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Real-time issues in smart manufacturing systems

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PARCO
Parallel Computing Lab

FORMAL METHODS for ENGINEERING

NeST

Agenda

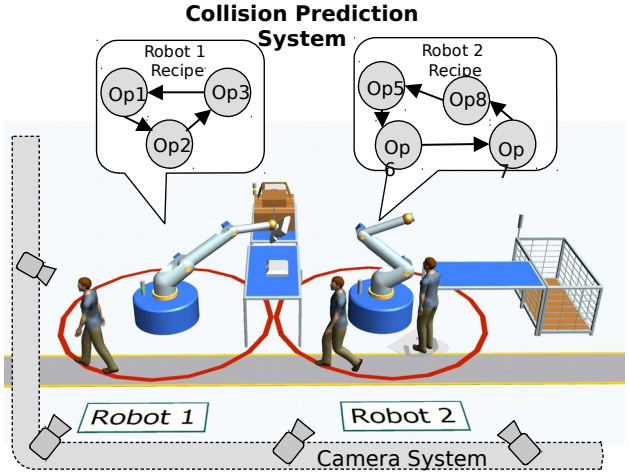
- Background and Motivation
- Problem Statement
- Methodology
- Experimental Setup and Results
- Conclusions and Future Work

Background

- Robots and humans share the same work environment and the human could intersect the trajectory of a robot

- Many studies exist on **collision avoidance** to circumvent injuries and production down times

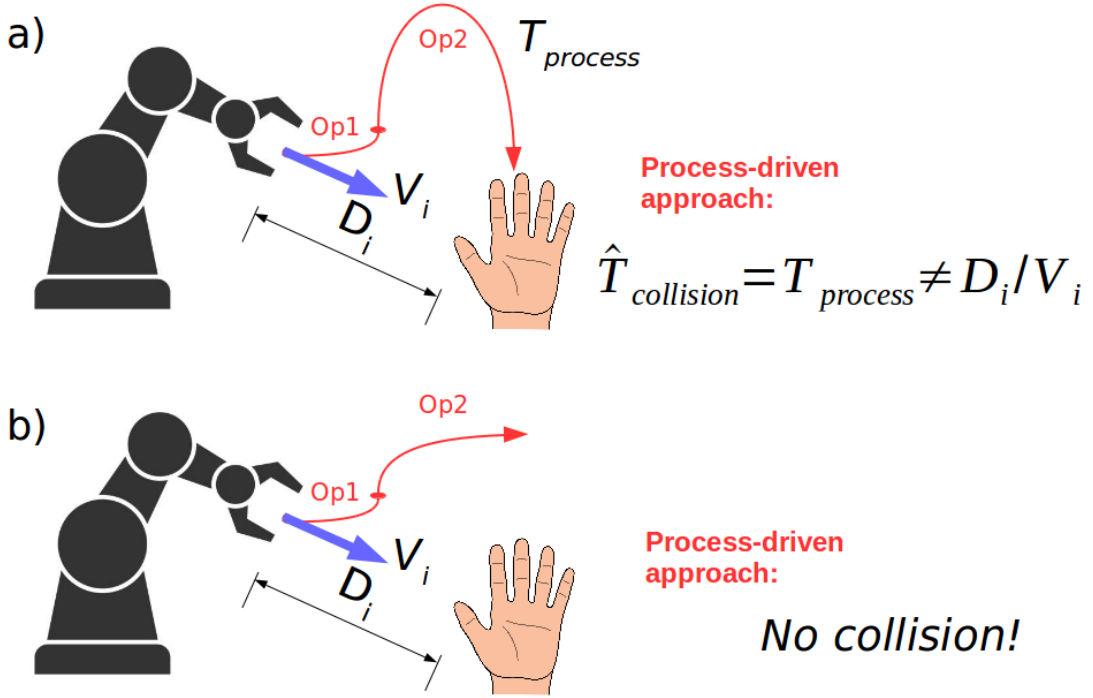
- **Common problem: to know in advance that a collision may occur within a specific time margin**



