A Hybrid Digital Twin Using Sensor Simulation for Physics-Informed Intelligent Predictive Maintenance

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What is new?

- Hybrid Digital Twin with integrated sensor simulation pipeline for increased prediction quality of intelligent predictive maintenance
- Wear-dependent, adaptive control of a parallel kinematic on an autonomous agricultural machine in a time-critical process
- Wear-avoidant process optimization

Introduction

Predictive maintenance is state of the art in industry applications because of its great potential to save costs. An overview of maintenance strategies includes [1]:

- *Corrective*: replacing or repairing in an unplanned downtime
- *Preventive*: scheduled replacement, waste of intact equipment
- *Condition-based*: recognizes the necessity of maintenance actions based on machine behavior
- *Predictive*: knows beforehand when a component will fail

Intelligent predictive maintenance is a technique using machine learning. Physics-based ML approaches can increase the prediction quality by combining data-driven techniques with first order modeling.

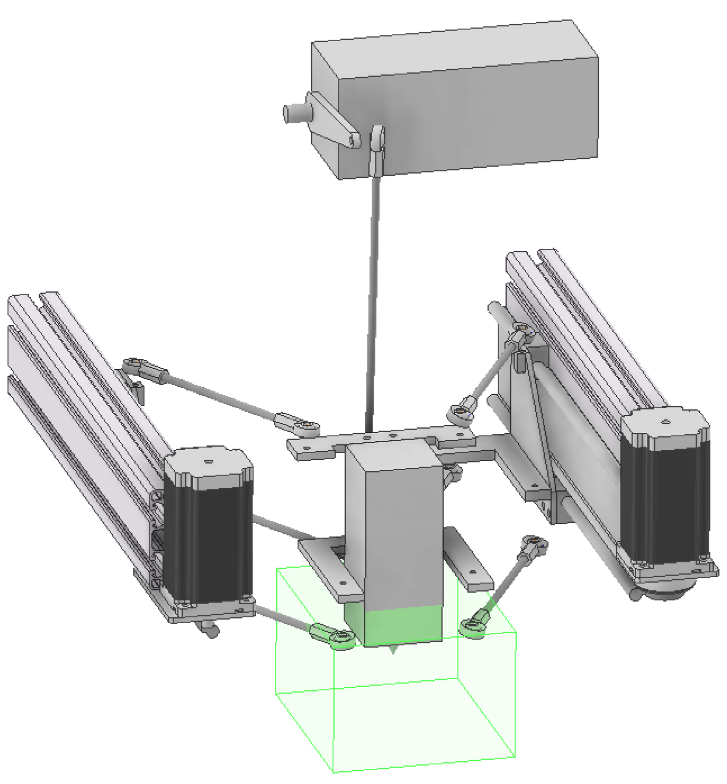
Digital Twin technology helps to synthesize failure data that is lacking in real data.

Use Case

In the context of the **Jaetrobi project** [2], a mobile agricultural machine for automatic, herbicide-free weed control in seeded vegetable cultures will be developed. The weed killer will be a laser mounted on a *3-DOF parallel kinematic*.

As a use case, the continuous wear of the parallel kinematic mechanism moving the laser will be monitored, and its **remaining useful life will be predicted**. The position control of the laser will be **adapted to account for wear effects**. Finally, the path planning of the laser movement will be **optimized to minimize wear**.

Mobile agricultural machine for automatic, herbicide-free weed control of the naiture GmbH & Co. KG, image: naiture

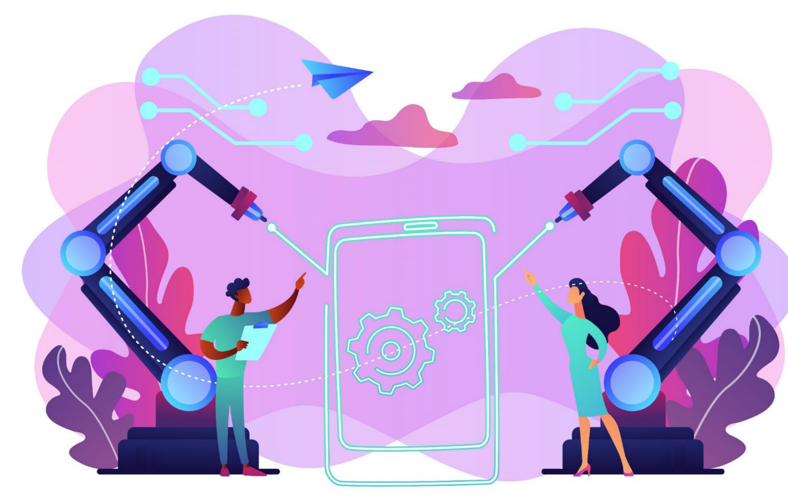


CAD model of the parallel kinematic carrying a laser and a camera, image: Dr.-Ing. Sebastian Schröder

Research Questions

#1 Physics-informed intelligent predictive maintenance algorithm

Can using a hybrid digital twin that models the mechanistic principle of the sensor used to collect the data increase the remaining useful life prediction quality compared to a pure machine learning approach?



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#2 Wear-dependent adaptive control

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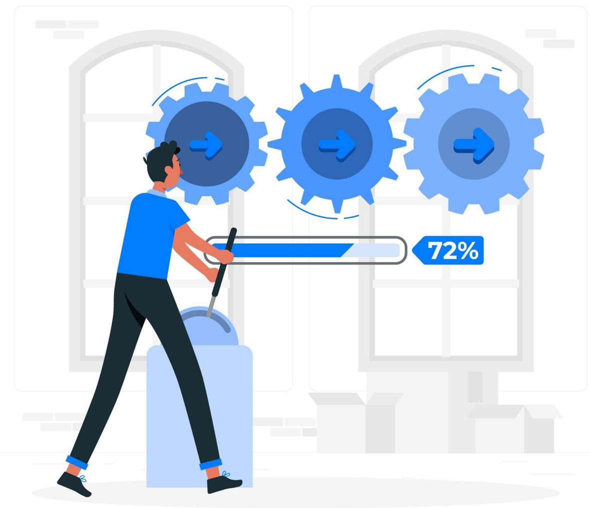
Can the process controller be automatically adapted in an online manner so that the control performance stays constant in spite of system behavior drift?

#3 Wear-avoidant process optimization

Can the process control strategy be automatically modified to minimize the wear on the system?



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First Steps

- **Analyze the Jaetrobi system** and identify the components or subsystems that are most susceptible to wear
- **Ascertain** which variables are related to wear effects and **how to measure** them; **procure sensors** to measure these variables
- **Build** a Jaetrobi parallel kinematic analog **test bed** and integrate the sensors into it
- **Simulate wear** by mechanically processing the wear-susceptible components
- **Collect data**

Please find the digital version, related work, and contact info here:

References

[1] R. van Dinter, B. Tekinerdogan, and C. Catal, “Predictive maintenance using digital twins: A systematic literature review,” Information and Software Technology, vol. 151, p. 107008, Nov. 2022.

[2] “Jaetrobi Projekt” atb-potsdam.de. https://jaetrobi.atb-potsdam.de/de/project (accessed Feb. 20, 2024).

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