PhD Topic: Creation of the Digital Twin of the Operating Room (OR-Twin)

Surgical and Interventional Procedures of the Future | Équipe ICARE | Inserm, Université Cote d'Azur

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Keywords

Digital twin, signal processing, AI, operating room, risk management, healthcare improvement.

Context

Surgery represents a strategic area for improving practices with high potential to reduce risks and complications, provide higher quality patient care, and enhance the working conditions of surgical teams. According to the French National Authority for Health (HAS) report, 1,187 serious adverse events associated with care (EIGS) per million inhabitants were recorded, and half of these could be avoided (HAS, 2019). In operating rooms (ORs), such events account for 17%. In industrialized countries, they are one of the leading causes of mortality and represent a significant societal cost. Preventing these events from the initial stage of care and optimizing safety in the OR have therefore become major healthcare and economic priorities.

Surgical activity in the OR is particularly demanding both technically and cognitively for surgeons and their teams due to the increasing complexity of procedures, time pressure linked to activity-based financing (T2A), and the necessity for rapid decision-making. These constraints, coupled with inadequate (sometimes counterproductive) organizational practices, contribute to burnout among surgical teams and directly or indirectly compromise patient safety. Currently, the only accessible trace of events that occur in the OR is the surgical report, usually limited to a non-standardized A4 sheet. However, this document is only a narrative summary and does not adequately reflect the complexity of interactions, hazards, and risk factors that may occur during a procedure.

In this context, the proposed PhD project aims to develop an innovative strategy to evaluate the efficiency and quality of surgical care. This strategy is based on data science, combining the acquisition of multimodal/heterogeneous surgical data with artificial intelligence. Although this approach has been studied extensively in simulation (Tolvanen, et al.), there are currently no practical, integrated, or deployable applications. Furthermore, significant gaps remain in identifying risky practices and in defining performance indicators and measures, which limits opportunities for improvement, training, and evaluation. This is why the project takes a strongly applied approach: based within a real orthopedic and trauma surgery OR, it aims to develop predictive models and solutions adapted to the concrete needs of surgical teams.

The digital representation of the OR environment and its actors is key to identifying risky situations, events, and behaviors to optimize their management during surgery. In a complex and highly technical environment, OR safety requires the simultaneous management of numerous flows (material resources, human resources, technical environment, etc.) to ensure smooth surgical procedures. This project aims to centralize and process, in real-time, the critical signals from the OR ("making the operating room speak"). To build a reliable and functional digital model, it is essential to capture all data that could potentially impact surgical safety: environmental data (staff and equipment flows, OR conditions, door openings), patient data (monitoring, medical history), surgeon data including stress indicators (heart rate, mental workload questionnaires, eye tracking and pupillometry, etc.), and intervention-related data (procedure type, anesthesia, etc.). The challenge is to anticipate risks by integrating all human, technical, and organizational factors into a dynamic model of the OR.

This project will be developed within the ICARE team (Artificial Intelligence, Computer Science & Augmented Surgery, Data Reuse and Multiparametric Evaluation – Inserm U1091, UniCA at IBV) and the surgical facilities of the University Institute for Locomotion and Sports of the University Hospital of Nice. The ICARE team operates at the interface between R&D activities involving researchers, engineers, and industrial partners, and applied activities carried out by surgeons on test platforms (anatomy lab, augmented OR, simulators) and in real-world OR contexts. ICARE develops 3D bone models (segmentation, reference systems, clinical measurements) to provide reliable and automated preoperative models for treating bone fractures and osteoarthritis, as well as a digital twin of the OR. The laboratory's strategy is to create automated digital models, notably using machine learning and AI tools, for use in diagnostics, decision-making, and surgical procedures. To assess their usability through different application tools, the lab conducts stress tests under real conditions and develops multiparametric usability matrices for digital solutions. The lab's activities are part of a 360° evaluation of digital tool usage in the OR to ensure continuous feedback and performance assurance. Human factors are taken into account, whether subjective (mental workload, situational awareness, or acceptability) or objective (heart rate, sweating, etc.), during the procedure to develop indicators that predict the usability and acceptability of digital surgical devices.

Methodology and Expected Results

The PhD project aims to develop a digital model integrating heterogeneous data from various sources in the OR to analyze human and material flows, detect risky or unusual behaviors, and optimize OR organization. Within this context, the project will combine the dynamics of surgical procedures, the cognitive state of the surgical team, and artificial intelligence.