Motivating examples

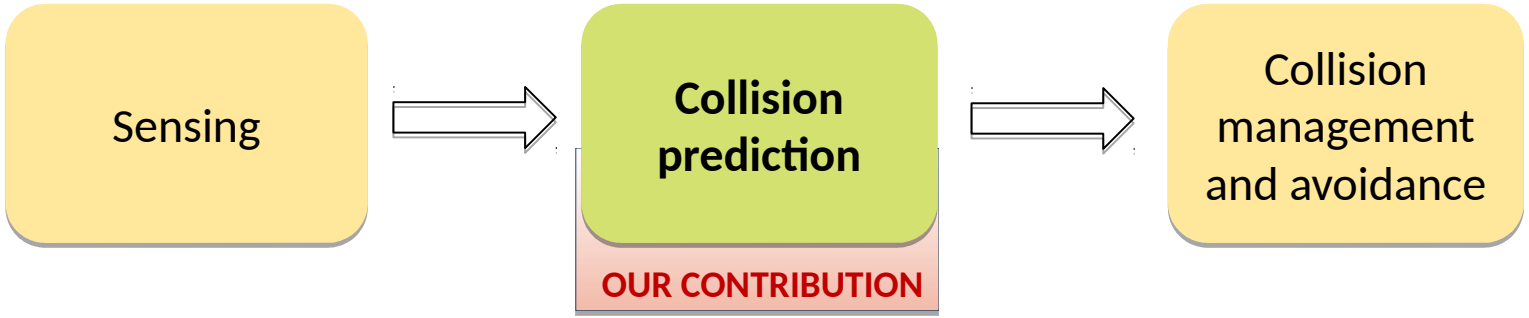
Process = (Op1, Op2, …)

Geometrical approach: $\hat{T}_{collision} = D_i / V_i$



Problem statement

Human-robot collision management system workflow:



GOAL: Given a working environment with *n* robots and *m* operators, monitored by multiple cameras, what is the minimum time for a (potential) collision?

