Proposition de sujet de stage M2/PFE Ingénieur 2025-2026

Titre du sujet : **Guarranteed Learning Based control for Tumor Therapy.**

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1 Introduction

The modeling and control of tumor growth play a crucial role in advancing our understanding of cancer progression and in guiding personalized therapeutic strategies. By quantitatively describing the dynamics of tumor expansion, invasion, and the underlying biological mechanisms, mathematical and computational models provide powerful tools to predict tumor responses to different therapies. These predictive insights enable clinicians to design and adapt treatment plans tailored to individual patient profiles, ultimately improving therapeutic efficacy and patient outcomes.

The dynamic modeling of tumor growth today involves several mathematical approaches from simple analytical models to complex mechanistic ones that rely on patient-specific data [8, 9]. This rapidly evolving field centers on key challenges: faithfully reproducing the multiscale dynamics of tumors, integrating biological phenomena (angiogenesis, tumor microenvironment, resistance mechanisms, etc.), and developing actionable or control strategies such as optimal therapy, dosage adaptation, or sequential/continuous treatment administration [3, 4].

The objective of the stage is to consider several model of tumor grown, then using simulated data issue from these model to perform and study what garrentty around safty and robustess we can get using learning based control and more precisely we wish to answer the following question:

- How can artificial intelligence and model-based control be integrated to ensure the safety of tumor therapies in the presence of uncertainty?

2 State of the art

Tumor growth modeling is traditionally categorized into several major classes, each offering unique insights into cancer dynamics. Empirical and phenomenological models, including exponential, logistic, and Gompertz laws, remain widely used for describing global tumor growth, with extensions such as the Bertalanffy model and dynamic carrying-capacity formulations further refining these approaches [2]. Mechanistic and multiscale models explicitly incorporate biological mechanismssuch as cell diffusion, angiogenesis, migration, and microenvironmental interactionswithin frameworks based on partial differential equations or stochastic systems [5, 7]. Finally, patient-specific modeling is increasingly central, leveraging individual patient data (metabolomic, genomic, and imaging) to parameterize models and predict tumor progression or therapeutic response [8, 9].

Various optimization frameworks are employed to modulate tumor dynamics and improve therapeutic outcomes. Optimal control and adaptive feedback approaches utilize control theory to optimize treatment regimens, enabling real-time adjustment of drug dosages or combinations based on observed tumor evolution, often drawing inspiration from PID, LQR, or MPC control strategies [3, 4]. Learning and automatic calibration methods leverage statistical inference and machine learning to fine-tune model parameters using cohort or individual patient data, thereby identifying optimal therapeutic protocols. Additionally, dynamically modeled innovative therapiessuch as the application of tumor-treating fields (TTF) and detailed simulations of angiogenesis under chemotherapyare increasingly integrated to refine treatment strategies and predict responses [10].

To ensure the safety of the system, we extend the results in [6]. We first consider a linear system as in [6], treating the tumor-induced nonlinearity as a bounded perturbation [6]. Leveraging the framework of continuous piecewise-affine (PWA) functions commonly used in neural-network-based control, we model the nominal linear dynamics separately from the perturbation effects. This formulation allows the application of set invariance principles, specifically Nagumos theorem, to verify the safety of a given state-space region despite the presence of perturbations. The proposed approach systematically partitions the state space and evaluates boundary conditions to guarantee invariance, providing a rigorous and computationally tractable method for ensuring safety under uncertain tumor dynamics. Furthermore, this methodology can be compared with barrier-certified feedback (BCF) approaches [1], which similarly aim to enforce safety through the design of invariant sets, highlighting potential synergies and differences between the two frameworks.

3 Profils

We are seeking a final-year Masters intern specializing in control theory (automatic control) and/or applied mathematics, with proficiency in Python programming for simulation and machine learning.

4 Perspective

In a more boarder view this stage objective is to investigate the potencial of control theorey and stafety toward the tretement of tumor groth. The work on simulated data is needed before whishig to applided it on real data

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