PhD Position open in 2025 **Montpellier, France**

Real-time control of aroma synthesis in oenological fermentation

Context

Agri-food bioprocesses are still largely unoptimized. However, they must meet increasingly stringent requirements in terms of productivity, robustness and product quality. In the current context of climate change, energy sobriety and rising energy costs, it is also essential to minimize the environmental impact of these practices. In order to achieve production targets while meeting the numerous constraints of the process, the use of **control** becomes essential. Control theory has been extensively used in bioprocesses, but has been scarcely applied to alcoholic fermentation for wine production. Wine fermentation is a bioprocess carried out in a fermentor, where yeasts convert grape sugar into ethanol and CO2, and the synthesis of other metabolites (glycerol, organic acids, aroma compounds, etc.) that constitute the aromatic profile of the final product. The latter includes esters—and, to a lesser extent, higher alcohols—that contribute directly to the fruity aroma of wines. Until now, industrial practices have been essentially dictated by practical considerations of cellar management. The aim is generally to speed up fermentation, i.e. to accelerate the conversion of residual sugar, which is slower at the end of fermentation (when ethanolic stress is at its highest for the yeasts). To achieve this objective, two practices are commonly used: 1) the addition of nitrogen at the start or during fermentation, and 2) anisothermal fermentation management, which generally consists of raising the temperature at the end of the process. In recent works, it has been shown that these practices also influence the final aroma content of the wine, with very different impacts depending on each aroma compound. By regulating the amount and timing of nitrogen addition, and adjusting temperature in real time, it is possible to **control aroma synthesis** during alcoholic fermentation and achieve a predefined aroma and energy target.

Objectives of the PhD project

The aim of this PhD project is to **control the synthesis of aroma compounds during the wine fermentation process by developing innovative real-time control strategies based on predictive mathematical models**. These strategies will also have to take into account numerous constraints related to the control scheme, and the energy consumption of the fermentation, which must remain sufficiently low. The PhD will be carried out in the context of the **ANR DigitWine project** (ANR-24-CE10-4479-01), a multidisciplinary initiative involving research teams from Paris, Montpellier and Narbonne working conjointly on cutting-edge IT and control methods for the development of **digital twins** in wine fermentation. Researchers at the University of Grenoble working on the modelling and control of microbial consortia will also be involved in the supervision of the PhD. In the framework of the DigitWine project, the PhD candidate is expected to interact with other PhD students and researchers working on modelling, optimization, observers design and experimental validation. In previous works, a deterministic dynamical model of ODEs was developed, which represents the main kinetics of wine fermentation, the synthesis of the main aromas, and the energy consumption of the process. Using this model, a first, simple MPC (Model Predictive Control) loop has been designed and tested on the real process, which constitutes a proof of concept of the approach. In this context, multiple research directions can be explored:

- **Synthesis of nonlinear and constrained control laws for wine fermentation:** based on the existing models, tools from nonlinear and adaptive control can be used to design feedback controllers adapted to the peculiarities of the wine fermentation process (sparse and partial state measurements, input constraints, control costs, etc.)

- **Nonlinear and constrained control for general fermentation processes**: by designing simplified control-oriented models, more general theoretical problems can be studied. Starting from the wine fermentation process as a reference case study, control strategies of wide applicability can be explored for general alcoholic fermentation bioprocesses in batch fermentors.

- **Robust real-time control strategies**: in this more applied perspective, the aim is to take into consideration aspects such as performance and robustness to model uncertainty. This can be done through optimality-based control algorithms (like robust MPC) targeting multi-criteria objectives (e.g., energy

consumption, total fermentation time, etc.), and by exploring data-driven approaches where unknown dynamics altering the modelled process dynamics are learned from offline or online data.

The project will involve theoretical investigation of the mathematical problems above, numerical simulations and, in collaboration with experimentalists, validation of control laws to be applied and tested on the real process located at the Pech Rouge Experimental Unit in Gruissan.

Keywords

Control theory, wine fermentation, nonlinear control, model predictive control, biological models

Required skills

We are looking for a background in **automatic control** or **applied mathematics** with a taste for applications. Knowledge of biological processes or systems is not required, but recommended. Good programming skills are required (Python/Matlab/R/Julia).

About the research center

The PhD candidate will be based at the UMR MISTEA (Montpellier), on the Gaillarde campus of Montpellier SupAgro. The student will be supervised by Agustin Yabo and Céline Casenave, both researchers at MISTEA (INRAE Occitanie-Montpellier); and Eugenio Cinquemani, researcher in the Microcosme team (Inria center of the University Grenoble Alpes). The project will be held in collaboration with UMR SPO (Montpellier), SayFood (Paris), MIA Paris-Saclay (Paris), the INRAE Pech Rouge Experimental Unit (Gruissan), and potentially private partners. It will include online exchanges with as well as visits from / to the supervisor in Grenoble, and possibly other collaborators.

General information

Duration: 36 months
Location: Montpellier, France
Gross salary per month: approx. 2200€ (1st year), 2300€ (2nd year) and 2300€ (3rd year)[1]
Starting date: Between October and December 2025
Benefits: reduced canteen rate, free public transport[2], social security, paid leave, flexible working hours

Contacts

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[1] https://www.enseignementsup-recherche.gouv.fr/fr/le-financement-doctoral-46472
[2] https://www.montpellier3m.fr/connaitre-grands-projets/gratuite-des-transports-en-commun