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"Smart Autonomous Robotic Assistant Surgeon"

D4.1 – Tasks mapping

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D4.1 – Tasks mapping

Editor
Alícia Casals

Contributors
Albert Hernansanz
Narcís Sayols

Reviewers
All partners

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Executive Summary

The actions performed by the assistant surgeon during the MULTIROBOTS-SURGERY will be mathematically described and parameterized in order to be executed and adapted at run time by the SARAS assistive robotic arms.

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1. Introduction

The role of work package 4 is on the one side, the development of strategies and algorithms for the planning and adaptation of trajectories for robot motion in dynamic environments dealing with moving and deformable tissues and operating within a constrained workspace. On the other side, WP4 aims to develop a multirobot platform in which the various arms cooperate in an optimal and safe way. This context implies the need of modeling the different tasks along a procedure to parametrize trajectories and actions. The goal is to be able to determine the control strategy for the SARAS assistive robots to dynamically adapt to each patient and working conditions at each phase of a procedure without interfering with the main surgeon operation.

Based on the analysis of the interventions considered in the project SARAS, Radical Prostatectomy, RP, and Laparoscopic Nephrectomy, LN (radical or partial), this first step is to provide the means to automate the assistance of the SARAS assistant robots, which in the first SARAS platform are teleoperated by the assistant surgeon. Therefore, the main objective at this step is to be able to distinguish the different phases of a given operating task associating to them a function that gives to each of them a qualitative level of relevance and the data obtained from the instruments, movement and status. Referring to relevance, for instance, in a suturing task, the insertion of the needle is relevant (precision) while the posterior operation of steering the thread once it has traversed the tissue is not critical, that is, have high dispersion in its execution. In its first phase, the relevant task (precision), that is, puncturing at the starting of the suture, the action is launched by the surgeon while the non-relevant task, needle traversing and thread steering, can be performed by the system either automatically or assisting the surgeon.

For an effective Human-Robot cooperation in this context, or for an automatic operation, it is necessary to have available actuation models for each task and operation phase. These models will have to parameterize for each case the required information (anatomy, patient, positions, …). From the simplified analysis of procedures of the two operations considered in SARAS, the subtasks involved are of the type: Holding, Traction, Suction, Cutting, Putting (hemoclip/s), Visualization and Navigation.

In a first attempt, these tasks have been reproduced and monitored in a robotic platform with a synthetic and realistic environment in order to extract the data necessary for their mathematical modeling and parameterization, so as they can be afterwards used to control the assistive robots. The aim was to extract the mathematical formulation for each segment as it has been defined (from analytical functions) their analysis was expected to yield to the extraction of the relevant parameters that characterize each task. However, due to the characteristics of the signals obtained the characterization of the tasks in this way has not been possible, and thus a new approach, based on graphs of states has been developed.

This document describes the criteria for the segmentation of the tested tasks and subtasks, the tried methodologies and the obtained results. These results have oriented the proposal based on simplified models of the movements of each tool along the execution of the different tasks. These models will allow to face the following of the working phases consisting in the robotic assistance to the surgeon or the autonomous execution of the task.

2. Task data acquisition of the procedures subtasks

As a means to experiment in a realistic surgical workspace to emulate the different tasks considered a robotic and surgical scenario platform has been arranged. The aim is to be able to characterize the tasks from a set of repetitions based on the emulation of such tasks, which are expected to be realistic enough to be exploited once the real data sets of interventions are available. We have developed a pad which, although not being a precise reconstruction of the operating zone, allows us to test the different defined tasks. The multi-layer pads contain the different elements necessary for the analysis of the defined tasks, that is, fat, connective tissues for the holding and traction actions, vascular system for hemoclipping and adherences for cutting. Figure 1 shows two views of such pads.

Figure 1 Views of the pads for testing. Left: layered tissues, Right: details of anatomical elements

The platform is composed of:

- a master 6DoF haptic device (Touch) with a new header to control grippers of robotized laparoscopy tools (currently, working with daVinci Tools)
- a 6DoF robot endowed with an articulated instrument
- a holder to handle an assistant instrument acting as the second arm
- a training platform which contains the testing pads and provided with the fulcrum points (i.e. the trocars)
- Software library (RobLib). This library allows the control and supervision of the teleoperation platform together with the visualization of the robots and instruments, control the master devices and the communication between the different modules.

Figure 2 shows the haptic device and the developed end effector.

