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Open-Source Demonstration Platform For Predictive Maintenance Of Robots Based On Digital Twins

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Robotic systems play a crucial role in automated manufacturing, demanding exceptional reliability and extended lifetimes. The potential financial repercussions of an unforeseen factory shutdown resulting from robot malfunctions are substantial, with daily losses estimated between 100,000 to 200,000 euros (Mathur et al. 2001). Research indicates that maintenance costs can represent a significant portion, ranging from 60% to 70%, of the overall lifecycle expenses for production systems (Dhillon, 2006). Consequently, the optimization of maintenance schedules emerges as a pivotal endeavor within factory operations, directly influencing a company's competitive standing.

In response to these challenges, scholars have introduced Predictive Maintenance (PdM), leveraging historical data and prognostic models to anticipate optimal times for maintenance interventions. The exploration of PdM encompasses diagnostics, which scrutinize the causes of failures post-occurrence, and prognostics, focused on modeling degradation processes to predict the future state or Remaining Useful Life (RUL) of machinery or its components (Aivaliotis et al., 2021). Three primary approaches to degradation modeling are recognized: knowledge-based, utilizing expert or fuzzy systems; physical model-based, employing mathematical models; and data-driven, often employing Neural Networks, regression, filtering, stochastic models, and their combinations to enhance prognostic performance (Aivaliotis et al., 2021).

While extant predictive maintenance methodologies share a common limitation—namely, a dearth of historical failure data—digital twins, as one of the enabling technologies of Industry 4.0 (Fuller et al., 2020), have emerged as a promising solution. Digital twins can accurately simulate system behavior, engaging in real-time data collection through condition monitoring. Leveraging these capabilities, researchers have developed digital twin models for physical systems, utilizing them to generate simulation data for training machine learning and artificial intelligence models for fault diagnostics and RUL prediction (Ellefsen et al., 2019). Aivaliotis et al. (2019, 2021) integrated degradation models with digital twins of an industrial robot, employing them to formulate predictive maintenance models. However, these initial studies only explore the integration potential of digital twins with predictive maintenance, lacking detailed insights into employing advanced machine learning models for precise fault detection and RUL prediction. Additionally, considerations for system-level maintenance planning and scheduling remain unaddressed.

To booster the research on applying digital twins for better predictive maintenance, we develop an open-source demonstration platform for research purposes. The platform allows simulating the behavior of the physical robot through its digital twin, and also collecting real-time condition-monitoring data for predictive maintenance. Failure and degradation behavior can be injected artificially to test the performance of the developed predictive maintenance models. The architecture of the model is given in Fig. 1. A robot with 6 degrees of freedom, as shown in Fig. 2, is used in the demonstration platform. It is a fully open robot built based on Raspberry pi and ROS system. It is connected to a master PC through wifi and the communication protocol defined in ROS. A condition-monitoring system is developed in the master PC based on ROS, where the position, temperature, and voltage of the six motors of the robots can be collected in real-time. A digital twin model of the robot is developed in the

master PC that allows simulating the behavior of the robot under normal operation and failure states. The demonstration platform can be used to simulate the failure behavior of the robot, which can be further used as training data to develop AI-based predictive maintenance models. The source code and generated data from the platform is open-sourced and can be accessed from https://github.com/sonic160/digital_twin_robot.

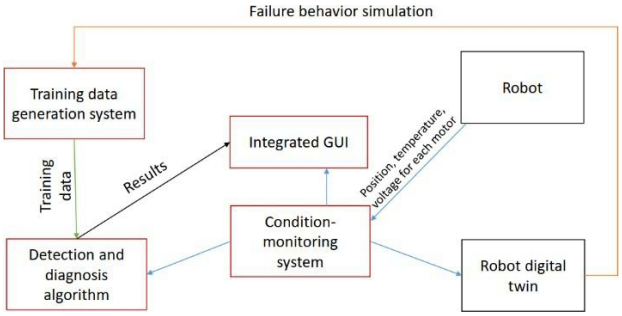

Fig. 1. A sample problem from the HumanEval-R3 dataset.

Fig. 2. The robot used for the demonstration platform.

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