# Design and Prototyping of a Robotic Assistant For Microsurgery

L. Vanthournhout[1], B. Herman[1], J. Szewczyk[2], B. Lengelé[3], and B. Raucent[1]

*[1]Institute of Mechanics, Materials, and Civil Engineering and the Louvain Bionics, Université catholique de Louvain, lena.vanthournhout@uclouvain.be.*

*[2]Institute for Intelligent Systems and Robotics, Université Pierre et Marie Curie Paris 06 – CNRS.*

*[3]Morphology Research Group, Institute of Experimental and Clinical Research, Université catholique de Louvain, and the Department of Plastic and Reconstructive Surgery, Cliniques universitaires Saint-Luc.*

## INTRODUCTION

Microanastomosis is a surgical gesture that consists in connecting two tiny blood vessels together with a series of stitches (see Figure 1). This gesture is used in many operations such as face allograft, torn member saving or breast reconstruction by DIEP (Deep Inferior Epigastric Perforator). It requires high dexterity and accuracy, and only few microsurgeons are able to perform such challenging gestures on vessels with sub-millimetric diameter. This is due to the tremor magnitude that, even for a skilled microsurgeon, rarely decreases below 100 µm with a frequency ranging from 6 to 15 Hz [1].

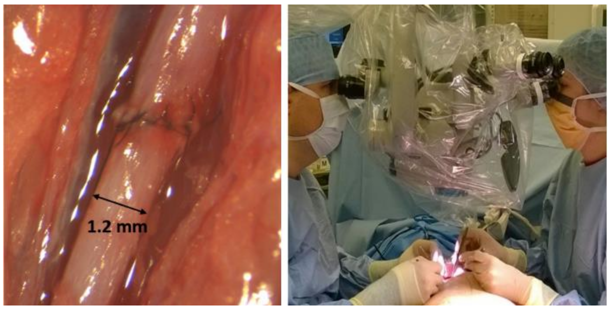



**Figure. 1.** Microanastomosis – Operating field during microsurgery.

In order to increase microsurgeon's accuracy, it is quite obvious to think of robotics. Several solutions use teleoperation for reducing the tremor magnitude, by filtering and scaling motions of the master interface while offering similar dexterity as the human hand, required for complex movements. Examples of telesurgery systems used in microsurgery include the Da Vinci, RAMS, MSR or a neurosurgery robotic platform from Tokyo University (references can be found in [2]). However, if these systems increase the surgeon's precision, they also induce a longer operation duration by slowing down the movements. But time is an important factor to reduce ischemia time of the tissue and prevent necrosis. The aforementioned systems only offer a fixed or a manually adjustable scaling ratio that is usually set as a compromise between speed (low ratio) and accuracy (high ratio).

This paper introduces the design of a first prototype of a teleoperated robot devoted to microsurgical gestures. Firstly, the needs analysis is summarized and the robot topology selection is explained. Optimization of the robot geometric parameters is then presented, so that it matches the specifications under several important constraints. Finally, the first prototype is described. Our final goal is to use this prototype in the near future to implement and compare several control schemes capable of (semi-) autonomously adjusting the motion reduction factor during gestures.

## ROBOT SPECIFICATIONS AND TOPOLOGY

In order to quantify the required workspace, velocity, and acceleration of the slave robot, surgeons' movements study were recorded while performing dissection and microanastomosis on a rat. The procedure and the results are reported in minute details in [3] and [2]. The specifications are summarized in Table I.

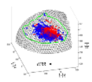
| | Workspace | Velocity | Acceleration |
|---|---|---|---|
| Translation | 40x50x40 mm | 100 mm/s | 1000 mm/s² |
| Own rotation | > 360 ° | 74 °/s | 520 °/s² |
| Transversal rotation |  | 28 °/s | 240 °/s² |

**Table. I.** Robot Specification.

The robot topology was chosen subsequently to decouple translations from rotations. Indeed, if the positioning accuracy must be high (~10 µm) to achieve good quality anastomoses, the orientation accuracy does not need to be better than with a human hand. The robot is therefore made of 3 orthogonal linear axes followed by a spherical wrist allowing the tool orientation (see Figure 2).

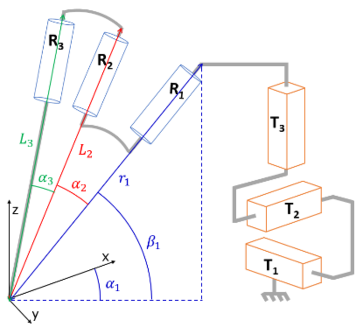
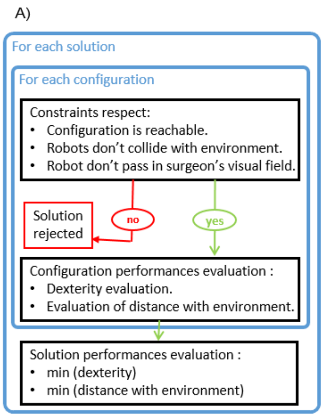



