A closed loop methodology for robotic prognostics and diagnostics based on multi-model architecture

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Abstract - **The applications of robotics have expanded in the industrial environment, improving the performance level of processes and the human safety. High levels of reliability and maintainability are required to satisfy the market needs, in particular when robots are integrated in production cells and assembly lines. The paper presents a framework for the evaluation of robotic system reliability aimed at monitor the remaining useful life (RUL) through the integration of FMECA (Failure Modes, Effects and Criticality Analysis), life data analysis, data driven and model based methods. This research is a part of PROGRAMs: PROGnostics based Reliability Analysis for Maintenance Scheduling, H2020-FOF-09-2017-767287. The contribution is a demonstration case study designed, developed and disseminated in the EU founded research project.**

Keywords—Robotics, Reliability analysis, Residual useful life

I. INTRODUCTION

An effective estimation of residual useful life (RUL) is based on a full awareness of the element degradation mechanisms under different stresses and environmental conditions. Robot components show fatigue failures that may depend on the operational conditions but may also be determined by the human responsibility. To manage sub-system failures, users have to recognize and classify failure modes and their causes. The robust design permits to develop new parts or systems more reliable to perform the required industrial production tasks. Data-driven methods need to collect and study multidimensional dataset that includes different information (e.g. environmental state, direct-indirect measures of degradation) from a population. Diagnosis aims to define the status of a component while prognosis is the prediction of the component future state and duration. This evaluation depends on a broad range of factors, influencing the accuracy of the RUL calculation. Data-driven methods apply Machine Learning techniques (e.g. ARIMA, Bayes Network, Fuzzy c-Means, k-Means) based on recursive phases of training-learning of the system, collecting and processing data and information continuously. These iterative processes allow to increase the accuracy of RUL estimation, limiting the amount of data-knowledge. They are easy to be implemented with limited costs, nevertheless the physical interpretation may be a complex task and a significant tuning period is often required. The Model-based (M-B) approach requires the development of a mathematical model able to represent the system use and degradation. In this way, the operational data are indispensable to fine-tune model parameters. The aim is to correlate the kinematic-dynamic and physical models to the component degradation. This approach permits to extrapolate an accurate RUL estimation, nevertheless the model validation may be expensive and time consuming, requiring a high knowledge of the system and the physical lows, making it no sustainable in industrial application. The proposed closed loop methodology is based on the integration of FMECA, Life Data Analysis (LDA) and Data-driven and Model-based methods in order to determine the RUL of a robotic system. The iterative approach collects information from the field, processes data to estimate RUL and, finally, shares the results with enterprise resource planning systems to plan production and preventive maintenance activities.

II. H2020-PROGRAMs CONTRIBUTION

The main contribution of this EU founded project is to develop a model-based prognostics method integrating different signals for the smart prediction of equipment condition. The consortium purpose has been to enable the improvement of the overall business effectiveness with the following perspectives: increasing availability and mean time between failure; continuously monitoring the criticality of system components by performing the FMECA analysis; building physical-based models of the components that have a higher criticality level; creating a schedule for the maintenance activities that will optimize the overall system performance; providing robust and customizable data analysis services by a cloud-based platform.

III. RUL ESTIMATION: MULTI-MODEL APPROACH

Remaining useful life is a real-time evaluation of the lifetime of an element, exploring the occurrence of a failure.

RUL estimation is based on four topics: (i) the electromechanical systems age is influenced by their usage and environmental conditions; (ii) the damage accumulation is a monotonic progression; (iii) the failure event was anticipated by a detectable signal, (iv) the correlation between degradation signals and reliability performance need to be statistically significant. Methods of degradation analysis include physical examination, monitoring of damaging features (e.g., vibrations, acoustic emissions, oil temperature, energy consumption), and non-destructive inspections. Direct methods are expensive and not always effective due to the low occurrence rate of the failure event.

