A V-REP Simulator for the da Vinci Research Kit Robotic Platform

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Motivation

- da Vinci Research Kit (dVRK): repurposed core components donated by IS since 2012 coupled with software and controllers developed by research users
- an already quite wide community sharing the dVRK (32 systems in 28 sites worldwide)

- a simulation tool to
  - overcome the difficulty of replacing components in case of malfunctioning
  - test new tools design
  - validate control strategies
  - integrate learning in a simulation environments
  - provide an easy-to-access educational tool to students

Available surgical simulators

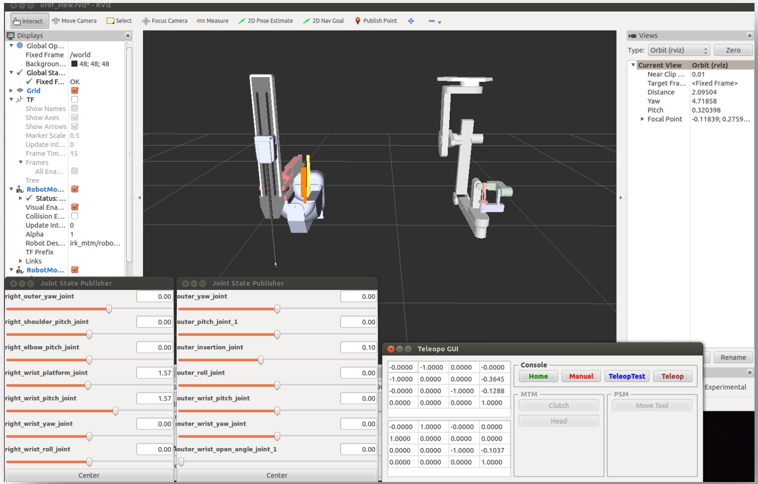
Surgical training simulators

Xron

dV trainer

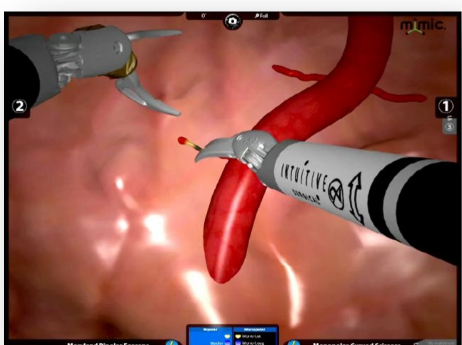
Research simulator

da Vinci Research Kit RVIZ



- integrated in ROS
- integration with other languages (Matlab, Python) but only using the dVRK code
- no Setup Joint simulated
- only visualizer: no physics
- not easy integration of objects, sensors etc. into the environment

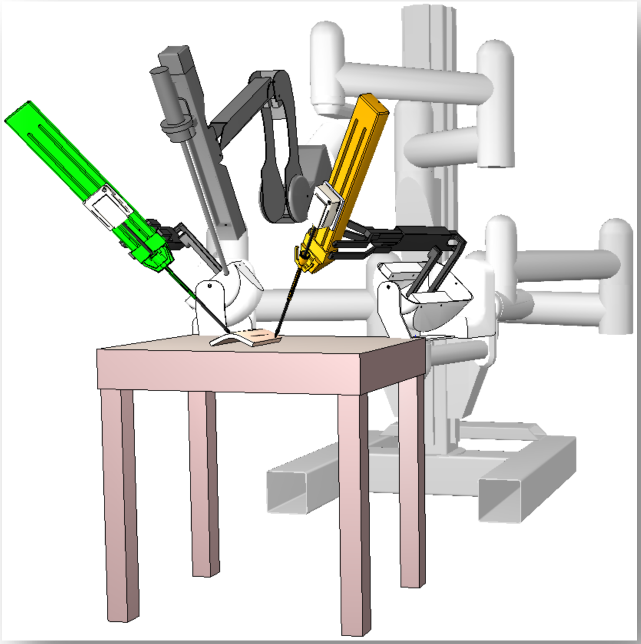
da Vinci skills simulator



robotix mentor

V-REP simulator for the dVRK

- versatility and simplicity of this software for multi-robot applications
- each object/model can be individually controlled via an embedded script, a plugin, a ROS or BlueZero node, a remote API client, or a custom solution
- controllers can be written in C/C++, Python, Java, Lua, Matlab or Octave
- the simulator can be easily interfaced with the real surgeon master console
- new objects and robots can be imported in the scene by using a graphical interface

