SOMIPs: Simulation, Optimization and Monitoring using AI-based Digital Twin Technology for Incineration Plants

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***Abstract*—The SOMIPs - Simulation, Optimization and Monitoring using AI-based Digital Twin Technology for Incineration Plants - project aims to develop an advanced control and monitoring solution for Biomass Valorisation Plants, addressing the operational complexity arising from biomass variability—moisture, type, granulometry, as well as equipment condition and pollutant emissions. Current operations rely heavily on continuous human supervision, leading to significant inefficiencies and reduced productivity. Through the development of a hybrid digital twin, fuzzy and predictive control systems, virtual sensors, predictive maintenance techniques, and customised visualisation interfaces, SOMIPs aims to increase energy production per biomass volume by at least 5%, reduce human intervention in process parameterisation by at least 40%, and reduce corrective maintenance by at least 20%. The resulting framework will be scalable, adaptable, and applicable to other industries with biomass boilers, such as pulp and paper, cement, and waste incineration.**

***Index Terms*—Digital Twin, Biomass Valorisation, Advanced Process Control, Predictive Maintenance, Virtual Sensors**

I. Introduction

Biomass Valorisation Plants (BVP) convert biomass into energy through combustion, generating electricity and/or heat via the Rankine cycle. These plants have been considered strategic for forest valorisation and sustainability, described as a way to increase the sustainability and economic value of forests, diversify and enhance rural employment, ensuring proper fuel management in rural areas [1].

Despite recognised technological benefits, the operation of a BVP is complex due to the high variability of biomass characteristics such as moisture, type, and granulometry, as well as equipment condition and pollutant production. The resulting uncertainty requires constant balancing of various parameters, which is currently carried out through continuous human supervision. This model is common across many production sectors, but human intervention inevitably leads to inefficiencies and reduced productivity [2], [3]. To address this, advanced control techniques, such as fuzzy logic control (FLC) and model predictive control (MPC), have been developed over the past few decades, and are capable of handling multiple variables and high uncertainty.

In the BVP market, customers tend to buy specialised solutions from recognised companies (e.g., DUBLIX Technology ApS and ADEX). However, current market limitations include the failure to consider multiple operational dynamics, lack of adaptive model updating, and absence of virtual sensor integration for hard-to-measure variables [4]. Furthermore, existing predictive maintenance systems struggle to cope with the dynamics of real-world facilities through frameworks that evolve over time, and digital twins are currently static and cannot be used for online control or adapt to time-varying process behaviour [5]. Industrial operator interfaces are also rigid and overloaded with information, often leading to interpretation errors [6].

These combined gaps confirm that no integrated digital solution currently exists for the biomass incineration sector. SOMIPs addresses this need by proposing a holistic framework that combines hybrid digital twins, advanced control, virtual sensors, predictive maintenance, and customised visualisation, aiming to overcome the limitations of existing industrial solutions and deliver tangible operational gains.

II. The proposed approach

The SOMIPs project will deliver a validated digital platform specifically designed for biomass valorisation plants. The proposed solution, illustrated in Figure 1, incorporates the following innovative components:

- **Hybrid Digital Twin:** A simulation engine combining first-principle modelling (differential equations) with data-driven approaches (interpretable neuro-fuzzy techniques), enabling both simulation and predictive control with more than 70% model accuracy;
- **Virtual Sensors:** Real-time estimation of hard-to-measure variables (e.g., pollutant emissions and laboratory analyses) using non-linear regression

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techniques (e.g., random forest, SVR, LSTM) with statistical incorporation of temporal delays;

- **Predictive Maintenance:** Unsupervised clustering approaches for process signature identification, combined with vibration analysis using proprietary low-power electronics, enabling early fault detection and reducing corrective maintenance by at least 20%;
- **Advanced Control System:** Fusion of FLC and MPC, incorporating human heuristic knowledge with predictive models, enabling automatic setpoint manipulation and adaptation to multiple operational dynamics;
- **Customised Visualisation Interface:** Web-based, user-configurable interface using micro-frontend technology, tailored to individual operator needs and reducing operational errors by at least 20%;
- **KPI Monitoring with Bottleneck Detection:** Real-time KPI calculation with causal identification via sensitivity analysis and non-linear correlation, achieving more than 50% detection of bottlenecks and KPI degradations.