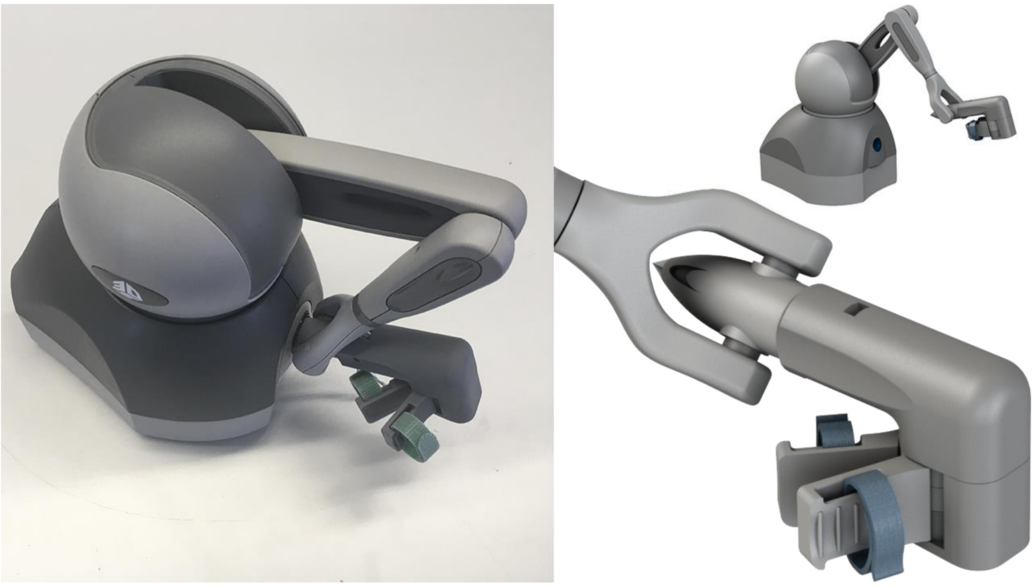


Figure 2 Master station with the haptic device and the developed end effector for the control of the gripper in the slave side.

Figure 3 shows the visualization of the simulated robots for development of the control algorithms. The whole testbed is shown in Figure 4.

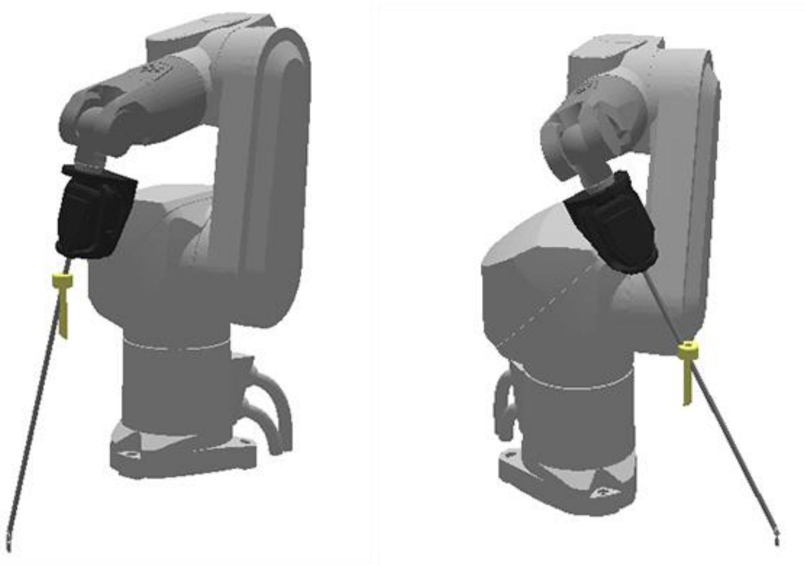


Figure 3 Simulated environment for software implementation

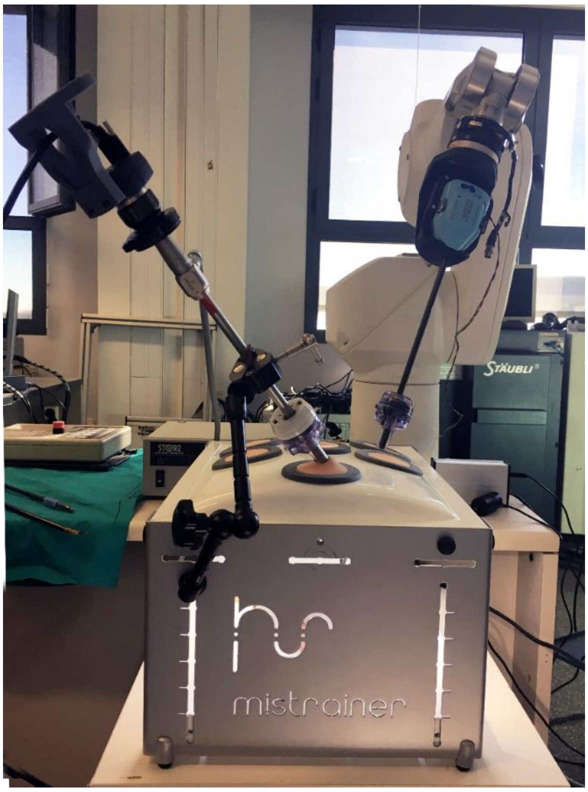


Figure 4 Tested for task data acquisition

A schema of the teleoperation platform integrating all modules for control and communication is shown in Figure 5.