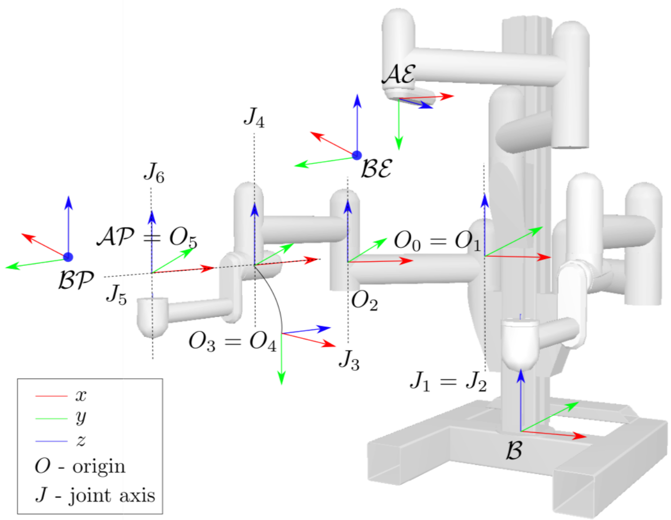


The complete simulator* is available at:
https://github.com/unina-icaros/dvrk-vrep.git.

* currently recommended OS/middleware combinations: Ubuntu 14.04+ROS Indigo, Ubuntu 16.04+ROS Kinetic

dVRK kinematics: SUJ

- the two PSMs and the ECM are mounted on the SUJ, an articulated robotic structure composed by three arms
- the two PSMs are located at the end of two 6-DoFs arms
- the ECM is located at the end of a 4-DoFs arm
- the real SUJ joints are not actuated by motors but it is possible to control breaks in each joint and read the angular position using potentiometers
- the simulated SUJ joints are position controlled

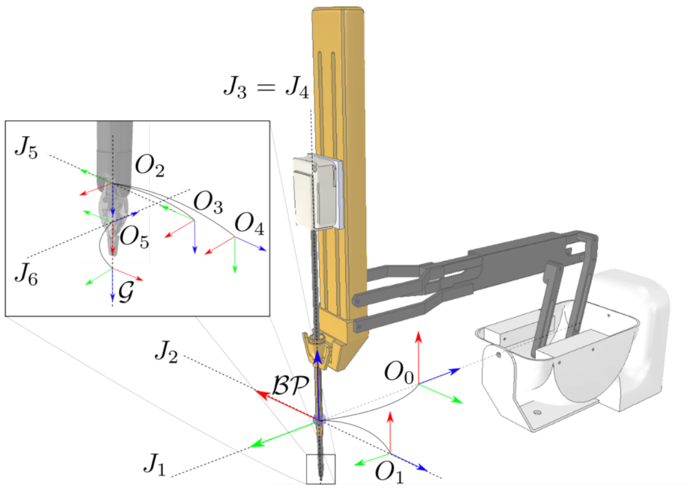


DH PARAMETERS OF THE SUJ

link	joint	a_i	α_i	d_i	θ_i
1	P	0	0	$q_{se,1}$	—
2	R	a_2	0	—	$q_{se,2}$
3	R	a_3	0	—	$q_{se,3}$
4	R	0	$-\pi/2$	—	$q_{se,4}$
5	R	0	$\pi/2$	$-d_4$	$q_{se,5}$
6	R	0	0	—	$q_{se,6}$

dVRK kinematics : PSM

- each PSM is a 7-DoF actuated arm, which moves a surgical instrument about a Remote Center of Motion (RCM)
- the first 6-DoFs correspond to Revolute (R) or Prismatic (P) joints, combined in a RRPRRR sequence
- the last DoF corresponds to the opening and closing motion of the gripper
- dynamic parametrs identified in [1] included
- torque control possible