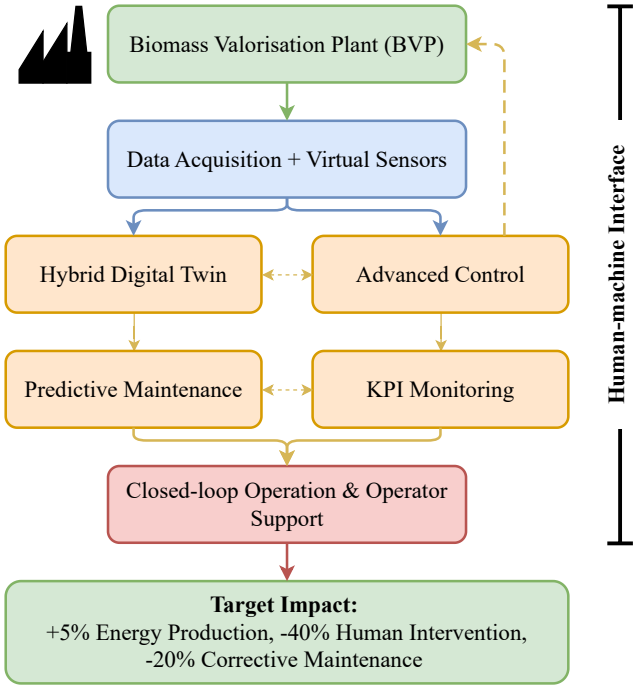

Fig. 1. Outline of the technology resulting from the SOMIPs project

This integrated approach is motivated by the current market fragmentation. Existing digital twins are static and cannot be used in controllers, nor do they consider time-varying process behaviour. Virtual sensors are established in other sectors but lack specific application for atmospheric pollutant estimation in combustion processes. Predictive maintenance solutions are non-evolving and do not involve operator inputs, leading to high imprecision and eventual abandonment. Advanced control systems fail to account for multiple operational dynamics, lack adaptive updating, and do not manipulate setpoints automatically. Industrial interfaces present excessive static information that can induce errors, and no automated solution exists for detecting bottlenecks or performance degradation causes.

III. The Consortium

The consortium brings together two complementary partners. Oncontrol Technologies Lda., with over 20 years of experience in industrial automation and advanced control, offers proven expertise in fuzzy systems, neural networks, predictive control, and data mining, along with a strong international customer network and the commercial infrastructure to bring the solution to market. University of Coimbra contributes deep academic expertise in computational intelligence, process modelling, predictive maintenance, virtual sensors, and decision support systems. Together, they connect fundamental research with practical, market-ready solutions, building on a strong history of successful collaborative R&D projects in industrial process optimisation.

IV. Conclusions

The SOMIPs project represents a significant advance in the digitalisation and optimisation of biomass valorisation plants, addressing critical gaps in the state of the art through the integrated development of hybrid digital twins, virtual sensors, predictive maintenance, advanced control, and customised visualisation. The consortium's competencies ensure comprehensive coverage of the scientific and technological challenges involved. Beyond technological innovation, the project will reduce operational costs, increase energy efficiency, and enhance the sustainability of biomass valorisation, contributing directly to Portugal's energy transition and circular economy objectives. The scalable and adaptable framework is transferable to other industrial sectors with biomass boilers, such as pulp and paper and cement, amplifying the project's long-term impact and market potential. In additions, contributes to forest fire prevention by valorising forest excesses and providing supplementary income to rural communities.

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