

PhD. Proposal

Université de Reims Champagne-Ardenne

École Doctorale : MATHÉMATIQUES, PHYSIQUE, SCIENCES DU NUMÉRIQUE ET DE L'INGÉNIEUR – MPSNI

CReSTIC EA 3804

Moulin de la Housse, 51097 Reims

Title : Explainable AI-driven Digital Twin for Smart Irrigation and Agricultural Monitoring Systems

Key-words: Digital Twin, Smart Irrigation, Agricultural Monitoring, Machine Learning, Explainable AI (XAI), Anomaly Detection, Data-driven Modelling

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Description of the research problem

Sustainable agriculture faces major challenges related to climate change, water scarcity, and resource optimization. In Mediterranean and European farming systems, irrigation practices are often based on empirical rules, leading to water overuse and limited adaptability to environmental variability.

Digital Twin technology, combined with Machine Learning techniques, offers new perspectives for modelling agricultural systems in real time. By integrating heterogeneous data sources such as soil moisture sensors, weather forecasts, crop growth indicators, and irrigation control signals, Digital Twins enable predictive simulation and decision support.



However, current AI-based solutions often operate as black-box models, limiting their adoption by farmers and stakeholders. There is therefore a strong need to develop explainable and trustworthy AI-driven Digital Twin architectures capable of:

- Predicting optimal irrigation timing and quantities,
- Detecting anomalies in irrigation and monitoring systems,
- Providing interpretable recommendations to end-users.

This PhD aims at designing an Explainable AI-driven Digital Twin framework for smart irrigation and agricultural monitoring systems.

The research will consider agricultural systems equipped with heterogeneous sensors (soil, climate, crop status) and actuators (irrigation systems), producing continuous and discrete signals. The operational cycle typically consists of:

- a) acquiring environmental and crop data,
- b) processing and predicting system states,
- c) generating irrigation recommendations or control updates,
- d) continuously updating the Digital Twin representation.

The project will tackle prediction and anomaly detection problems by leveraging data-driven approaches, combining machine learning techniques with domain knowledge, without relying exclusively on purely physical models.

The PhD will pursue the following objectives:

1. Design a scalable Digital Twin architecture integrating multi-source agricultural data and enabling real-time simulation of soil–crop–climate interactions.
2. Develop Machine Learning models for:
 - Irrigation demand forecasting,
 - Detection and isolation of anomalies in irrigation and monitoring systems.



3. Automatically adapt model architectures and hyper-parameters to different agricultural contexts and data characteristics.
4. Ensure explainability of predictions and anomaly detection results through:
 - XAI methods for time-series analysis,
 - Feature attribution techniques,
 - Model-based or hybrid interpretability approaches, enabling farmers and agronomists to understand and trust the recommendations.

The work will rely on experimental agricultural datasets provided by project partners and on digital simulation environments developed within CReSTIC. It will also benefit from the HPC Romeo computing platform of the Université de Reims Champagne-Ardenne for large-scale model training and validation.

The proposed course of the PhD is outlined as follows:

Step 1: Identification of methodological gaps and definition of initial architectural hypotheses, and familiarization with the research topic and comprehensive literature review on:

- Digital Twins for cyber-physical systems,
- Smart irrigation systems,
- Machine Learning for time-series forecasting,
- Explainable AI methods.

Step 2: Data collection, preprocessing and structuration. This step involves:

- Identification of available sensor and contextual data sources,
- Data cleaning and synchronization of heterogeneous time-series,
- Feature engineering,
- Definition of benchmark scenarios for irrigation optimization and anomaly detection.

Step 3: Development and implementation of Machine Learning models. Experimental validation will be performed on real datasets and Digital Twin simulation environments.

Algorithms will be designed and trained to:

- Predict soil moisture evolution and irrigation needs,
- Detect abnormal behaviours in irrigation or monitoring systems,
- Provide decision-support indicators.



Step 4: Integration of Explainable AI techniques. This phase will focus on:

- Analysing trained models using XAI techniques (e.g., feature importance, local explanations),
- Designing interpretable decision-support interfaces,
- Evaluating the usefulness of explanations for non-expert users.

Special attention will be given to dissemination and exploitation of research findings, notably through scientific publications (international journals and conferences), open-source demonstrators, and contributions to project deliverables. By following this plan, the thesis aims to contribute to the development of trustworthy AI-driven Digital Twin systems for sustainable agriculture, reducing water footprint while improving resilience and operational efficiency.

References

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Netography

Kaa IoT: <https://www.kaaiot.com/>

Faminga: <https://unstoppabledomains.com/d/faminga.com>

IoT Dashboard: <https://iotdashboard.io/lander>

CropAnalytica: <https://www.cropanalytica.com/>

Profile and required skills: This PhD is aimed at students holding a M.Sc. or M.Eng. degree in Computer Science, Artificial Intelligence, Data Science, Automation or Control Systems.



Candidates should have:

- Strong theoretical and practical knowledge in Machine Learning,
- Good programming skills (Python, ML frameworks),
- Interest in cyber-physical systems and sustainability issues,
- Scientific rigor and analytical thinking,
- Ability to work in an international collaborative research environment.

Experience in time-series modelling, Digital Twins, or Explainable AI will be appreciated.

Application

Send by email to ramla.saddem@univ-reims.fr and alexandre.philippot@univ-reims.fr a single PDF file containing the following information:

- A detailed explanation of your interest in the proposed topic and the related skills you have;
- Your CV;
- Your academic transcripts;
- The names and contact details of referees.