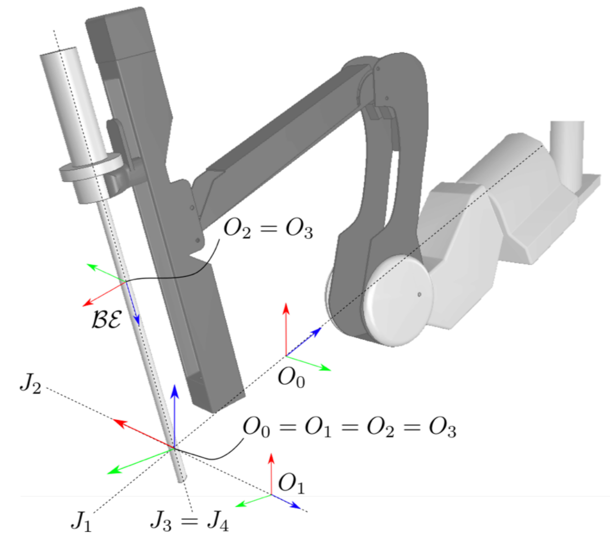
DH PARAMETERS OF THE PSM

link	joint	a_i	α_i	d_i	θ_i
1	R	0	$-\pi/2$	$-$	$q_{p,1}$
2	R	0	$-\pi/2$	$-$	$q_{p,2}$
3	P	0	0	$q_{p,3}$	$-$
4	R	0	$\pi/2$	$-$	$q_{p,4}$
5	R	a_5	$-\pi/2$	$-$	$q_{p,5}$
6	R	0	$-\pi/2$	$-$	$q_{p,6}$

[1] G. A. Fontanelli, F. Ficuciello, L. Villani, B. Siciliano, "Modelling and identification of the da Vinci Research Kit robotic arms" IROS 2017

dVRK kinematics : ECM

- the ECM is a 4-DoF actuated arm, which moves the endoscopic camera about the RCM through revolute and prismatic joints, combined in a RRPR sequence
- at the end tip of the endoscope two cameras have been included to simulate the binocular vision system of the real dVRK endoscope
- controlled in position



DH PARAMETERS OF THE ECM

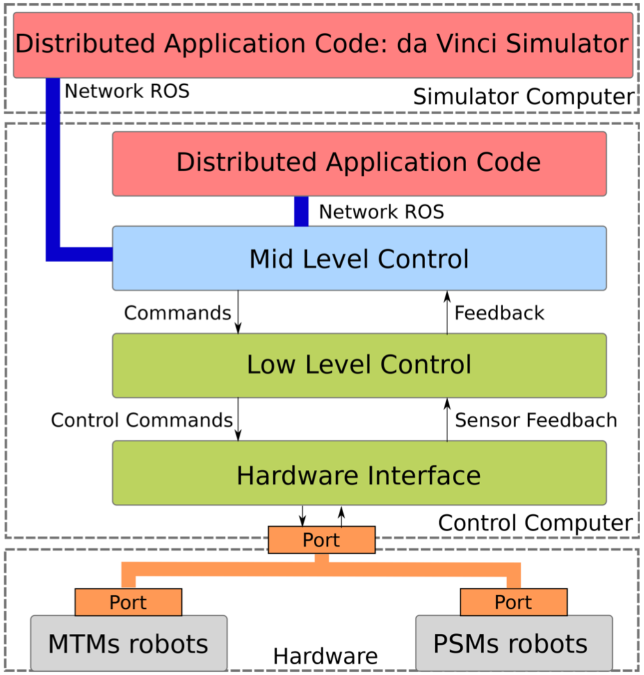
link	joint	a_i	α_i	d_i	θ_i
1	R	0	$-\pi/2$	$-$	$q_{e,1}$
2	R	0	$-\pi/2$	$-$	$q_{e,2}$
3	P	0	0	$q_{e,3}$	$-$
4	R	0	0	d_4	$q_{e,4}$

