pre-curved super-elastic tubes actuated by relative rotations and translations. Their dexterity is attractive for minimally invasive surgery, but torsional coupling can cause elastic instabilities (snaps): sudden losses of stable equilibrium that produce abrupt, unsafe tip motion.

Existing CTR NMPC uses Cosserat-rod forward prediction and constraints to avoid unrecoverable configurations, but snap handling is implicit and does not use an explicit elastic-stability margin in the cost. This thesis will augment a Khadem-style NMPC with a real-time stability-margin layer.

An elastic-instability manifold will be characterized offline from a bifurcation-based stability test over the CTR joint space. A signed distance field (SDF) to this manifold will be queried online and used as both a hard stability constraint and a soft safety-buffer cost.

The soft-cost weight will be a three-parameter function of the current SDF margin and the predicted rate of approach to the instability boundary. Parameters will be tuned offline using Bayesian optimization and evaluated on stability-grazing trajectories against no-margin, fixed-weight, and current-margin-only baselines.

TOOLS

Python or MATLAB (CasADi), Cosserat-rod CTR 2/3-tube CTR model, SOFA, ROS.

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KEYWORDS

Concentric tube robot, snapping, elastic stability, signed distance field; NMPC, optimization

EXAMPLES / POSSIBLE ACTIVITIES

- Build and validate a bifurcation-based stability map/SDF for a simulated CTR.
- Integrate SDF-based hard constraints and soft safety-buffer costs into NMPC.
- Tune fixed, current-only, and trajectory-aware schedules offline using optimization.
- Evaluate tracking error, minimum stability margin, stability violations, and runtime costs.

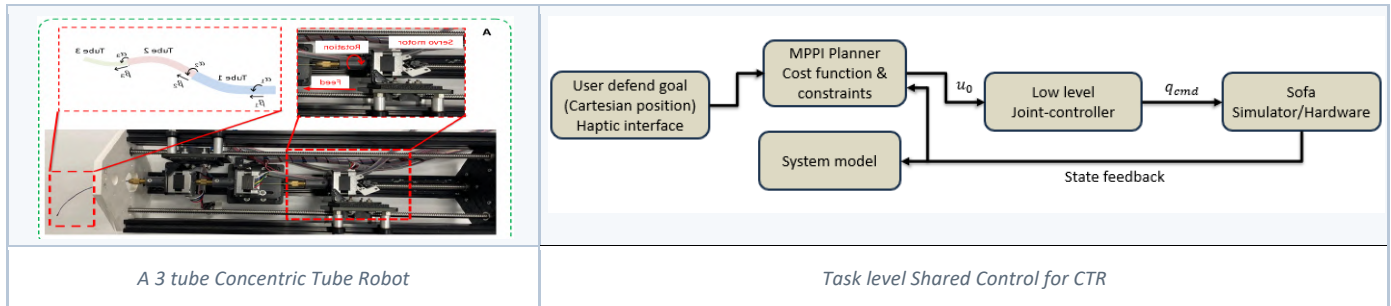
PREREQUISITES / NOTES

Recommended: Basic continuum mechanics and numerical optimization.

MS thesis, 6-8 months

RELATED BIBLIOGRAPHY

- Khadem et al., Autonomous Steering of CTRs via NMPC, IEEE T-RO, 2020.
- Gilbert et al., Elastic Stability of CTRs, IEEE T-RO, 2016.
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A 3 tube Concentric Tube Robot

Task level Shared Control for CTR

THESIS OVERVIEW

Concentric tube robots (CTRs) are continuum manipulators built from nested pre-curved super-elastic tubes that can be rotated and translated to steer the robot tip. This thesis will develop a simple, functional task-level shared-control framework for a CTR in SOFA. The user provides a desired Cartesian target point, while the controller computes joint-space commands that guide the tip toward the target. The assisted controller will address three objectives: target reaching, joint-limit constraint satisfaction, and obstacle avoidance. The control problem is formulated as a two-level architecture: a high-level Model Predictive Path Integral (MPPI) controller and a low-level joint controller.

