Laboratoire de Traitement de l'Information Médicale
Laboratory of Medical Information Processing

PhD Offer

Generative AI for Multi-Modal Tumor Evolution Imaging within Digital Twins for Personalized Prostate Cancer Radiotherapy

Scientific Context

External radiotherapy (RT) is a widely used and effective treatment for localized cancers such as prostate, head and neck, and cervical tumors. However, despite its benefits, a significant proportion of patients still experience tumor recurrence. These recurrences arise due to multiple factors including tumor location, patient-specific biological features, and risk profiles. Consequently, the ability to accurately predict how an individual tumor will evolve and respond to radiation therapy has become a critical research priority. Improving this predictive capacity would enable optimized treatment planning, reduce recurrence rates, and ultimately enhance long-term patient survival.

A new wave of therapeutic possibilities has emerged with the development of MR-Linac technology, which integrates Magnetic Resonance imaging with linear accelerators. This system allows clinicians to adapt radiation delivery in real time based on the patient's anatomy on each treatment day. As a result, radiotherapy is becoming more personalized than ever before. Still, determining the optimal treatment strategy for a particular patient remains highly complex, as it depends on both biological characteristics and therapy parameters. Addressing this complexity requires tools capable of modeling tumor behavior and response at multiple spatial and temporal scales.

In this context, Artificial Intelligence and computational modeling offer a unique opportunity to transform radiotherapy planning, enabling the development of predictive models capable of simulating tumor evolution and treatment response throughout therapy.

Hypotheses and questions raised

Digital twins offer a promising solution to address this challenge. A digital twin is a computational representation of an individual patient that can simulate real physiological processes and predict how a tumor will respond to different therapeutic interventions. In this project, the goal is to build a comprehensive digital twin for cancer patients that predicts tumor progression and radiotherapy response, enabling precise personalization of treatment.

This digital twin will be able to simulate different dose-fractionation schemes, helping clinicians identify the protocol that optimize the treatment. Treatment response will also be enhanced through a hybrid Trustworthy Artificial Intelligence (AI) framework that merges multi-omics population-level data with outputs from the digital twin. Prostate cancer has been selected as the initial application, but the methods developed can be easily transferred to other cancer types.

Job Description and Missions

Design, train, and validate multimodal AI models that transform mpMRI, augmented with innovative MRI sequences, PET and CT data, and a tumor evolution model, into realistic, patient-specific, and temporally consistent pseudo-PET (pPET) images and pseudo-CT (pCT) volumes for a prostate cancer digital twin. This digital twin will be used to virtually plan and deliver radiotherapy according to a given protocol, update the tumor evolution model based on the delivered dose, and subsequently regenerate the pPET and pCT for the next treatment iteration. This enables systematic testing and estimation of treatment response across different radiotherapy protocols. The thesis focuses exclusively on the AI component for synthesizing PET and CT images conditioned on the tumor evolution model.

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Key Objectives
The first stage will consist in developing an AI-based generative model that combines a baseline image acquired before treatment with the tumor model. This model should synthesize a new image that reflects the tumor evolution (growth, necrosis, response) predicted by the digital twin after each treatment fraction. Different AI models and strategies will be explored and evaluated, including:

- Conditional generative models (e.g., Diffusion Models) to synthesize future imaging volumes conditioned on tumor state variables and delivered radiation dose.
- Multimodal representation learning combining MRI, PET, and CT data to learn shared latent representations of tumor biology.
- Physics-informed or biologically guided AI models, integrating tumor evolution models directly within the generative framework.
- Image-to-image translation models to generate pseudo-modalities (e.g., pCT from MRI or pPET from multiparametric MRI), especially by exploring Diffusion Models.

The research will focus on the pelvic region since the target pathology is prostate cancer. In the workflow of testing a given protocol on the virtual patient and its digital twin, several imaging modalities are required. MRI is used for contouring the tumor and organs at risk. CT is used for treatment planning, and PET may be used, depending on the protocol, to refine the target volume. In MRI-Linac protocols, both MRI and PET are available before treatment and are part of the standard workflow, which is not the case for CT. The proposed tumor-evolution generative AI model must therefore be applied to the three imaging modalities: MRI, PET, and CT. For CT, the baseline image will also be synthesized from MRI using a dedicated AI model. The objective is to generate new pMRI, pPET, and pCT volumes for the virtual patient after each treatment fraction, reflecting the updated tumor evolution model, and to use these images for planning the next fraction.

Finally, the last objective is to integrate the pMRI, pCT, pPET, and tumor-state models into the main digital twin framework that virtually plans and delivers radiotherapy. This will enable the simulation of different clinical protocols, the propagation of dose-induced tumor evolution, and the evaluation of the proposed methods through comparison with real longitudinal clinical data.

Profile
- **Education**: MSc/Engineer in AI, Computer Vision, ML, Biomedical Engineering, or Applied Math.
- **Skills**: Proficiency in AI, image processing, 3D medical imaging, and programming, particularly in Python.
- **Qualities**: Autonomy, open-mindedness, motivation, and English communication skills.

Position Context
The thesis will be conducted at LaTIM UMR 1101 within the ACTION team, under the supervision of Julien Bert (senior research scientist) and Nassib Abdallah (research scientist). The project includes close collaborations with the LTSI laboratory, particularly with Pr Oscar Acosta for the tumor evolution model, and with the Centre Eugène Marquis for access to clinical data. The thesis is part of the TwinCaRT project funded by the PEPR Santé Numérique program.

The thesis is expected to start in the fall of 2026, with a duration of three years.

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