V-REP model of the complete dVRK

- each robot link has been realized by including two type of mesh:
  - one **visual mesh** with structure and texture similar to the real robot link,
  - one simplified **convex dynamic and respondable mesh** used to simulate dynamics and contacts
- the kinematic chain of each robotic arm is realized by linking mesh and joints in a **joint-respondable-visual** sequence
- dynamic parametrs included for each respondable link of the two PSMs
- the resulting complete robot is composed of **10178** triangles

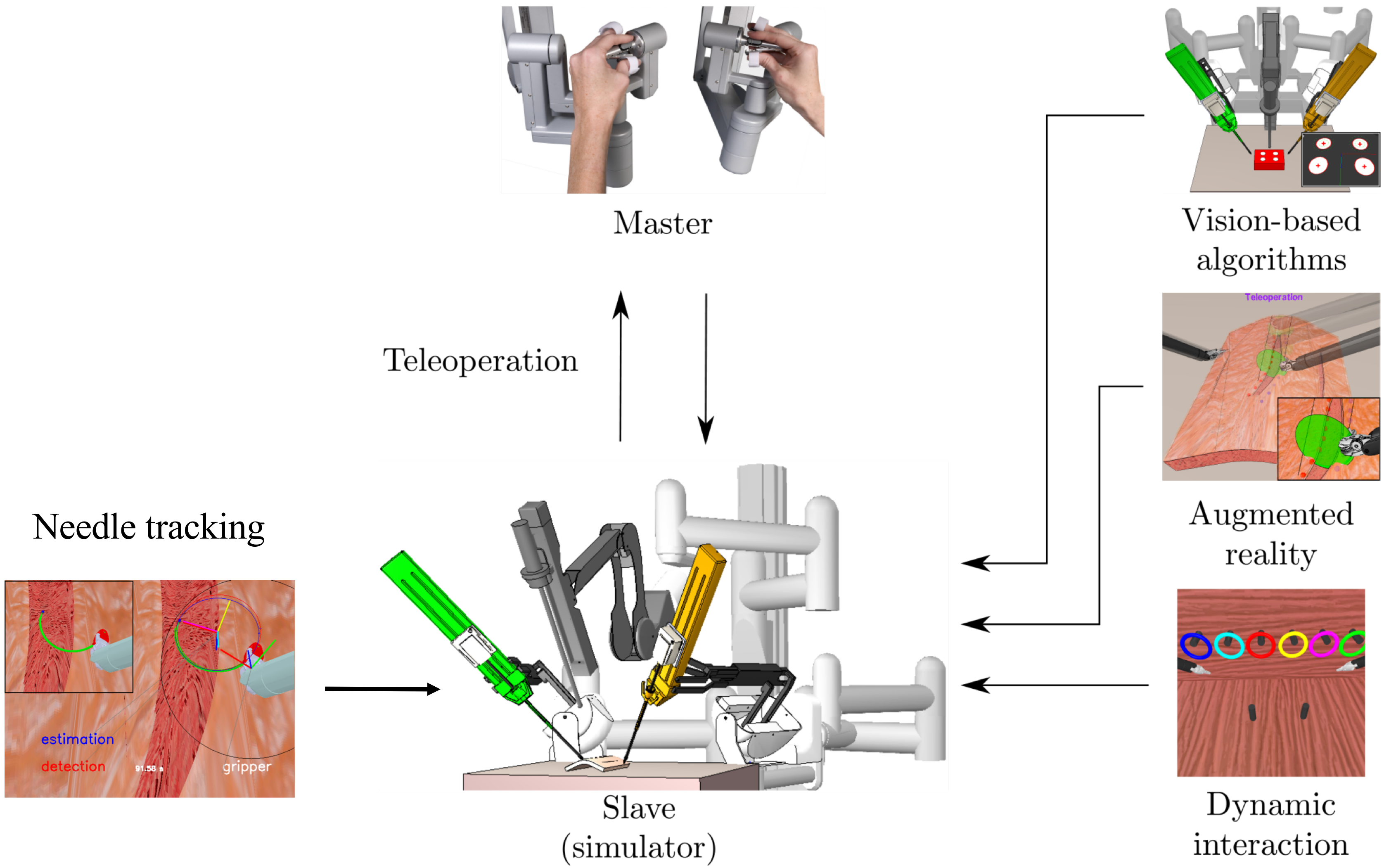
V-REP control architecture

- full integration into the high level ROS framework of the dVRK control infrastructure
- different control modalities:
  - telemanipulated using the dVRK MTMs;
  - in combination with the real robotic PSMs and ECM, to implement augmented reality algorithms;