At each time step, MPPI samples candidate joint-input sequences, propagates them through the CTR forward model or SOFA scene, and evaluates a cost function penalizing target error, joint-limit violation, obstacle proximity, and excessive control effort. Following receding-horizon control, only the first input is applied before the optimization is repeated.

Shared control is defined here as user task-level intent plus autonomous motion-level assistance. The expected output is a reproducible study comparing unaided motion, target-only assistance, and full MPPI assistance with safety costs.

TOOLS

Python or MATLAB (CasADi), CTR forward kinematics (dynamics), Sampling based control, ROS.

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KEYWORDS

Concentric tube robot, shared control, task level assistance, SOFA, sampling based optimal control

EXAMPLES / POSSIBLE ACTIVITIES

- Build and validate a bifurcation-based stability map/SDF for a simulated CTR.
- Integrate SDF-based hard constraints and soft safety-buffer costs into NMPC.
- Tune fixed, current-only, and trajectory-aware schedules offline using optimisation.
- Evaluate tracking error, minimum stability margin, stability violations, and runtime costs.

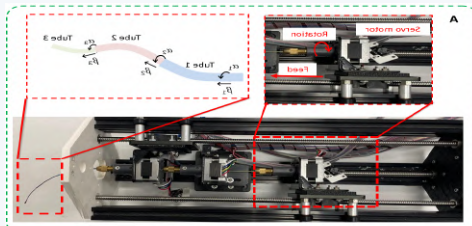
PREREQUISITES / NOTES

Recommended: Basic continuum mechanics and numerical optimization.

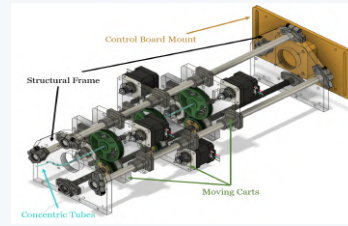
MS thesis, 6-8 months

RELATED BIBLIOGRAPHY

- Dupont et al., "Design and Control of Concentric-Tube Robots," IEEE T-RO, 2010.
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- Dragan & Srinivasa, "A Policy-Blending Formalism for Shared Control," IJRR, 2013.



A 3-tube Concentric Tube Robot



Example of a CTR design with 3 tubes, each with two motors: one for translation and one for rotation.

THESIS OVERVIEW

Concentric tube robots (CTRs) are nested continuum manipulators whose shape and tip position are controlled by the relative rotation and translation of pre-curved super-elastic tubes. Designing these robots is challenging due to the complex relationship between tube geometry (length, curvature, diameter) and the resulting workspace. This thesis will develop an integrated pipeline from parametric 3D modeling to physics-based simulation in the SOFA framework, followed by the development of an experimental hardware setup.

First, the student will establish a 3D CAD model of the CTR's tubes based on design parameters (length, curvature, diameter) and run simulation/kinematic modeling in MATLAB. This model will be imported into SOFA to simulate the robot's behavior.

Second, a hardware actuation platform will be designed and built. The student will select appropriate motors, integrate them with a microcontroller-based control unit, and develop the firmware.

Finally, closed-loop feedback controllers will be implemented in the firmware/MATLAB and tested to achieve precise translation and rotation of the tubes.

TOOLS

SOFA, MATLAB, 3D modeling, Microcontroller IDE, C/C++ (firmware), Stepper/DC motors.

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KEYWORDS

Concentric tube robot, 3D modeling, SOFA simulation, MATLAB, hardware-in-the-loop, embedded firmware, closed-loop feedback control.

EXAMPLES / POSSIBLE ACTIVITIES

- Create a parametric 3D CAD model of a 3-tube CTR.
 - Implement and validate a physics-based simulation of the CTR in the SOFA Framework and kinematics in MATLAB.
 - Design and assemble the mechanical/electrical hardware actuation setup.
 - Write microcontroller firmware using an appropriate IDE for real-time motor control and feedback reading.
- Test and compare closed-loop control strategies (e.g., PID) for precise tube translation and rotation.