**Figure. 2.** Robot topology and geometric parameters of the spherical wrist to be optimized.

## GEOMETRIC PARAMETERS OPTIMISATION

In order to make the robot fit at best the requirements and also the surgical context, an optimization procedure was performed to compute the best values for the 7 parameters of the spherical wrist (see Figure 2). The optimization algorithm systematically explores all the feasible geometric solutions by varying each parameter (see Figure 3B). Each solution is then evaluated with respect to three constraints and two objectives described in Figure 3A. Pareto front of the best solutions is depicted in Figure 3C. The chosen solution corresponds to good balance between a dexterity of 0.14 and a minimal distance to environment of 28.7 mm. Indeed, it is important that the robot remains far from microscope and patient to avoid any collision if the expected environment is slightly modified, and also to take into account the volume of motors and mechanical structure. A good dexterity is also required to reach all directions with the specified instrument velocity and acceleration without too high jumps in velocity and acceleration at motors.




B)

| | First optimization: large range and rough step | | | Final optimization: small range and fine step | | |
|---|---|---|---|---|---|---|
| | **Min** | **Step** | **Max** | **Min** | **Step** | **Max** |
| $r_1$ [mm] | 100 | 20 | 220 | 175 | 5 | 230 |
| $\alpha_1$ [°] | -80 | 2 | 80 | -68 | 1 | -56 |
| $\beta_1$ [°] | 40 | 2 | 80 | 51 | 1 | 61 |
| $L_2$ [mm] | 100 | 20 | 220 | 150 | 5 | 230 |
| $\alpha_2$ [°] | 20 | 2 | 60 | 45 | 1 | 50 |
| $L_3$ [mm] | 100 | 20 | 220 | 90 | 5 | 190 |
| $\alpha_3$ [°] | 20 | 2 | 60 | 42 | 1 | 53 |

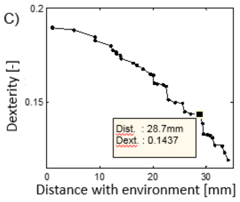



**Figure. 3.** Optimization scheme and results.

## PROTOTYPE DESIGN

Based on these optimization results, a prototype was designed and built. The Cartesian table consists of 3 linear axes (Newport M-ILS100CC) with a stroke of 100 mm and a resolution of 1 µm. The first spherical wrist axis actuated by a DC-motor (Faulhaber 2657 W012 CR) with a planetary gearbox (26/1 S, 23:1), mounted perpendicularly to the R1 axis by means of a helical gear. On the main R1 shaft is mounted a high resolution encoder (7500 pulses/rev.). Axes R2 and R3 are made of DC motors (Faulhaber 2232 U012 SR and 1224 E 012 SR) with backlash-free planetary gearbox (22/5 69.2:1 and 12/5 69:2). Both motors are equipped with encoders (1024 and 100 pulses/rev.) and aligned with the R2 and R3 axes respectively, allowing to know the wrist orientation with the required precision. Indeed, this precision is needed to counterbalance by software the possible fabrication inaccuracies and play in the spherical wrist that could induce an unwanted linear movement. Finally the robot is controlled with a 6 DOF joystick (Phantom Omni) through a computer running on Linux and interfaced with a Technosoft control board. A picture of the current system robot is shown in Figure 4.

**Figure. 4.** Prototype.

## FUTURE WORK

The mechanical performances of the prototype are currently being assessed. The geometric model of the robot will then be calibrated to take into account mechanical inaccuracies. A symmetrical prototype will then be built for bimanual telemanipulation. Finally, future work will be devoted to the implementation and comparison of specific teleoperation schemes, aiming at overcoming the traditional opposition between gesture accuracy and speed of motion thanks to adaptive strategies for adjusting the scaling factor in real time.


## ACKNOWLEDGEMENT

This work was supported by own funds from UCL and ISIR, and by the F.R.S.-FNRS. Authors are grateful to Jérôme Dusit, François Château, and all members of microsurgery teams of Cliniques universitaires Saint-Luc who took part in discussions and experiments. Authors would like to thank all colleagues from the CEREM and ISIR for their help and support in this project.


## REFERENCES


[1] K. Veluvolu and W. Ang, "Estimation and filtering of physiological tremor for real-time compensation in surgical robotics applications," The International Journal of Medical Robotics and Computer Assisted Surgery, 2010; 6(3):334–342.

[2] L. Vanthournhout, B. Herman, J. Duisit, F. Chateau, J. Szewczyk, B. Lengele, and B. Raucent, "Requirements analysis and preliminary design of a robotic assistant for reconstructive microsurgery," in Proceedings of the 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2015:4926–4930.

[3] L. Vanthournhout, B. Herman, J. Duisit, F. Chateau, J. Szewczyk, B. Lengele, and B. Raucent, "Toward user-friendly robotic assistance for enhancing accuracy and safety of reconstructive microsurgery," in Proceedings of the 4th Joint Workshop on New Technologies for Computer/Robot Assisted Surgery (CRAS), 2014:104–107.