  - as standalone, by controlling the simulated robot using the ROS framework, (through C++, MATLAB or Python ROS nodes), or directly in V-REP using custom scripts
- cameras topics streamed at 60 Hz*
- joints and objects topics streamed at 220Hz



*The simulation requires to be run in threaded-rendering mode, in order to decouple the rendering and the control scripts and speed up the execution.

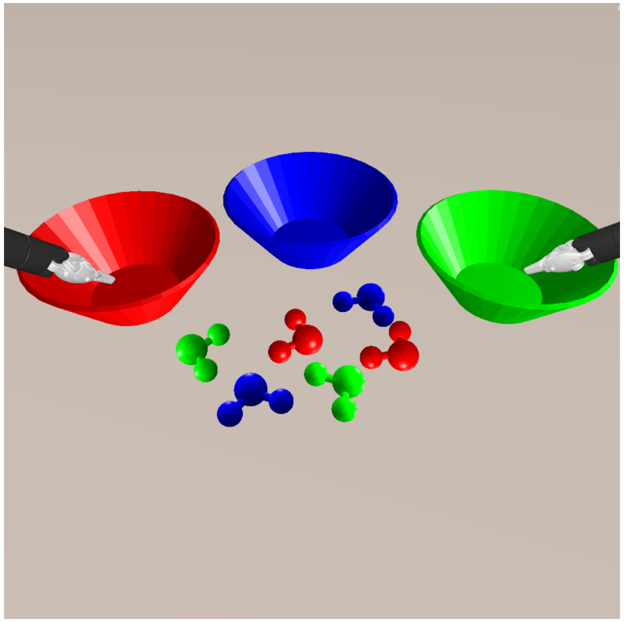
Example scenes



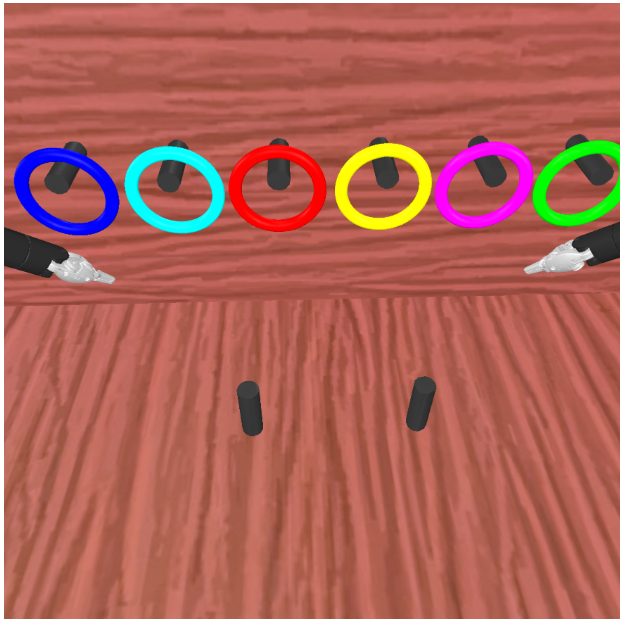
Example scenes: training

- engineers may need to train themselves to develop and test novel control strategies
- contacts and interactions among objects have been simulated by creating respondable and simplified dynamic entities through the embedded V-REP functions
- a proximity sensor between the needle driver pads is used to simulate objects grasping