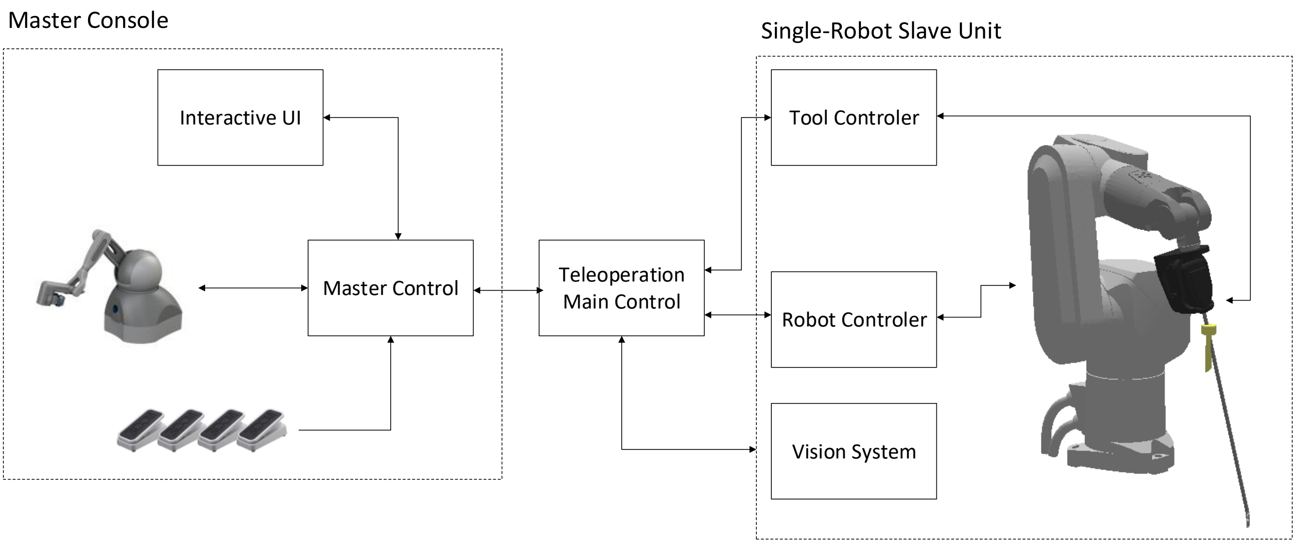


Figure 5 Schema of the testbed platform

From the description of the interventions in WP.1 and based on the observation of videos of the referred interventions, 10 repetitions of the described subtasks have been performed and the registered data has been analyzed for their modeling.

In all cases imitating the trajectories and actions of the reference surgeries, the task has been performed in an adequate scenario. For clamping the action operates over a vein; in the case of suction acting on the hernia following the lateral walls of the well it forms; in grasping a sequence of movements as approaching, picking the tissue, holding it while clutching and then release, and finally, for visualization a generic path has been followed by moving all around the operating frame of the pad making elliptic trajectories moving from the top and down to the bottom.

The trajectories in each case are shown in the following figures and then analyzed. For the task of clamping Figure 6 shows its trajectory. Figure 6(left) shows the 3D movement, while the movements in the three axes and tool status are shown in Figure 6(right). The tool is active in the moment of clamping (pass from Open to Close and open again in the action of grasping a vein). Figure 7 shows the visualization of ten repetitions of this clamping action. In the figure the regions of approximation/depart and clamping can be observed at a glance, but it has not been possible to find a numerical indicator for its parametrization. In the graph in Figure 8 we indicate from these 10 trajectories the four significant zones: approximation, wrapping, clamping and departing. However, this classification has been done based on the knowledge of the actions performed, but not enough information is available for its automatic detection. Form these data there are no evaluators that can distinguish these phases in an unequivocal way.

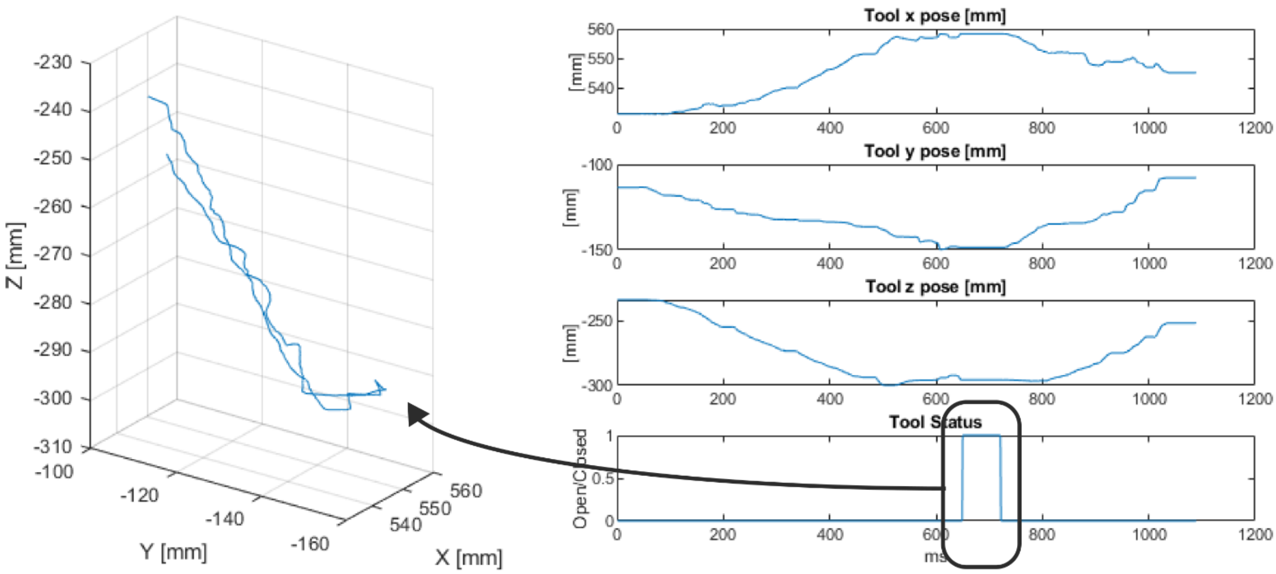


Figure 6 Clamping trajectory. Left: 3D representation, right: visualization of the 3-axis run and clamping action

