Diagnostics and Prognostics of Industrial and Collaborative Robots

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Borsa di studio di Ateneo

What is PHM?

Prognostics and Health Management is a discipline which aims to predict the Remaining Useful Life (RUL) of a component by trying to predict the development of a fault into a failure.
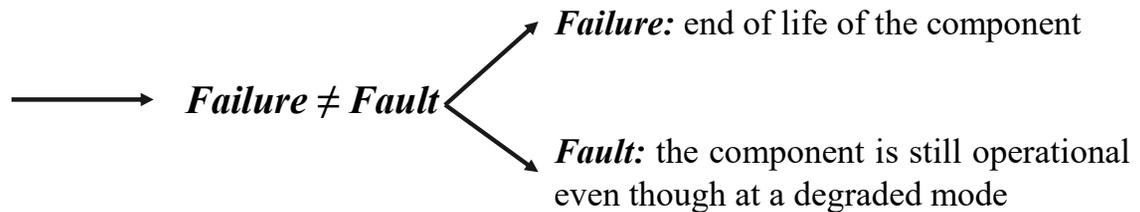
Why PHM?

From scheduled to *predictive maintenance*: cost and time reduction, risk mitigation and higher safety for the personnel.

Why PHM on robots?
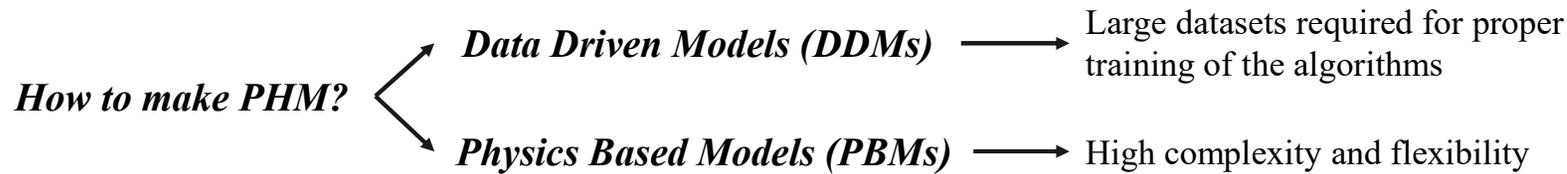
Mean Time Between Failures (MTBF):

- **ABB**: 80000 hours (~ 9 years)
- **Fanuc**: 60000 hours (~ 7 years)
- **Universal Robots**: 35000 hours (~ 4 years)

Failure ≠ Fault

Failure: end of life of the component

Fault: the component is still operational even though at a degraded mode

Diagnostics and Prognostics of Industrial and Collaborative Robots
State of the Art and Starting Point

How to make PHM?

Data Driven Models (DDMs) ⟶ Large datasets required for proper training of the algorithms

Physics Based Models (PBMs) ⟶ High complexity and flexibility

FMECA (Failure Mode, Effects, and Criticality Analysis)

Motors:
- Partial or complete poles demagnetization;
- Dynamic eccentricity;
- Short circuit;
- Overheat and overloading.

Gearboxes (Harmonic Drive):
- Wear/fatigue;
- Pitting;
- Flexspline cracks;
- Degraded lubricant;
- Uneven load distribution.

Encoders:
- Electrical failure (i.e. short circuit and high voltages);
- Seal failure & temperature cycles (optical encoders);
- Shocks and vibrations;
- Output signal failure.

Bearings:
- Wear/fatigue;
- Frequently fluctuating loads;
- Mounting errors;
- Degraded lubricant;
- Corrosion (frictional and fretting).

FTA
(Fault Tree Analysis)

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High Fidelity model of the UR5 collaborative robot
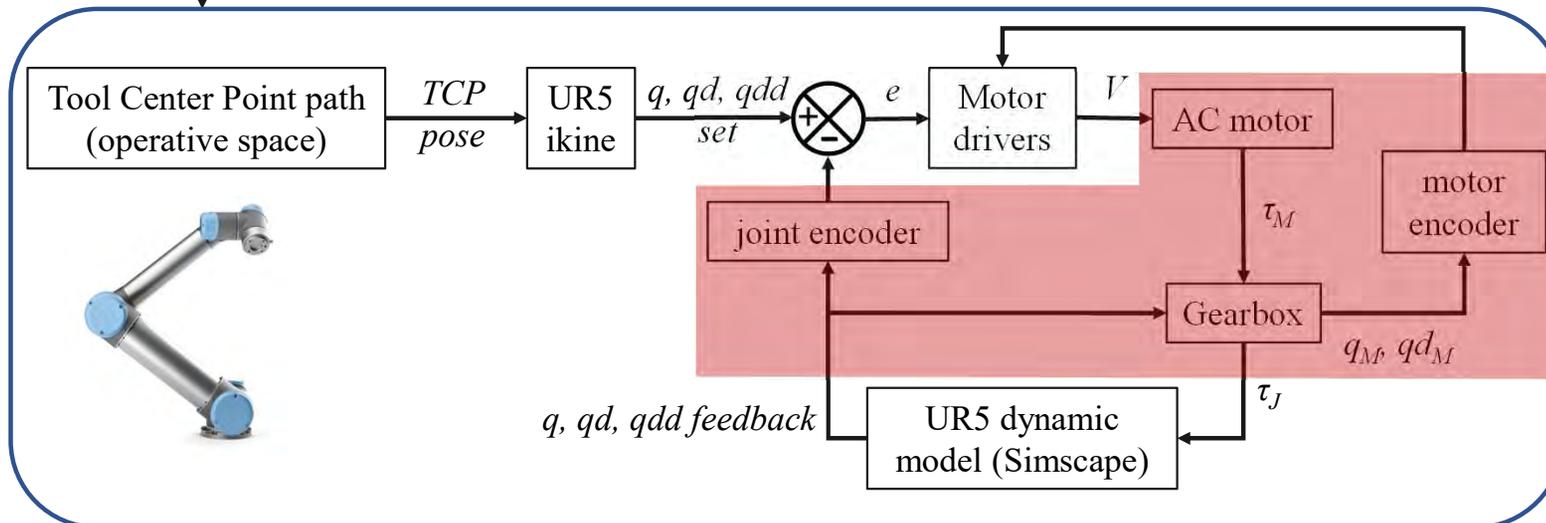
Common faults & failures from FMECA