pick & place



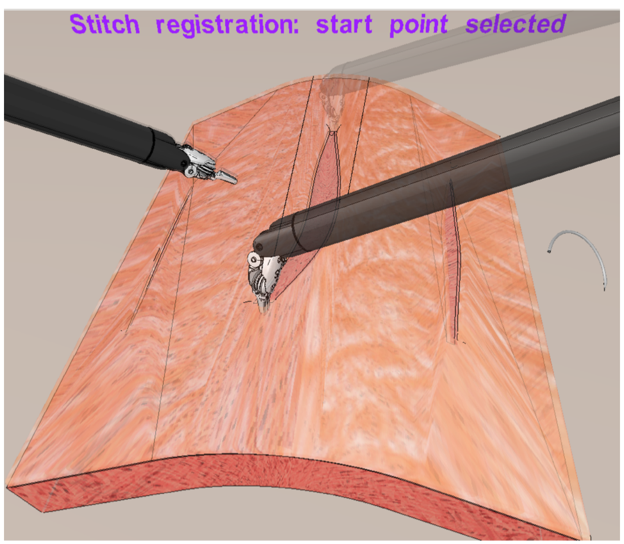
peg on board



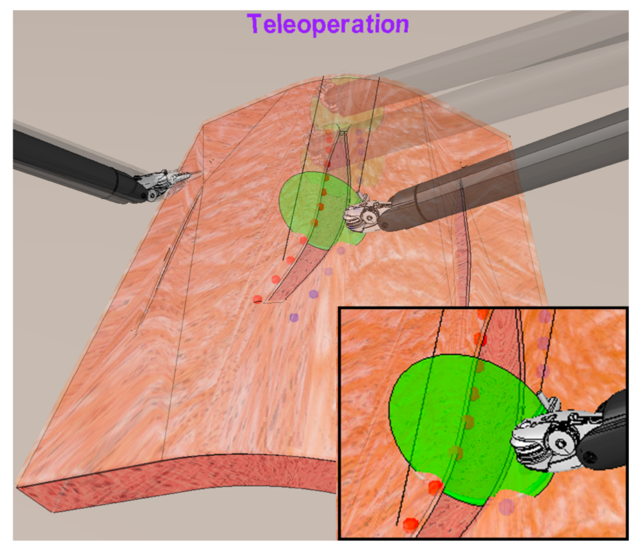
Example scenes: suturing

- a suturing phantom has been designed taking inspiration from real commercial phantoms
- banners and overlayed objects are included to give information through augmented reality

Wound registration



Stitch planning and execution

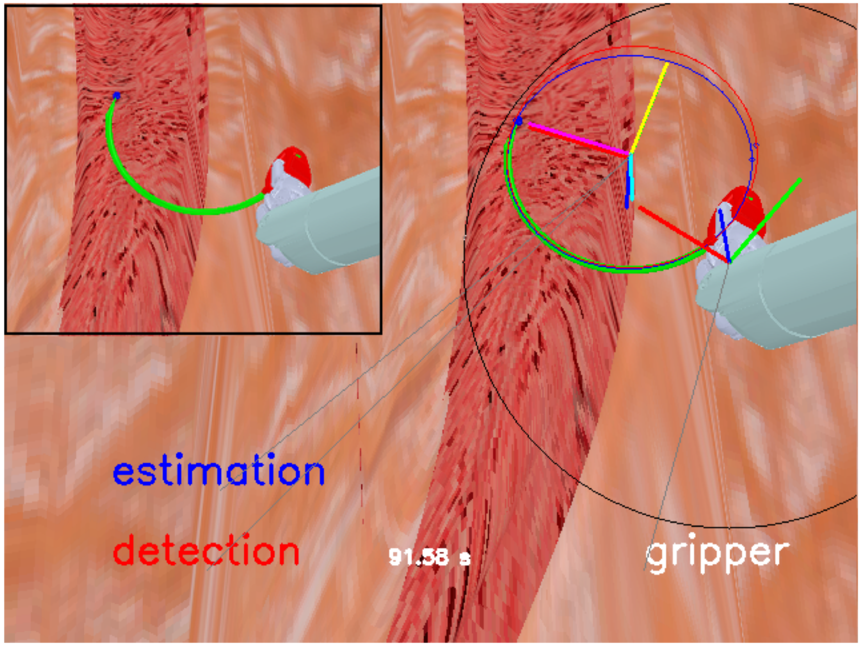


[2] G. A. Fontanelli, G. Z. Yang , B. Siciliano, "A comparison of assistive methods for suturing in MIRS" IROS 2018