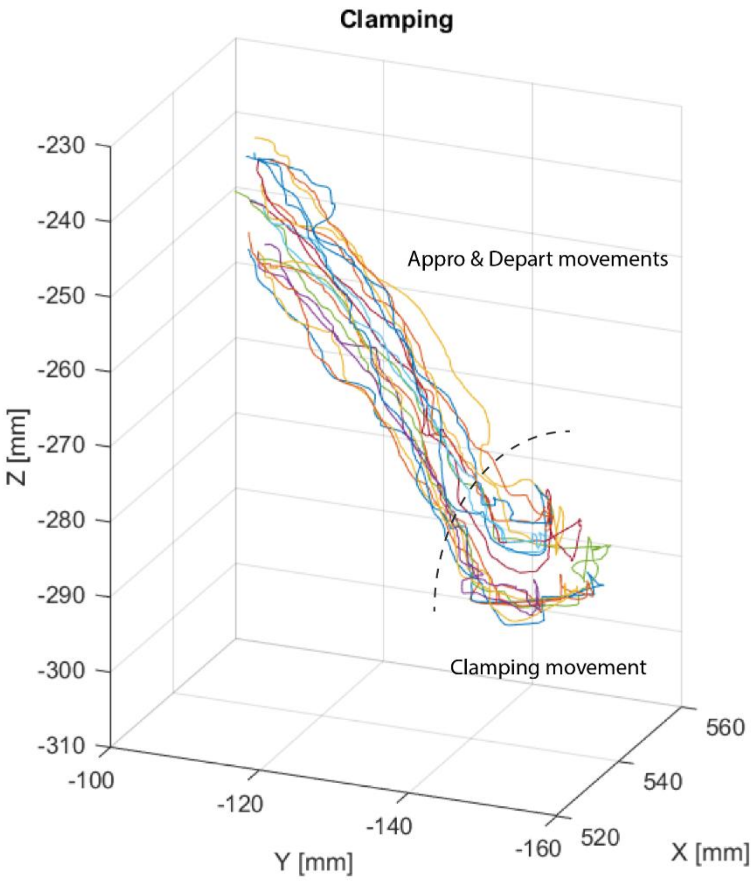


Figure 7 The sequence of clamping: approximation, clamping and depart

In the action of suction, the same situation occurs. The task once performed can be decomposed in three zones. The ripple in z is clearly visualized, but the suction action cannot be clearly distinguished from another movement like approx-depart performed in other tasks. Figure 9 shows the decomposition in the three zones while its 3D representation is shown in Figure 10.

Given the fact that the parametrization is not possible with the available data, a further analysis has been done based on public videos of the mentioned interventions and building a graph of states for their parametrization and modeling. This parametrization is described in Section 3.

