POLITECNICO DI MILANO

PhD in BIOINGEGNERIA / BIOENGINEERING - 39th cycle

PNRR 118 PA Research Field: MIXED REALITY TECHNOLOGIES FOR PRE- AND INTRA-PROCEDURAL SUPPORT IN NEUROSURGERY

Monthly net income of PhDscholarship (max 36 months)
€ 1400.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	In neurosurgical procedures, it is crucial to optimize the access to the brain as well as the route to the target structures when these are located deep in the brain. The route should be identified to avoid harming healthy tissues and vascular damage. The access should be positioned consistently with the identified route while coping with anatomical constraints, and minimizing its dimensions reduces complications. To these aims, pre-procedural imaging, acquired through computed tomography (CT) or magnetic resonance (MR) depending on the specific procedure, is exploited to plan interventions. Yet, position and dimensions of the access are intraoperatively defined usually relying on paradigmatic anatomical landmarks localized freehand on the patient's head. Errors in this process impact the feasibility of the planned trajectory as well. On this basis, this research proposes the development of a computational tool to support neurosurgeons pre-operatively, i.e., in the planning phase, and intra-operatively, i.e., when drilling the intracranial access through the skull and then defining the route to the target structure. The tool will be based on two technologies: mixed-reality (XR) to visualize the holographic 3D reconstruction of relevant tissues and to navigate them, and artificial intelligence (AI) to segment pre-procedural images to yield high-fidelity 3D anatomical reconstructions through a fast and operator-independent process.

Methods and techniques that will be developed and used to carry out the research	Three technological pillars will be developed: 1. AI-based segmentation of intracranial anatomical structures, skull and skin (including the patient's face) from pre-operative CT scans or MR imaging. Neural networks with different architectures (e.g., 3D UNET to segment ventricles and Attention-gated U-Net to segment tumors) will be trained and tested against manual annotations by expert operators. Other automated image processing methods, e.g., recursive thresholding, will be developed to detect specific anatomical structures that may not be efficiently segmented by neural networks. 2. XR-based applications allowing for the following pre-procedural functions: i) virtually navigating the 3D rendering of the reconstructed anatomies, ii) superimposing the visualization of the 3D rendering and of the pre-procedural images; iii) performing quantitative measurements on the 3D reconstructions, iv) defining and storing (for the subsequent intra-procedural use) the intracranial access and the route to the target. Volume rendering techniques such as ray marching will be exploited to allow for functions i) and ii). To make their performance acceptable in terms of rendering frame rate, solutions to reduce the XR headset computational workload will be identified and tested. 3. Markerless hologram-to-patient intra-procedural registration for the alignment of the holograophic 3D reconstruction onto the patient's head during the procedure. We envision the use of a depth camera to reconstruct a point cloud of the patient face, which will be the target in a registration algorithm based on an iterative closest point method. The depth camera may be the one embedded in the XR headset only, or it may be complemented by an external depth camera fixed in the 3D space of the operative room. When developing and preliminarily testing the developed technologies, ad hoc in vitro phantoms will be designed, implemented, and used. This will consist in the 3D-printed replicas of real anatomies and will allow for mimicking the real procedure with and without the support of the XR-

	based application, possibly in a blinded fashion, as well as for quantifying the differences in the performance of the operator in the scenarios. The activity will benefit from ongoing collaborations with clinical centers (e.g., IRCCS Istituto neurologico Carlo Besta in Milano and Policlinico Universitario Agostino Gemelli in Roma) to collect and manually annotate clinical imaging, and to test the developed technologies.
Educational objectives	The main educational objectives of the project are: - Acquiring a sufficiently deep understanding of brain anatomy and pathophysiology, as well of neurosurgical procedures - Becoming proficient in AI-based image processing - Becoming an expert in XR-based technologies - Mastering the experimental validation of computational tools
Job opportunities	AI and XR are becoming more and more ubiquitous in many applications, including biomedical ones. After finishing the PhD, the successful candidate will have job opportunities in Academia/ Research Institutes/Healthcare structures where the acquired skills could be applied for educational, research, training and planning purposes; opportunities are envisioned also in companies developing software for the segmentation of clinical imaging, in companies developing tools for pre- or intra-procedural support not necessarily limited to neurosurgical applications, as well as in companies developing human-machine interfaces in the context of robotics.
Composition of the research group	1 Full Professors 1 Associated Professors 1 Assistant Professors 3 PhD Students
Name of the research directors	PROF EMILIANO VOTTA

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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

National Operational Program for Research and Innovation	
Company where the candidate will attend the stage (name and brief description)	IRCCS Istituto neurologico Carlo Besta
By number of months at the company	6
Institution or company where the candidate will spend the period abroad (name and brief description)	Medical University of Vienna - Center for Medical Physics and Biomedical Engineering
By number of months abroad	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
The PhD student will be involved in educational activities along with teaching assistantship. A shared desk and computer will be given to the student for the time needed to carry out the research.