Example scenes: needle tracking

- using the simulated stereo-cameras to track a suturing needle
- both the visual information and the PSM arm kinematic information are provided by V-REP

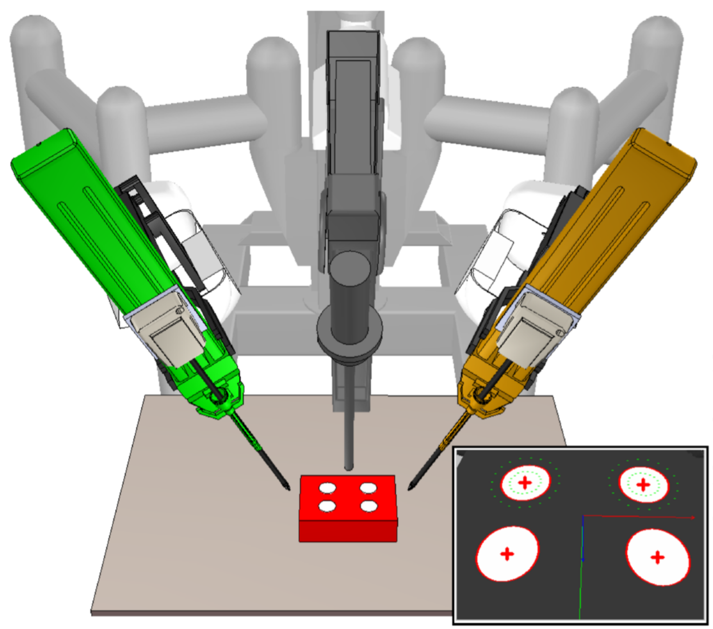
Needle visual segmentation and tracking

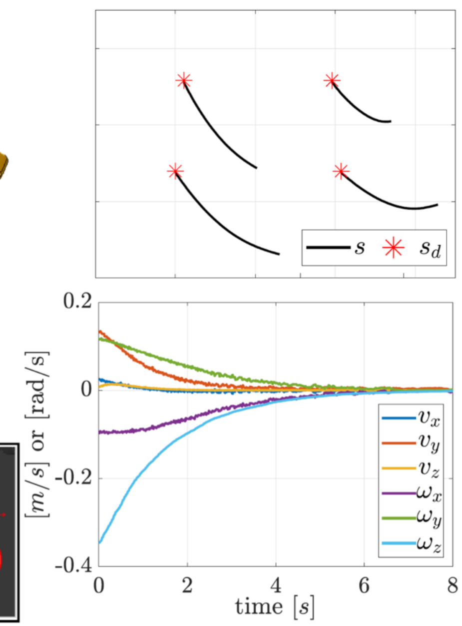


[3] M. Ferro, G. A. Fontanelli, F. Ficuciello, B. Siciliano, M. Vendittelli, "Vision-based suturing needle tracking with Extended Kalman Filter" CRAS 2017