In the first phase, the student will configure the sensors in the OR and reconcile heterogeneous signals from various sources involved in orthopedic or trauma surgery. To do this, the student will build a database to identify, collect, and centralize the necessary project data. The team is already equipped with a 360° camera, an eye-tracking system, video recordings of the surgical procedure (direct filming and arthroscopic video feed), and a device for recording heart rate.

In the second phase, the student will propose signal processing and data fusion algorithms to reconcile and synchronize all collected signals. A detailed analysis of the data will then be carried out to exploit all the collected information in a coherent and relevant way. Several existing tools will be integrated, such as eye-tracking, posture analysis, perioperative vital sign monitoring, automatic segmentation, psychological evaluation questionnaires, among others.

In the third phase, the project aims to develop a ready-to-use evaluation set and usable tools such as spider plot-type performance charts, and an automated augmented surgical report. This modular solution, with several components (cognitive, surgical, room, team, instruments, etc.), will each include a specific signal-capturing toolkit. This will enable the establishment of correlations between different signals (particularly objective parameters in relation to subjective data such as questionnaires) and allow the analysis, using machine learning approaches, of a surgical procedure to produce a risk assessment of intraoperative events and a performance scale for the surgeon, the team, and the OR.

The expected outcomes of this translational research project include original deliverables leading to a proof of concept in real-life conditions in the OR. The developed tool aims to offer a generalized, adaptable, and accessible solution applicable to all types of surgical procedures (arthroscopy, open surgery, etc.). Based on the analysis of surgical care effectiveness and quality, this work will enable clinical studies to assess the impact on patient outcomes according to the model's performance predictions, thus contributing to improving patient safety in the OR. The project also supports strategic goals by strengthening interdisciplinary research between researchers, engineers, and surgeons.

Skills

Education: Master's degree or engineering school diploma in computer science or a related field.
General: Knowledge of hospital environments and the healthcare sector, as well as innovative technologies: AI algorithms, image and signal processing, segmentation, modeling.
Specific: Processing and analysis of 360° video images, expertise in Deep Learning – experience with Python (TensorFlow, PyTorch, Yolo), Git and Matlab. Processing of medical signals (ECG and respiratory rate, blood pressure, galvanic skin response, pupillometry, body temperature, eye tracking).

Bibliography

HAS. Rapport : retour d'expérience sur les événements indésirables graves associés à des soins (eigs). Technical report, HAS, 2019.

Tolvanen, O., Elomaa, A.-P., Itkonen, M., Vrzakova, H., Bednarik, R., & Huotarinen, A. (2022). Eye-Tracking Indicators of Workload in Surgery : A Systematic Review. Journal of Investigative Surgery: The Official Journal of the Academy of Surgical Research, 35(6), 1340-1349. https://doi.org/10.1080/08941939.2021.2025282

Publications by the Team Related to the Project

1. Winter, Rémy, et al. "An Evaluation of the Reliability of Manual Landmark Identification on 3D Segmented Wrists." JBJS (2021): 10-2106. DOI.

2. Gauci, Marc-Olivier, et al. "Is preoperative 3D planning reliable for predicting postoperative clinical differences in range of motion between two stem designs in reverse shoulder arthroplasty." Journal of Shoulder and Elbow Surgery (2024).DOI.

3. Maiotti, Marco, et al. "IODA-shoulder®, a 3-dimensional automated software for glenoid bone loss quantification in shoulder instability. A validation study." Orthopaedics & Traumatology: Surgery & Research (2023): 103745. DOI.

4. Gauci, Marc-Olivier, et al. Validation of the shoulder range of motion software for measurement of shoulder ranges of motion in consultation: Coupling a red/green/blue-depth video camera to artificial intelligence. International Orthopaedics, 2023, 47.2: 299-307. DOI.

5. Gauci, Marc-Olivier, et al. "Simulation in shoulder arthroplasty education using three-dimensional planning software: the role of guidelines and predicted range of motion." International Orthopaedics 45.10 (2021): 2653-2661. DOI.

6. Winter, Remy et al., Mesure automatique tridimensionnelle de l'inclinaison et de la pente radiale : validation sur cas sain et séquelles de fractures, Hand Surgery and Rehabilitation, Volume 43, Issue 6, 2024, 101993, ISSN 2468-1229, DOI.

7. A.Caubere , S Rutigliano , S Bourdon, J Erickson, M Morelli, M Parsons, L Neyton, MO Gauci. How does humeral lateralization affect joint function ? A biomechanical observation using a "smart" RSA. International Orthopaedics, 2 septembre 2024. https://doi.org/10.1007/s00264-024-06282-6.