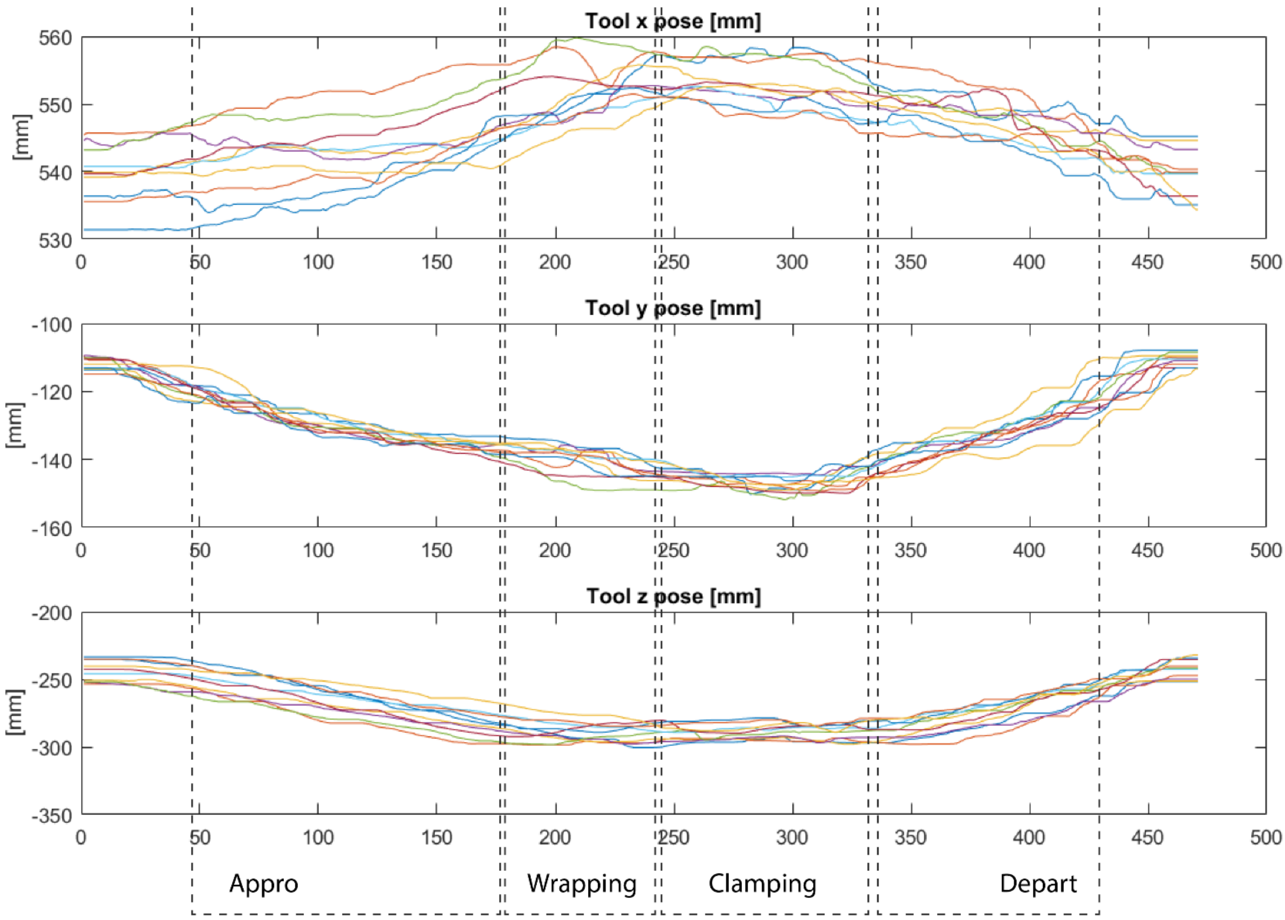


Figure 8 The four steps in the task of clamping

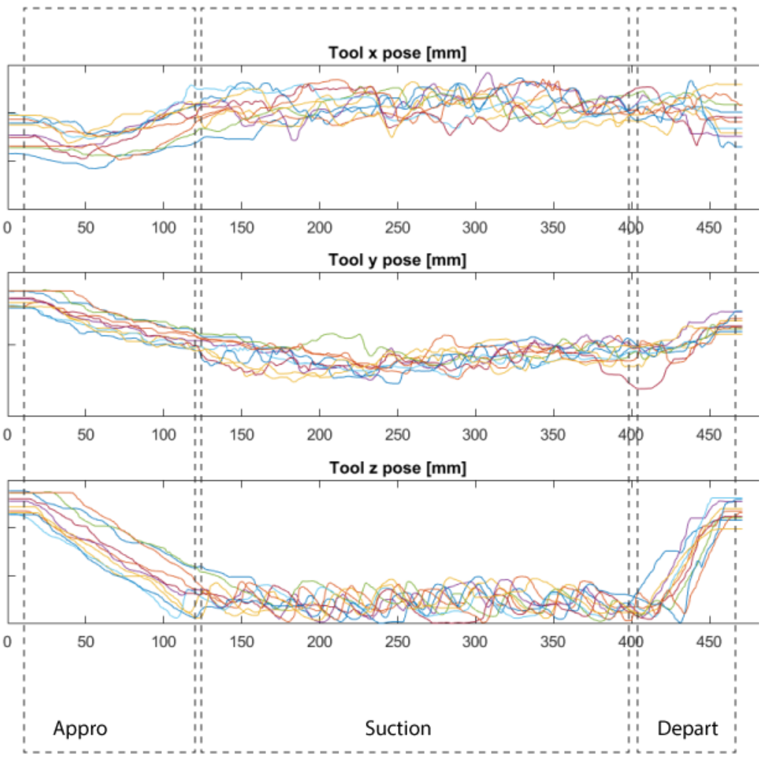


Figure 9 The three steps of a suction process

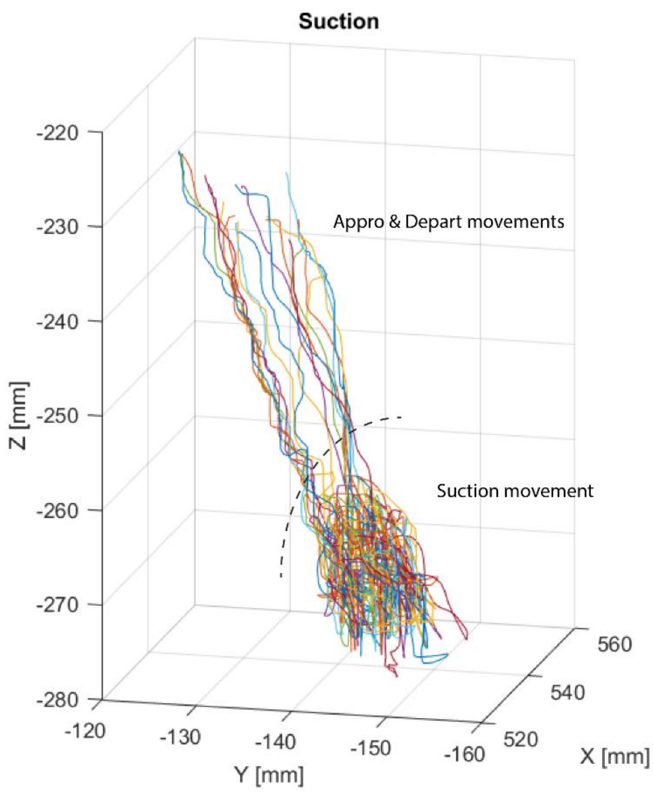


Figure 10 3D representation of a suction process

3. Mathematical formulation for the development of strategies for robot assistance

The problem to face is the identification of the different phases along a surgical procedure and the characterization of each segment to be able to formulate a mathematical model of the whole process and thus parametrize the intervention for the control of an assistant or an autonomous robot. Segmentation and context awareness within each segment along the workflow that determines a surgical intervention does not constitute a new problem. Most studies rely on the automatic learning of the procedure based on large datasets, however the diversity of situations makes difficult to learn in a generic way. Here, a step by step analysis has been done to relate the steps to the available parameters available along the surgery.