Problem statement

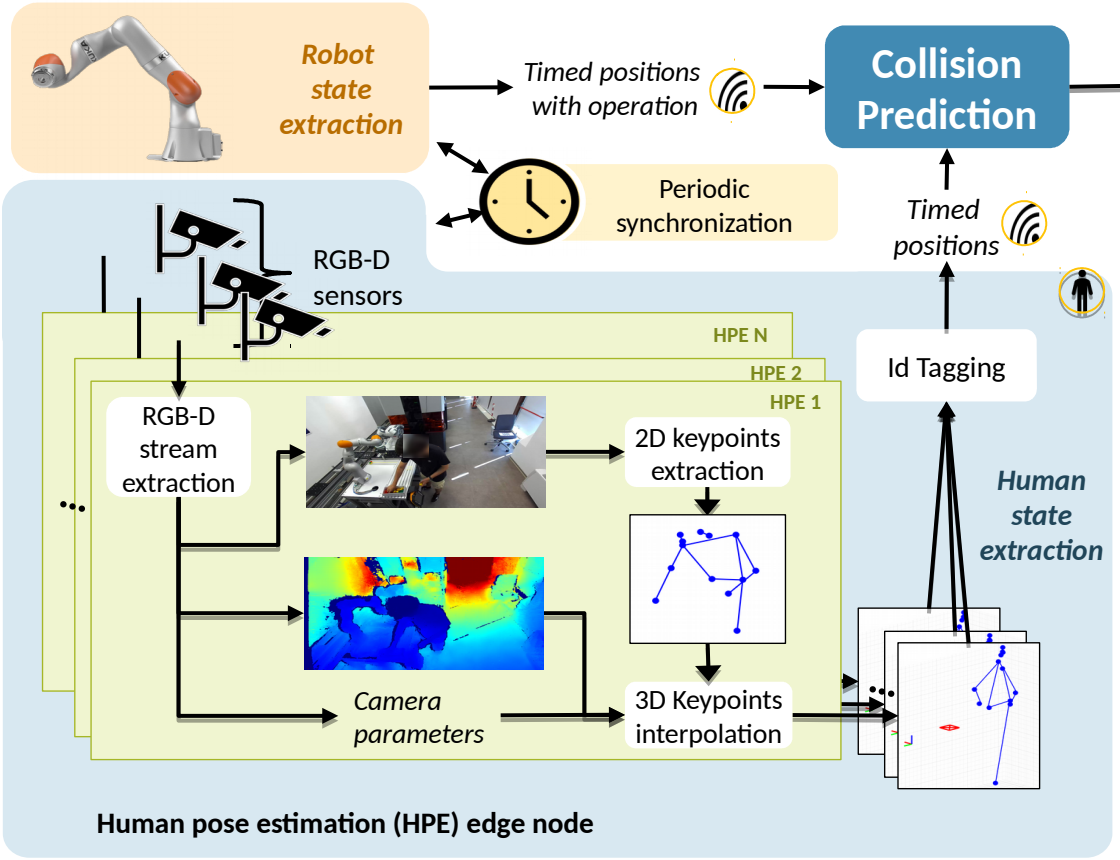
ASSUMPTIONS

- **Robot:**
  - Process variables and 3D position of joints are extracted from the robot firmware
  - Dynamics are not known in advance but repeated and thus predictable
  - Distinct operations correspond, partially, to distinct dynamics
- **Human:**
  - Human pose estimation (HPE) → 3D position of keypoints of the body
  - Timed keypoints collected with *not necessarily* fixed frequency

OBJECTIVE

For all human-robot body part pairs,
identify the minimum time for a collision and its likelihood

Architecture

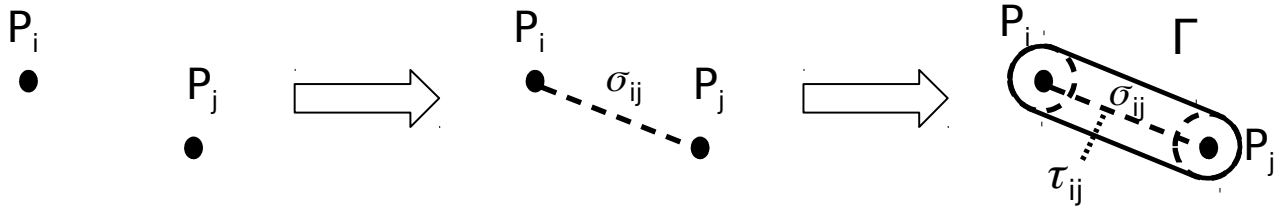


Shared industrial transmission channel: standard industrial protocol like MQTT, KAFKA etc…

Markerless real-time Human Pose Estimation: suitable for real industrial scenarios

Methodology

- **Body part**
  - Both human and robot parts are represented as **capsules**
  - Given P_i and P_j as keypoints/joints of human/robot, let σ_{ij} be the segment between P_i and P_j and Γ be the capsule generated by an isotropical expansion of σ_{ij} by the pre-calculated thickness τ
  - thickness τ can be adapted to model different humans/robots



Methodology

- The collision between the two bodies are predicted based on the possible intersection between all the parts
- **Intersection check:** Given two capsules $\Gamma'$and Γ'' and their overapproximated thickness ρ', ρ'' defined as the sum of the thickness of the segments with an uniform error measure:

No collision: $d(\sigma', \sigma'') > \rho' + \rho'' \Longrightarrow \Gamma' \cap \Gamma'' = \emptyset$

Collision : $d(\sigma', \sigma'') \leq \rho' + \rho'' \Longrightarrow possibly\ \Gamma' \cap \Gamma'' \neq \emptyset$

Methodology

- Prediction steps:

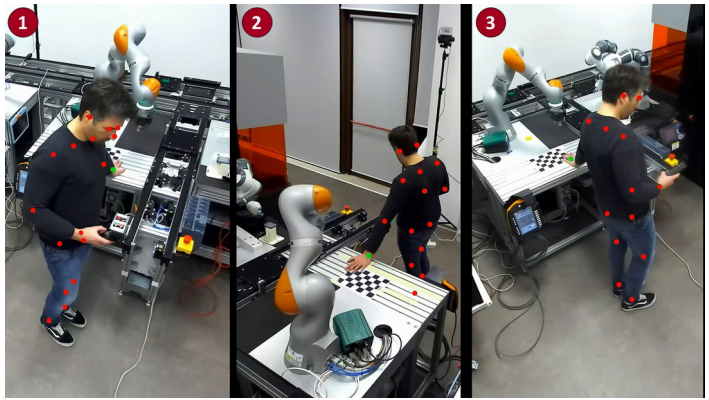
Presentation message for a new body:
- ID
- Human/Robot
- Thickness
- Segments
- Hz (only robot)