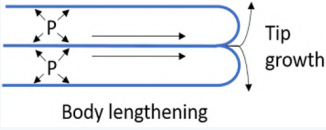
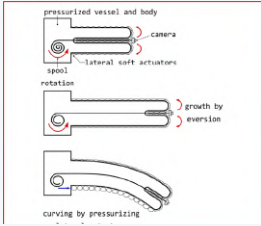
PREREQUISITES / NOTES

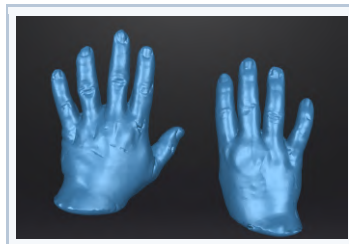
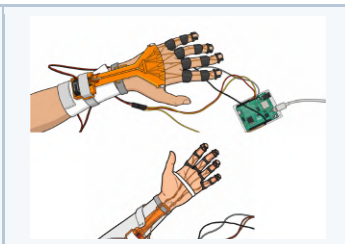
Recommended: Experience with 3D modeling, MATLAB scripting, basic robotics kinematics, embedded programming, and control systems.

MS thesis, 6-8 months

RELATED BIBLIOGRAPHY

- Dupont et al., "Design and Control of Concentric-Tube Robots," IEEE T-RO, 2010.
- Webster & Jones, "Design and Kinematic Modeling of Constant Curvature Continuum Robots," IJRR, 2010.
- Coevoet et al., "Software Toolkit for Modeling, Simulation, and Control of Continuum Robots," Advanced Robotics, 2017.
- Lu et al., "A Starter's Kit for Concentric Tube Robots," arXiv:2407.06943, 2024.



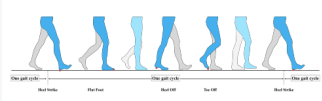

			
<p>This is an example of a soft robot that grows from the tip.</p>	<p>Actuation of the soft robot</p>		
<p>THESIS OVERVIEW</p> <p>Soft robotics has opened new perspectives in minimally invasive medicine, offering solutions capable of navigating complex and delicate environments such as the human body with a reduced risk of tissue damage. In this context, eversion robots represent a particularly promising emerging technology for endoscopic applications, thanks to their ability to advance through continuous inversion of their structure, thereby minimizing friction and the forces exerted on internal walls.</p> <p>Building on these premises, this thesis proposes the development of an eversion robotic system for colonoscopy applications, designed to operate safely and effectively within the intestinal tract. The work will involve a feasibility study integrating aspects related to materials, structural design, and actuation mechanisms, with the goal of identifying solutions that ensure flexibility, biocompatibility, and controllability of the device. The main activities include the selection of suitable materials for biomedical eversion robots, the design and modeling of the robotic system with a focus on navigation in confined and deformable environments, the development and analysis of the actuation system for eversion-based motion, and a preliminary evaluation of the device performance under simulated endoscopic conditions.</p>		<p>TOOLS</p> <p>SolidWorks, Solid Edge, AutoCAD, quickSurface, magnetic sensor, Python, Matlab, Arduino, Simulink, SOFA</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR</p> <p>Mariarosaria Meola mariarosaria.meola@unina.it Marcella Piacentino marcella.piacentino@unina.it Emanuele Gaudino em.gaudino.eg@gmail.com</p> <p>KEYWORDS</p> <p>3D printing; design and control; soft robots</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • CAD modeling of the eversion robot structure • Material selection and testing for biomedical applications • Development and testing of the actuation mechanism with preliminary experiment 			
<p>PREREQUISITES / NOTES</p> <p>Basic knowledge of CAD modeling, mechanical design, and programming (Python, Matlab, or Arduino), together with an interest in robotics, biomedical systems, and prototyping; familiarity with sensors and experimental testing is considered a plus.</p>	<p>RELATED BIBLIOGRAPHY</p> <p>[1] C. Suulker <i>et al.</i>, «State of the art in soft eversion robots for colonoscopy: a review», <i>Progress in Biomedical Engineering</i>, vol. 8, fasc. 1, p. 012012, 2026.</p> <p>[2] S. Al Harthy <i>et al.</i>, "Tip-Growing Robots: Design, Theory, Application," in <i>IEEE Transactions on Robotics</i>, vol. 41, pp. 5511-5532, 2025, doi: 10.1109/TRO.2025.3608701.</p> <p>[3] E. Franco, "Model-Based Eversion Control of Soft Growing Robots With Pneumatic Actuation," in <i>IEEE Control Systems Letters</i>, vol. 6, pp. 2689-2694, 2022, doi: 10.1109/LCSYS.2022.3175385.</p>		