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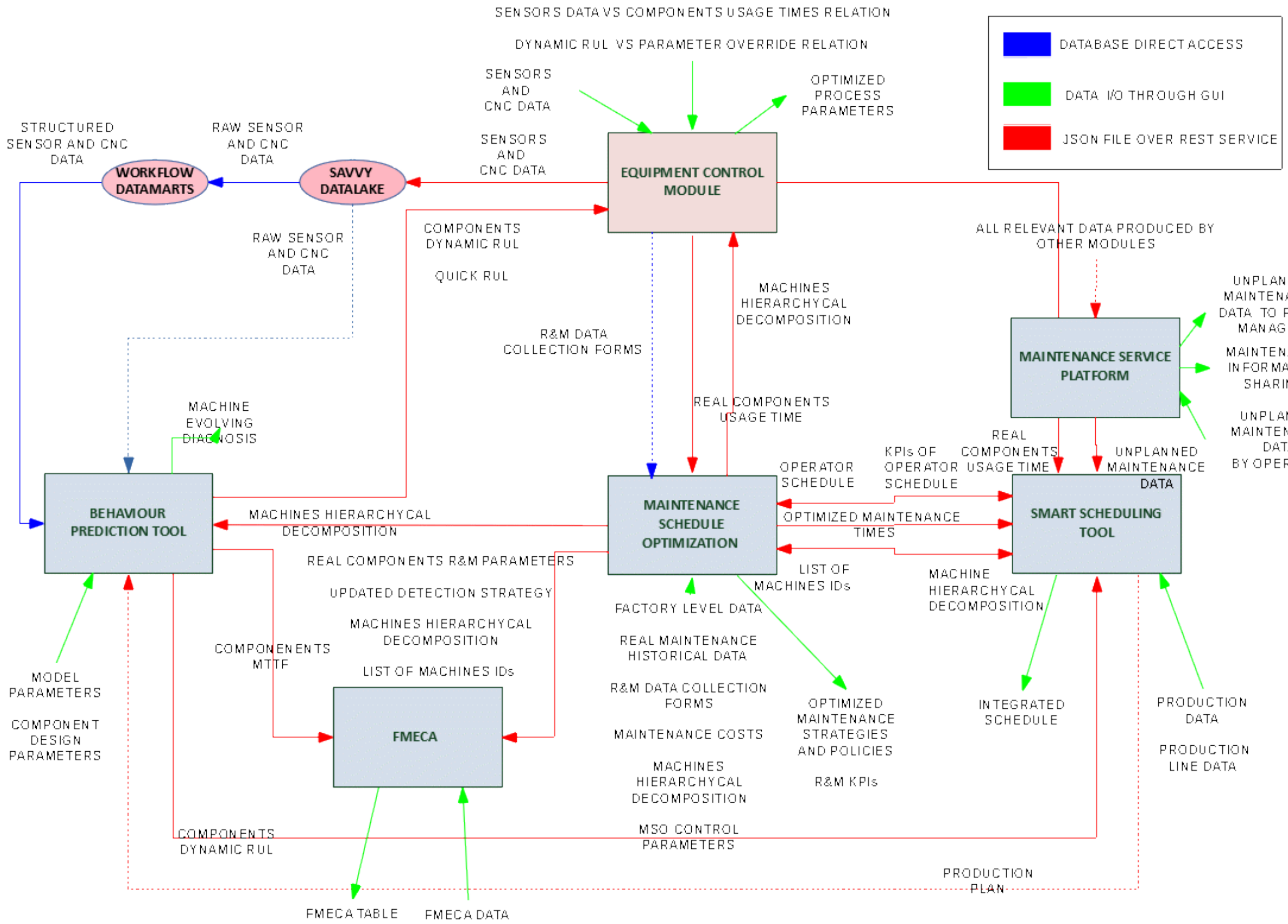

Fig. 1. PROGRAMs architecture framework.

Methods for indirect evaluation are based on models of physics of failure or life data analysis of a component. Fig. 1 describes the iterative loop of the proposed methodology. For a complex system (e.g. robotic cell), the initial phase is a failure investigation using the FMECA, defining the critical breakdowns. The existing tools are not able to completely use updated data and information in real time, compromising the results. For this reason, starting from the FMECA, a shared database covering the life data of existing and operating components in the field are upload and processed. Then, LDA permits to assess the current state of robot reliability performance, identifying strengths and weaknesses of subassemblies and components. Appropriate sensors and devices, selected by historical analysis on the occurred failures, collect life data. Then, using data-driven and physical-based degradation models, a hybrid RUL is predicted, supporting both FMECA analysis and production-maintenance decisions. In this way, the user is guided to recognize appropriate prognostics models based on physical insight and operational conditions to increase the estimation precision of the failure evolution.

IV. ARCHITECTURE EXPLOITATION

Future works will aim to expand this procedure including several unstable and dynamic conditions. The research team on University of Brescia (ING-IND/13) aims at extending diagnostics and prognostics in many areas including features (e.g. vibrations, currents), sensors (e.g. accelerometers, thermocouples) and signal positions that will be considered in order to increase the model performance in real time.

Further active research in this context proposes a thermo-mechanical error modeling procedure to compensate the distortions of a 5-axis commercial machine tool structural parts made of Carbon-Fiber-Reinforced-Polymers. These anisotropic materials are becoming an effective solution to reduce mass and damp vibrations; nevertheless their physical complexity may generate undesired effects, in particular when they are subject to external loads. The preliminary published study focuses on the vertical Z-axis structure evaluating numerical and data-driven prediction models.

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