Update the history trace of the robot from the beginning of the operation

Use the history trace and the current human state to check the intersection

Experimental setup

- **Realistic industrial setup:** ICE Lab
- **3 HPE edge nodes**
  - RGB-D camera + Edge computing board
- **Robotic arm** KUKA LBR IIWA R820

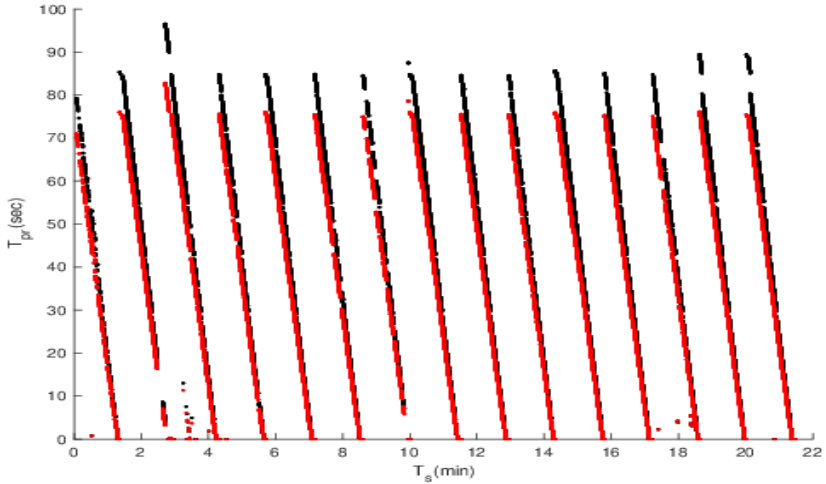


- Two types of **scenarios**:
  - Static: to test the quality of the prediction based on the quality of samples (occlusions and positions) -> *Pre trained system*
  - Dynamic: to simulate a real work environment -> *Online learning*

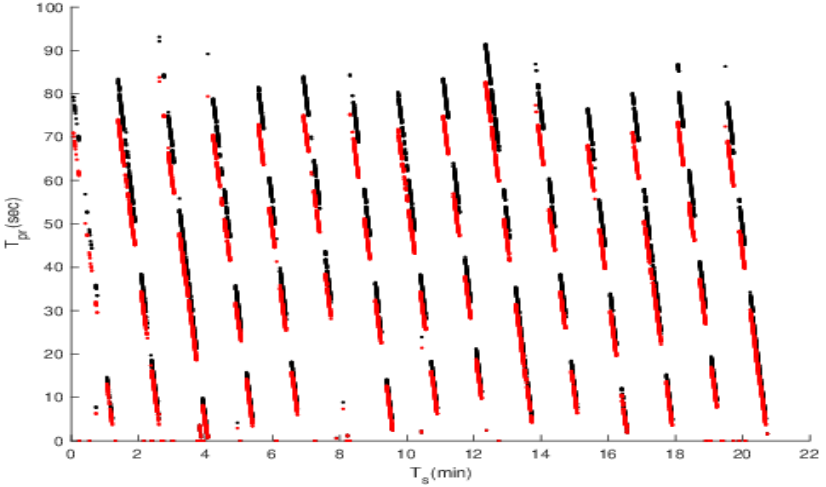
Experimental Results

- Lower bound
- Upper bound

- Prediction time T_{pr} :
  - Robot performs the same recipe in both the scenarios



Static: human at fixed position, 15 collisions



Dynamic: human switches from a position to another every 10s

Conclusions and Future Work

- This formal methodology is shown to be sound and effective to identify potential collisions with a manipulator
- The scalability has been demonstrated on a wide range of scenarios, also assessing the impact of occlusions
- This work is an enabling technology that aims at safety but also efficiency of the production process
- **Future work:**
  - Human pose forecasting techniques to predict the operator behavior

Thank you!

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