THE INSTITUTE OF INTELLIGENT SYSTEMS AND ROBOTICS*

PhD OFFER

Subject : "Towards automated pedicle screw placement in spinal surgery using robotics and multimodal control"

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Context

There are many spinal pathologies and they can be classified into four main groups: degenerative (e.g. herniated discs, narrow lumbar canal), traumatic (e.g. dislocation and fractures), spinal deformities (scoliosis and kyphosis) and primary or secondary tumor lesions. These pathologies can lead to significant functional repercussions (pain) or even a severe handicap that can lead to paralysis of the limbs (paraplegia or tetraplegia). Some pathologies are treated conservatively (medication and rehabilitation) but, for serious cases, surgery may be necessary. The number of spine surgery procedures is steadily increasing, both for trauma-related cases (Kumar, 2018) and for degenerative surgery indications due to the aging population (Ravindra, 2018). This increase in activity creates a need for innovations that will involve the introduction of new technologies in the operating room.

Among the main issues in spine surgery are safety and precision. Poorly positioned pedicle screws can lead to bone or disc damage, which threatens the stability of the surgical fixation. More rarely, the injury may be vascular or nervous, with a risk of neurological or even life-threatening complications.

Advances in the use of preoperative and intraoperative imaging coupled with three-dimensional navigation systems have led to significant improvements in surgical protocol. Indeed, some common spine surgery procedures such as pedicle screw placement require further scientific and technological innovation. Pedicle screw placement can be made more difficult, especially in patients with severe spinal deformity (such as scoliosis), osteoporosis or tumor. The literature reports that approximately 20% of pedicle screws are malpositioned (Mason, 2014), implying neurological symptoms in the medium term that can often lead to a second surgery with all the risks and cost that this entails (Verma, 2018). It is in this context that robots have entered the operating room for several years.

Currently, these robots are used to materialize the guidance calculated by a navigation system.

**The Institute of Intelligent Systems and Robotics (Isir) is a Joint Research Unit (UMR7222) under the supervision of Sorbonne University, The French National Centre for Scientific Research (CNRS) and Inserm (ERL-U1150). This multidisciplinary research laboratory brings together researchers and teacher-researchers from different disciplines of Engineering and Information Sciences as well as Life Sciences.*

Thus, rather than having the planned drilling axis appear in a 3D recalibrated image, a physical drilling guide is placed in the surgical environment, opposite the vertebra, by the robot. The procedure remains manual, guided by the robot, under the surgeon's control.

These devices, whose principles were first introduced almost 30 years ago (Lavallee, 1992), in the early days of surgical robotics, suffer from the same limitations as navigation systems:

- installation is time-consuming and tedious and increases the duration of the operation,
- registration is mostly done by means of dosing X-ray imaging,
- the images do not allow for a fine representation of the anatomy (bone density, invisible structures, resolution),
- the geometric errors of the robot's sensors, tracking systems, imaging and instrument deformation combine to produce significant positioning errors,
- the gesture itself induces deformations in real time that affect the registration.

For all these reasons, the accuracy of robotic systems is not significantly better than navigated manual placement (Yu, 2018).

In this context, this doctoral research project aims to significantly improve pedicle screw placement using robotic solutions through the integration of sensor-equipped surgical instruments, real-time multimodal data processing algorithms, and robotic control schemes that incorporate this data.

Scientific objective

Our objective is to get out of the paradigm of semi-autonomous surgical robotics dominating for 30 years the robotization of orthopedic surgery and based on the triptych imaging (dosing) - planning - registration. For this, it is necessary to be able, from a geometrical configuration and an initial plan, to adapt in real time the behavior of the robot: speeds, forces, impedances, etc. We will evaluate the possibility of integrating different local sensors: visual, force, electrical impedance (DSG technology from SpineGuard). With all these signals, our objective is to learn to detect events imposing changes or adaptations of behavior (unsuitable trajectory imposing to modify the direction of insertion).

The scientific objectives are therefore:

- in the processing of multi-physical signals and their fusion, by means of Artificial Intelligence, to detect model breaks; for example, we plan to fuse the electrical impedance signal and an estimate of the mechanical impedance to determine the nature of the tissue (cancellous bone, cortical),

- in the programming of reactive behaviors of the robot adapted to these signals and to the mechanical interaction with the surgeon and with the tissues. For example, we plan to program an adaptive impedance that will allow precise manual pre-positioning of the instrument tip while finely adjusting the orientation of the penetration axis. We will also try to work on the realization of a precise drilling of mobile parts, as the vertebrae are. Thanks to models and sensors, we will be able to estimate the deformations and mobilities in real time in order to adapt the behavior (force / speed / impedance) and improve the precision.

In addition, we will simultaneously design the robotic system, composed of one or two arms Kuka (available at ISIR) and the associated surgical process. It is on this crucial point that the interaction between the two research teams is crucial. The aim is to design a scenario that minimizes installation time and maximizes the medical service rendered. The design of the control and dialogue interfaces is a critical point that we will be able to address by relying on the expertise in Human-Machine Interface (HMI) of colleagues from ISIR.

Suitability to the University Institute of Health Engineering (IUIS)

The supervising team will be composed of Brahim Tamadazte (CR-HdR, CNRS, ISIR) and Raphaël Vialle (PUPH, Orthopedic Surgeon, APHP, Institut Univ. de Chirurgie du Rachis, IUCR, Hôpital Trousseau). The more global framework of this work includes an industrial partnership (CIFRE thesis directed by Guillaume Morel and ending in 2021) with the company SpineGuard (www.spineguard.com) which develops innovative instruments for spinal surgery. One patent has already been issued and two others are in the process of being filed, which secures the feasibility of transferring the results to clinical practice. An EU H2020 project - FAROS, takes up part of these themes but the clinical team of this project is Swiss and the interactions are more complex.

The present thesis aims at involving Prof. VIALLE's surgical team in this vast project and thus to be able to make full use of the complementarities of engineering - surgery expertise within Sorbonne University, in a fast loop.

The rapprochement was undertaken this year, with the recruitment at ISIR, thanks to the support of Labex CAMI, of an orthopaedic surgeon from Prof. Vialle's team, Dr. Elie Saghbiny. This work makes it possible to collect data in the OR, which will be very valuable for the design of AI algorithms for tissue characterization.

It is envisaged, during the course of the thesis, to recruit another intern who will be able to work in pair with the PhD student to maximize the impact of the research on the clinical level thanks to a realistic approach to the application. This model has already been practiced by ISIR and its clinical partners for many years and has been widely proven to be translational (Endocontrol, Koelis, GEMA, Base Camp Vascular, Moon Surgical, GE Healthcare are either commercializing or in the process of commercializing medical devices resulting from this research model at ISIR).

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