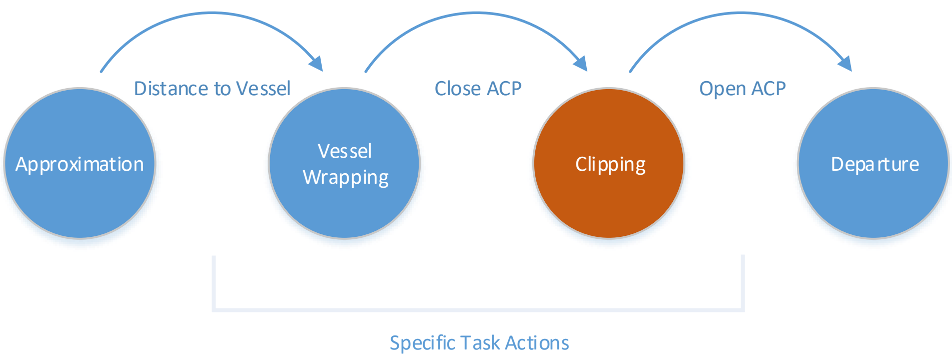
In this section the different tasks involved in the two considered surgeries, RP and LN, are described in the form of graph states identifying the discriminant actions and the instruments involved. Most of the information can be extracted from the instruments in operation, which indicate the launching of the task and thus the start of the controllable part of each operation phase. The previous analysis of instruments' tip poses of the different tasks have provided scarce information in the identification of tasks or subtasks due to the dispersion on the ways to execute a given task and even the similitude of movements in some of them. Therefore, an automatic learning process based on the executed movements of different users appears to be of few relevance. For instance, in hemoclipping vessel wrapping this analysis demonstrates the inadequacy of relying on the analysis of executed movements. First, the region for access and the clipping point can vary significatively, and additionally, the trajectory is like those of other tasks. Also, indexing from this information can be misleading since a pause state can be due to the execution of a precise action or to the need of keeping the instrument still while another action is in course. Consequently, the system has been modeled based on a graph of states.

3.1 *Task: Hemoclipping*

Surgery type: RARP, LRN&LPN

Discriminant: Tool (Automatic Clip Applier)

Action: Close Automatic Clip Applier

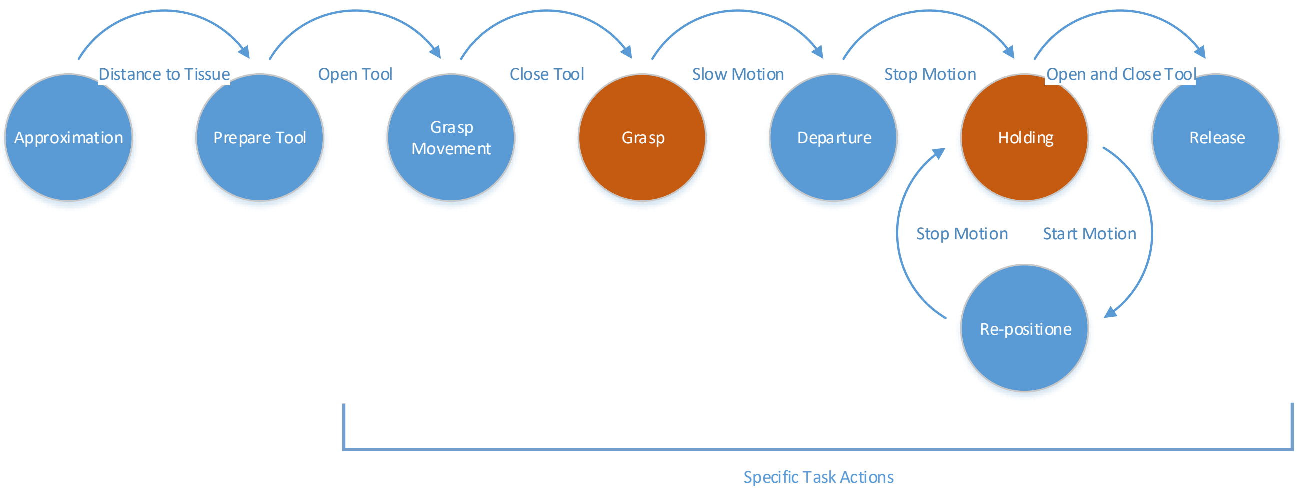


3.2 *Task: Holding/Traction*

Surgery type: RARP, LRN&LPN

Discriminant: Tool (Grasper), Tool Action (Open)

Action: Open tool (prepare tool) followed by close tool (Grasp tissue).