			
<p>3D scan of two hands, with the right hand missing the thumb</p>	<p>Current state of the art of the device</p>		
<p>THESIS OVERVIEW</p> <p>In recent years, wearable robotics has increasingly focused on soft-material solutions due to their ability to conform to the human body while ensuring comfort and safety during interaction. In this context, soft wearable devices for functional monitoring and assistance represent a promising yet still underexplored research area, particularly in terms of the integrated design of materials, structures, and sensing systems.</p> <p>This thesis aims to develop a soft wearable system, including a glove and a wristband manufactured through additive manufacturing technologies. The work will investigate suitable materials to ensure flexibility, durability, and compatibility with sensor integration, while also addressing the design and embedding of sensing systems for motion and interaction monitoring. The project will further include feasibility analysis, device modeling, material characterization, and preliminary techniques for signal acquisition and interpretation.</p>		<p>TOOLS</p> <p>SolidWorks, Solid Edge, AutoCAD, quickSurface, EMG sensor, Python, Matlab, Arduino</p> <p>SUPERVISOR</p> <p>Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>TECHNICAL SUPERVISOR</p> <p>Mariarosaria Meola mariarosaria.meola@unina.it Marcella Piacentino marcella.piacentino@unina.it</p> <p>KEYWORDS</p> <p>3D printing; 3D scanning; sensor prototyping</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • Material bending tests • 3D printing of soft components • Development of an EMG-based control system 			
<p>PREREQUISITES / NOTES</p> <p>Basic knowledge of CAD modeling, 3D printing, and programming (Python, Matlab, or Arduino), together with an interest in wearable robotics and prototyping; familiarity with sensors and electronics is considered a plus.</p>		<p>RELATED BIBLIOGRAPHY</p> <p>[1] A. Mohammadi, J. Lavranos, P. Choong, and D. Oetomo, "Flexo-glove: a 3d printed soft exoskeleton robotic glove for impaired hand rehabilitation and assistance," in 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE, 2018, pp. 2120–2123.</p> <p>[2] B. B. Kang, H. Lee, H. In, U. Jeong, J. Chung, and K.-J. Cho, "Development of a polymer-based tendon-driven wearable robotic hand," in 2016 IEEE international conference on robotics and automation (ICRA). IEEE, 2016, pp. 3750–3755.</p> <p>[3] D. Chiaradia, L. Tiseni, M. Xiloyannis, M. Solazzi, L. Masia, and A. Frisoli, "An assistive soft wrist exosuit for flexion movements with an ergonomic reinforced glove," <i>Frontiers in Robotics and AI</i>, vol. 7, p. 595862, 2021.</p> <p>[4] S.-S. Yun, B. B. Kang, and K.-J. Cho, "Exo-glove pm: an easily customizable modularized pneumatic assistive glove," <i>IEEE Robotics and Automation Letters</i>, vol. 2, no. 3, pp. 1725–1732, 2017.</p> <p>[5] Tsabedze, E. Hartman, E. Abrego, C. Brennan, and J. Zhang, "Tsabrag: a twisted string actuator-powered biomimetic robotic assistive glove," in 2020 International Symposium on Medical Robotics (ISMR). IEEE, 2020, pp. 159–165.</p>	