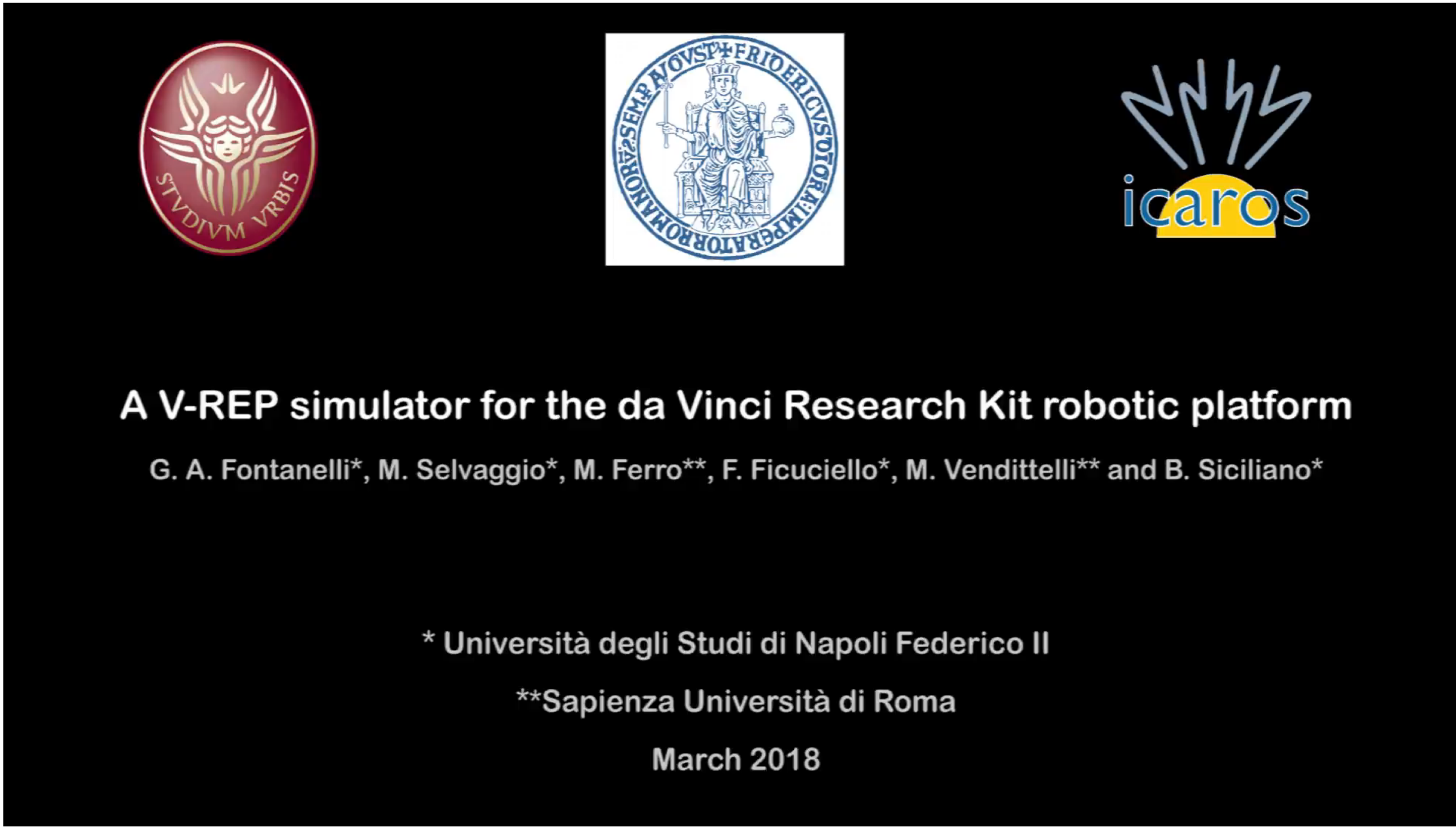
Example scenes: visual servoing

- autonomously regulating the pose of the ECM to track a desided object
- simulated images are streamed through customary ROS topics and are then processed to extract the needed visual features
- both the visual information and the PSM arm kinematic information are provided by V-REP





Example scenes



Future work

- improve the dynamic parameters and the simulation speed
- investigate the integration of deformable objects within V-REP using bullet engine [4] or SOFA [5] to extend the application scenarios

[4] F. Fazioli, F. Ficuciello, G. A. Fontanelli, B. Siciliano, and L. Villani, "Implementation of a soft-rigid collision detection algorithm in an open-source engine for surgical realistic simulation," in ROBIO 2016
[5] F. Faure, C. Duriez, H. Delingette, J. Allard, B. Gilles, S. Marchesseau, H. Talbot, H. Courtecuisse, G. Bousquet, I. Peterlik, and S. Cotin, "SOFA: A Multi-Model Framework for Interactive Physical Simulation," in Soft Tissue Biomechanical Modeling for Computer Assisted Surgery

Thanks for your attention!