# Towards Safe Human-Robot Interaction: evaluating in real-time the severity of possible collisions in industrial scenarios

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## I. Introduction

It is today a common opinion that a more structured and fruitful human-robot cooperation will facilitate industrial robots to be massively used also in SMEs. In order to guarantee a certain level of safety while removing physical barriers, a methodology to evaluate in real-time the severity of a possible impact between a robot and a human worker has to be established. Moreover safety-oriented control strategies, exploiting the computed severity measure, need to be developed.

## II. Real-Time Severity Evaluation

The problem addressed in this research is to evaluate the severity of a possible impact between a human being and a moving industrial robot, given the kinematic and/or dynamic configuration of both the human and the robot. The proposed severity evaluation methodology relies on the information coming from the robot's encoders, from a Human Detection and Tracking system (see [1]), that computes position and velocity of the human worker, and from a multi-spot LED-based distance sensor installed on the robot.

The following "Danger Indices" are computed in real-time:

- **injury type**: `FREE IMPACT` or `CLAMPING`;
- **body part**: `HEAD` or `THORAX`;
- **relative velocity** between the robot and the human;
- **equivalent mass** of the robot in the direction of the linear velocity of the impact point (see [2]);
- **force** exerted by the manipulator at the impact point;
- **radius** of the robot surface at the impact point;
- **stiffness** of the robot surface at the impact point.

Different values of the Danger Indices have been mapped to an overall Severity Index (`GREEN`, `YELLOW`, `ORANGE` or `RED`) by simulating a large number of collision between a mass and a FE model of the human being. Once all the indices have been evaluated, a "Lookup Table" is queried and the result of the query is the value of the Severity Index associated to the current interaction situation.

Finally the distributed multi-spot distance sensor measures the proximity of close obstacles (see [3]) and computes the Danger Field associated to these obstacles (see [4]).

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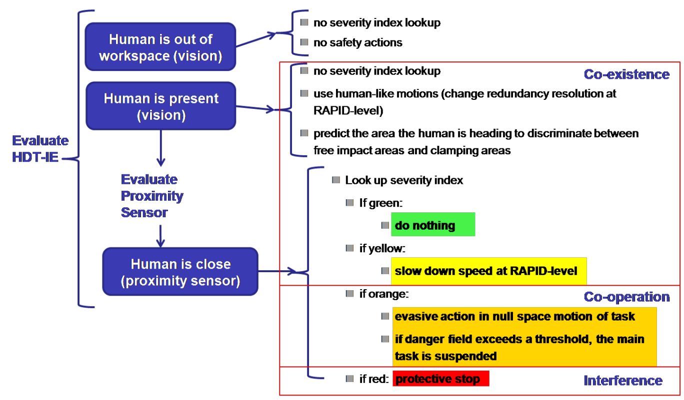


Fig. 1. Safety-Oriented Control Strategy Decision Tree.

## III. Safety-Oriented Control Strategy

The Safety-Oriented Control Strategy sketched in Figure 1 works as follows. If the distance between the human and the robot is larger than 1.5 m, no safety action is enforced, otherwise:

- **Severity =** `GREEN` $\Longrightarrow$ no safety action enforced;
- **Severity =** `YELLOW` $\Longrightarrow$ 50% speed reduction;
- **Severity =** `ORANGE` $\Longrightarrow$ the robot performs an evasive motion trying to maintain the task while moving as far away as possible from the human. More in depth, given a threshold value $\mathbf{DF_{th}}$ for the Danger Field:
  - ◇ $\mathbf{DF} < \mathbf{DF_{th}} \Longrightarrow$ TCP orientation task suspension;
  - ◇ $\mathbf{DF} \geq \mathbf{DF_{th}} \Longrightarrow$ full task suspension (TCP orientation and positioning);
- **Severity =** `RED` $\Longrightarrow$ protective stop is enforced;

Several experiments involving humans sharing the workspace of the sensorized ABB IRB 140 have been carried out (as documented in [5]), demonstrating the effectiveness of our approach within a realistic industrial scenario.

## References

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[4] B. Lacevic and P. Rocco, "Kinetostatic danger field - a novel safety assessment for human-robot interaction," in *IEEE/RSJ Int. Conf. Int. Rob. Sys.*, 2010, pp. 2169–2174.

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