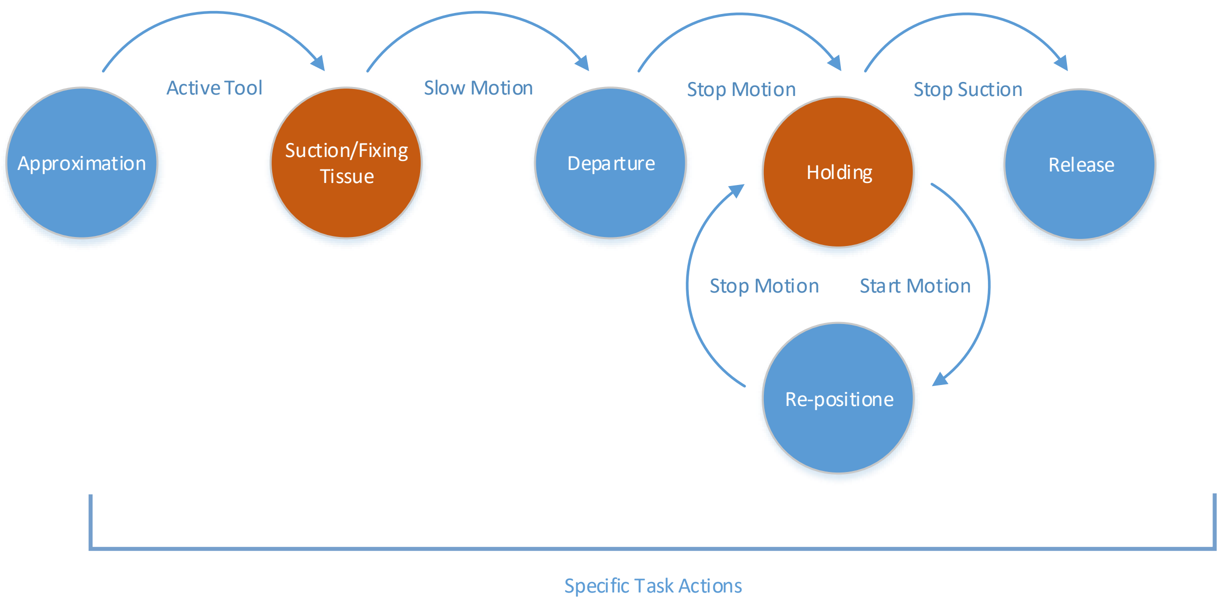


3.3 *Task: Traction/Suction*

Surgery type: RARP

Discriminant: Tool (Irrigator), Tool Action (Suction)

Action: Start suction to fix tissue to the tool tip; stop suction to release tissue



3.4 *Task: Cutting*

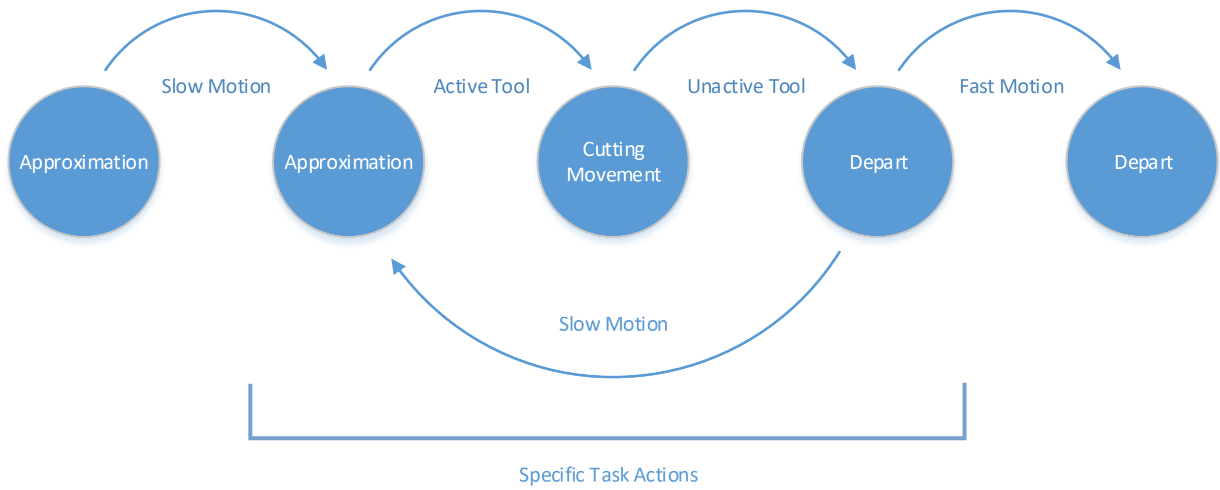
This task has been divided into electro-cutting and physical cut due to the differences on task description, actions and discriminants.

3.4.1 Task: Electro-cutting

Surgery type: RARP

Discriminant: Tool (Scissor), Tool Status (Energized)

Action: Energize tool tip to cut and coagulate.

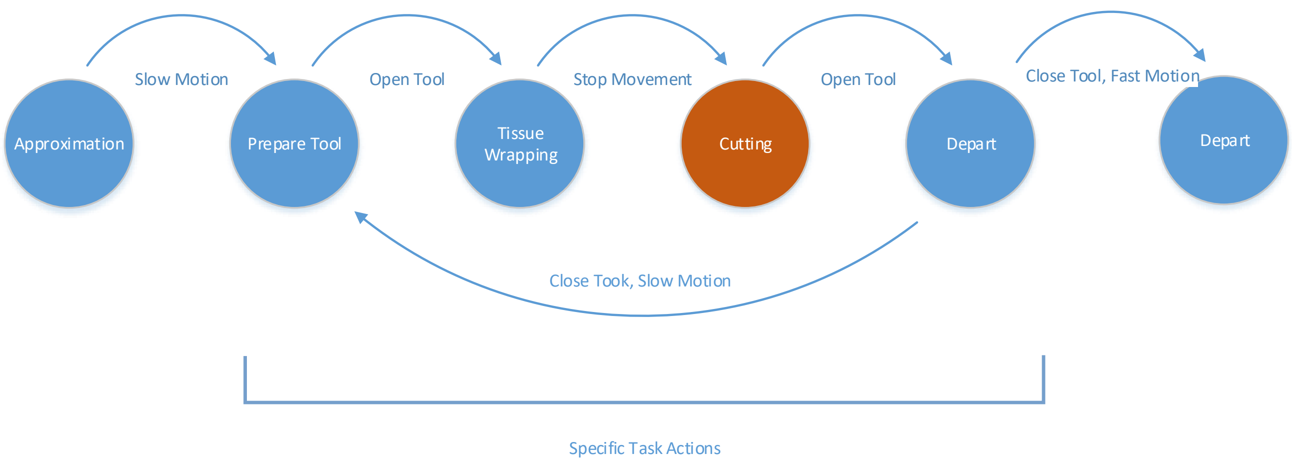


3.4.2 Task: Mechanical Cutting

Surgery type: RARP

Discriminant: Tool (Scissor), Tool Status (Open)