MedRob-20 – Biomechanics-Informed Variable Impedance Control for the Humotech Open Source Leg

Thesis sheet · PRISMA Lab



			
<p><i>Humotech Open-Source Leg prosthetic platform</i></p>	<p><i>Delsys Trigno wireless EMG acquisition system</i></p>	<p><i>Human gait cycle with the main kinematic events</i></p>	<p><i>OpenSim musculoskeletal model during gait simulation</i></p>

THESIS OVERVIEW

This thesis aims to develop a subject-specific variable impedance controller for the Humotech Open Source Leg, a robotic knee–ankle prosthetic platform for research on powered lower-limb prostheses. The controller will adapt the stiffness and damping parameters of the prosthetic knee and ankle according to the user’s gait phase, locomotion scenario and biomechanical characteristics. The main idea is to exploit information from the intact leg, measured through IMUs and optionally EMG sensors, together with a subject-specific biomechanical model developed in OpenSim. The intact-limb data will be used to estimate gait phase, walking speed, terrain transitions and movement intention, while the OpenSim model will provide subject-specific reference kinematics, kinetics and impedance profiles. The prosthesis will then modulate its impedance parameters in real time to improve stability, comfort and adaptability during different tasks, including level-ground walking, ramps, stairs and variable terrain. The expected outcome is a real-time control framework that combines prosthesis onboard sensing, contralateral-limb sensing and biomechanical modelling to achieve more biomimetic and adaptive locomotion.

TOOLS

Humotech Open Source Leg / OSL; OpenSim; OpenSense; Python; MATLAB/Simulink; ROS / ROS 2 if available; OSL Python library; IMUs on the intact leg; optional surface EMG sensors on the intact leg; prosthesis onboard encoders; motor current feedback; 6-axis load cell if available; pressure insoles or foot switches; motion-capture system if available; machine learning libraries, e.g. scikit-learn / PyTorch.

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KEYWORDS

powered prosthetic leg; variable impedance control; subject-specific modelling; OpenSim; contralateral-limb sensing; IMU-based gait estimation; EMG; adaptive locomotion.

EXAMPLES / POSSIBLE ACTIVITIES

- Analyse the Humotech OSL control interface and implement a baseline joint impedance controller for knee and ankle using stiffness, damping and equilibrium-angle parameters.
- Develop a subject-specific OpenSim model to estimate reference knee/ankle kinematics, joint moments and impedance-like profiles from healthy-limb or able-bodied gait data.
- Use IMUs on the intact leg to estimate gait phase, walking speed, slope/stair transitions and terrain-related features; optionally integrate EMG to improve intention and effort estimation.
- Design a variable impedance policy that adapts knee and ankle stiffness/damping across stance and swing phases, and across level ground, ramps, stairs and uneven terrain.
- Validate the controller in simulation, benchtop tests and progressive walking experiments, evaluating tracking error, gait symmetry, prosthesis work, transition detection, stability and user comfort.

PREREQUISITES / NOTES





Useful skills include robot control, Python/MATLAB, signal processing, biomechanical modelling and experimental robotics. Knowledge of OpenSim, gait analysis, impedance control and wearable sensors is appreciated. The thesis can be developed at different levels of complexity: a first version can use only IMUs on the intact leg, while a more advanced version can integrate EMG for movement intention and muscle effort estimation. If force plates are not available, inverse dynamics from OpenSim should be interpreted carefully and can be supported by prosthesis load-cell data, or literature-based gait references.