High Fidelity robot model

Degraded robot behavior

PHM features extraction

Database of simulated faults

State of the art: approximation of **geometric and non-geometric errors** by 6th degree Chebyshev polynomials

Tool Center Point path (operative space) — TCP $pose$ → UR5 ikine — q, qd, qdd set → + − e → Motor drivers — V → AC motor

joint encoder

motor encoder

Gearbox

τ_M

q_M, qd_M

τ_J

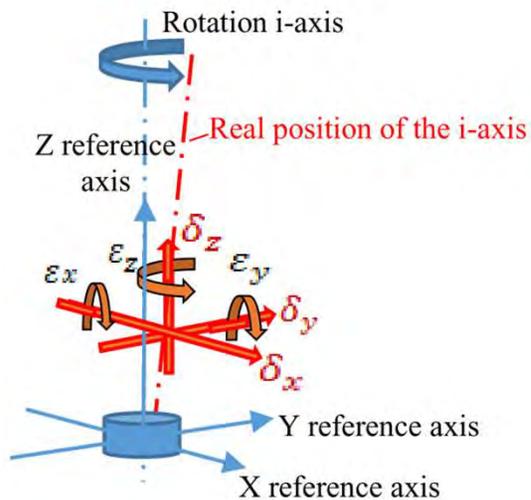q, qd, qdd feedback — UR5 dynamic model (Simscape)

Diagnostics and Prognostics of Industrial and Collaborative Robots

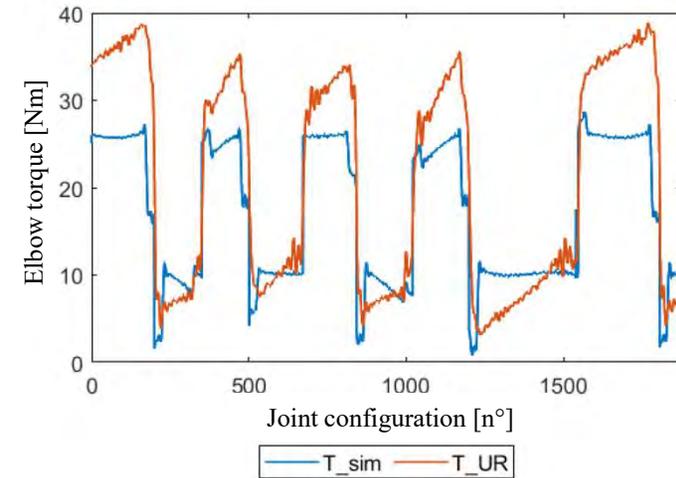*Improvements to the UR5 model: kinematic and dynamic parameters identification*

High-level model
of the UR5

Dynamic parameters identification
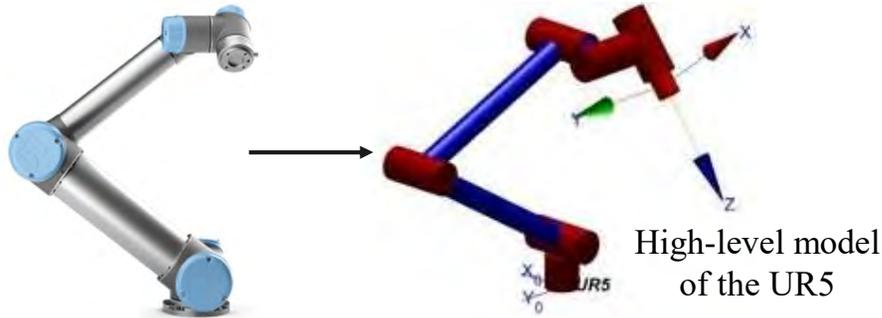
Kinematic parameters identification by Genetic Algorithm

- Geometric errors identification

- Enhanced model accuracy

- Better ikine algorithm

13 dynamic parameters for each joint/link (78 in total):
- Link mass (1)
- Position of the link center of mass (3)
- Link inertia tensor (6)
- Motor inertia (1)
- ***Coulomb and viscous friction coefficients*** (2)

Friction coefficients variations are the indicators of a
degradation in the robot health status

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PhD overview

Achieved results:
- Assembly of an experimental setup in the mechanical engineering laboratory;
- FMECA analysis of an industrial robot;
- High level model of the UR5 for kinematic and dynamic calibration;
- Development and test of the inverse kinematics algorithm for the UR5;
- Tests of the UR5 HF model with DC motors.

Work in progress:
- FTA analysis of an industrial robot;
- Tests of the UR5 HF model with mono-phase AC motors;
- Calibration of the PID controllers in the UR5 HF model control loops;
- Dynamic parameters identification of the UR5 collaborative robot.

Next steps:
- Implementation of a 3-phase AC motor into the HF model of the UR5;
- Development of a dynamic model of the harmonic drive;
- Experimental campaign for the UR5 HF model validation;
- Features identification and extraction for PHM analyses.