Action: Open tool to wrap tissue, close tool to cut the wrapped tissue

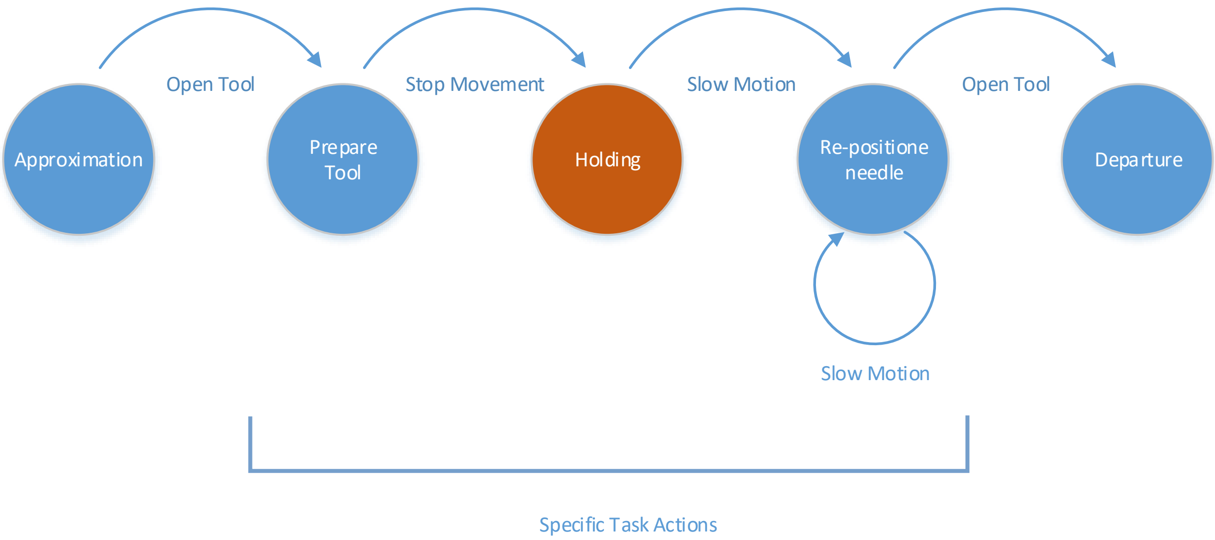


3.5 *Task: Holding Needle*

Surgery type: RARP

Discriminant: Tool (Grasper), main surgeon tool (needle holder)

Action: Assist main task holding the needle when required. Slow motion movements are expected to re-position needle for further main tool re-grasping.

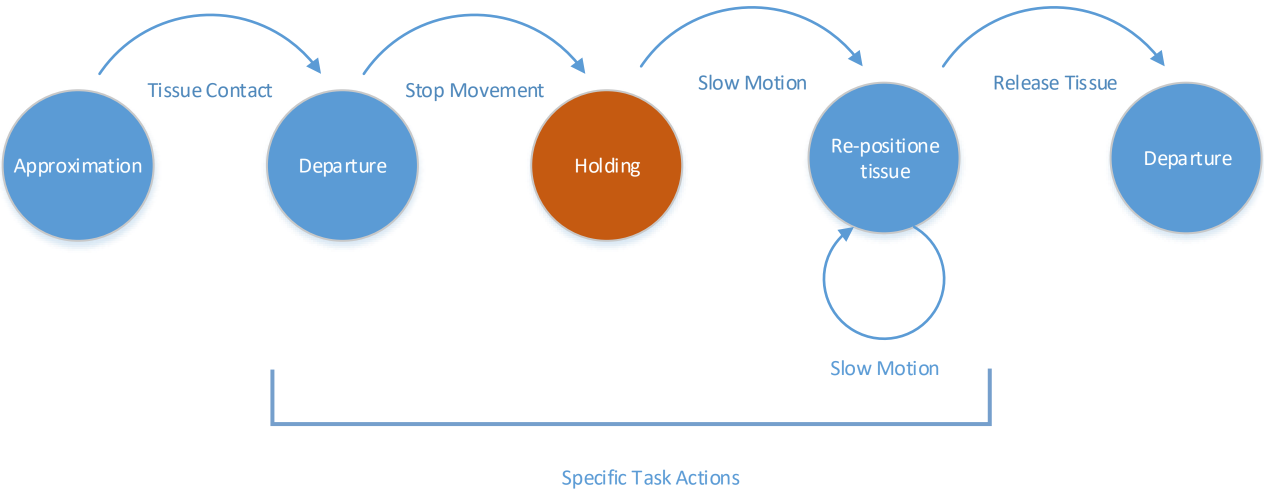


3.6 *Task: Traction*

Surgery type: LRN & LPN

Discriminant: Tool (Grasper), tissue contact

Action: Remove tissues from region of interest to ease the direct vision.



3.7 *Task: Visualization*

Surgery type: LRN & LPN

Discriminant: Tool (Laparoscope)

Action: Visualize region of interest. Smooth and continuous trajectories described by the laparoscope.

3.8 *Task: Movement*

Surgery type: RARP and LRN & LPN

Discriminant: None of previous tasks, tools are inactive/closed.

Action: Generic movements of tool navigation, approximation and depart. Considered as transitions between tasks.

4. Conclusions

Still lacking the videos of the labelled interventions, the modeling of the tasks to be characterized has been done exploiting the kinematics of the basic tasks, analyzing the different movements and actions performed. From this analysis, a graph of states allows the parametrization of all the sequence of the interventions considered in SARAS. The study done over the experimental platform from which the sequences of movements were registered, although not providing a way to model the tasks, has been useful to validate the sequence of actions and movements of the studied sequences of tasks in the two referred interventions.