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MedRob-21 – Multimodal Shared Control of A Robotic Wheelchair for ADL Assistance

Thesis sheet · PRISMA Lab

			
<p>Neatech Speedstar powered wheelchair platform</p>	<p>Kinova Gen3 collaborative robotic arm</p>	<p>NESM-γ upper-limb exoskeleton developed by SSSA</p>	<p>Delsys Trigno wireless sEMG acquisition system</p>
<p>THESIS OVERVIEW</p> <p>This thesis aims to develop a shared-autonomy control framework for the CARLA robotic wheelchair, a modular assistive platform integrating semi-autonomous mobility with upper-limb assistance through an exoskeleton or a robotic manipulator. The goal is to support users during activities of daily living by combining user commands, environmental perception and intelligent task interpretation within a safe human-in-the-loop architecture. A high-level multimodal layer, inspired by Vision–Language–Action approaches, will be used to interpret the user’s intention and the surrounding context, selecting the most appropriate assistance strategy for each task. The system will then coordinate the wheelchair, exoskeleton or manipulator through task-planning and whole-body control modules, enabling safe navigation, user-aware positioning, reaching and object manipulation. Particular attention will be given to modularity, safety, comfort and adaptability to different user profiles, so that the platform can provide different levels of autonomy depending on the residual motor abilities and the specific activity to be performed. The expected outcome is a software architecture for multimodal shared control, validated in representative ADL scenarios involving mobility, upper-limb assistance and manipulation.</p>		<p>TOOLS</p> <p>powered wheelchair platform; upper-limb exoskeleton; collaborative manipulator / cobot; RGB-D cameras; LiDAR or depth sensors; joystick; voice interface; eye-tracking; sEMG / IMU sensors; force/torque sensors; ROS 2; Python; C++; MATLAB/Simulink; Gazebo; OpenCV.</p> <p>SUPERVISOR</p> <p>Prof. Fanny Ficuciello fanny.ficuciello@unina.it</p> <p>KEYWORDS</p> <p>robotic wheelchair; Vision–Language–Action models; shared autonomy; multimodal HMI; whole-body control; mobile manipulation; upper-limb exoskeleton; cobot.</p>	
<p>EXAMPLES / POSSIBLE ACTIVITIES</p> <ul style="list-style-type: none"> • VLA-based intention and task understanding: develop a multimodal high-level module that combines vision, language/HMI commands and user-context information to infer the intended ADL task. • Interpretable task planning: implement a mid-level planner that decomposes VLA outputs into safe and verifiable action primitives for the wheelchair, exoskeleton and/or manipulator. • Shared-autonomy navigation: develop a semi-autonomous driving module for safe wheelchair navigation, obstacle avoidance and positioning in daily-life scenarios. • Upper-limb exoskeleton assistance: integrate the exoskeleton into the control architecture to support residual arm motion during ADL tasks. • Manipulator-based assistance: develop task primitives for the robotic manipulator, enabling object reaching, grasping and manipulation when the user cannot perform the action directly. • Whole-body coordination and safety: implement a supervisory control layer that coordinates wheelchair, exoskeleton and manipulator, managing task priorities, transitions, user comfort and safety constraints. 			
<p>PREREQUISITES / NOTES</p> <p>Useful skills include robot control, ROS 2, Python/C++, signal processing. The thesis can be scaled depending on the available hardware: one student may focus mainly on shared-autonomy navigation, another on exoskeleton assistance, another on manipulator control, while the full version addresses the integrated whole-body architecture.</p>		<p>RELATED BIBLIOGRAPHY</p> <p>T. Carlson, Y. Demiris, “Collaborative control for a robotic wheelchair: evaluation of performance, attention, and workload,” <i>IEEE Transactions on Systems, Man, and Cybernetics</i>, 2012.</p> <p>J. M. Catalán et al., “Hybrid brain/neural interface and autonomous vision-guided whole-arm exoskeleton control to perform activities of daily living,” <i>Journal of NeuroEngineering and Rehabilitation</i>, 2023.</p> <p>S. Crea et al., “Feasibility and safety of shared EEG/EOG and vision-guided autonomous whole-arm exoskeleton control to perform activities of daily living,” <i>Scientific Reports</i>, 2018.</p>	