Abstract

Labor shortage, safety risks, increasing competition, and the need to minimize repetitive and alienating jobs are the main drivers of the fast growth of automation in the past years. In addition to the standard big and heavy industrial robots, small, lightweight, and easy to program manipulators able to share their workspace with the human operator arrived into the market becoming universally known as collaborative robots (cobots). These machines made automation accessible also to small and medium enterprises, making robotics an omnipresent element in modern industry.

To support the high rhythms imposed by the global economy and guarantee the personnel's safety, it is of paramount importance to assure that such robots function properly. To do so, condition based maintenance, combined with prognostic and health management techniques, represents an efficient and cost-effective approach to optimize robots maintenance scheduling. To correctly estimate the health status and the remaining useful life of both industrial and collaborative robots, large datasets of both healthy and faulty manipulators are required. However, such data are often unavailable.

The present thesis provides a comprehensive model-based framework to be used to build a database of simulated robots behaviors both in nominal and degraded operating conditions from which to extract indicators representative of the health status of the machine. By monitoring their trend and changes over time, it will be possible to substitute the faulty component prior its failure. This would allow minimizing the risk of production stops and economical losses, as well as increasing the safety of the operator sharing the workspace with the cobot. The entire research was built around the digital replica of the UR5 collaborative robot from Universal Robots A/S to be used as a virtual test bench in which to inject faults and failures of different origin and magnitude to support diagnostics and prognostics algorithms. To define a representative digital copy of a specific UR5, its kinematic and dynamic parameters were experimentally identified through specific algorithms run on the

real manipulator. Once implemented into the UR5 digital replica, experimental results from several trajectories showed a good match between the simulated and the measured signals, proving the ability of the proposed model to replicate the behavior of the real robot in nominal operating conditions.
To study the effects of faults in the gearbox and their impact on the robot availability and reliability, a in-depth analysis of the failure modes in strain wave gears was conducted through failure modes effects and criticality analysis and fault tree analysis. The root causes of such degradations, together with the fault to failure evolution mechanism of the gear, were derived from an extensive research of the current state of the art and an experimental campaign focused on the introduction of wear in gears of different suppliers. Results showed how the change in the gear performance over time strongly depends both on the manufacturer and which elements are mainly subjected to wear. By analyzing such data, possible health features candidates for wear detection and prediction in strain wave gears were obtained. In addition, crucial insights on how such a failure mode affects the overall behavior of the strain wave gear were acquired. This information was crucial to create a high-fidelity multibody dynamic model of the strain wave gear able to effectively replicate such a phenomenon. The detailed digital replica of the gear was based on the interactions among the single contact interfaces of its main components. To do this, each tooth was modeled as a single body with its own dynamics, connected to the surrounding elements through equivalent visco-elastic models. Preliminary simulation results suggest a good match between the proposed model and state of the art research.