Collaborative robotized assembly of composite fuselage panels

Gaetano Lettera, Ciro Natale

UNIVERSITÀ DEGLI STUDI DELLA CAMPANIA LUIGI VANVITELLI

10th EASN Virtual International Conference

Innovation in Aviation & Space to the Satisfaction of the European Citizens

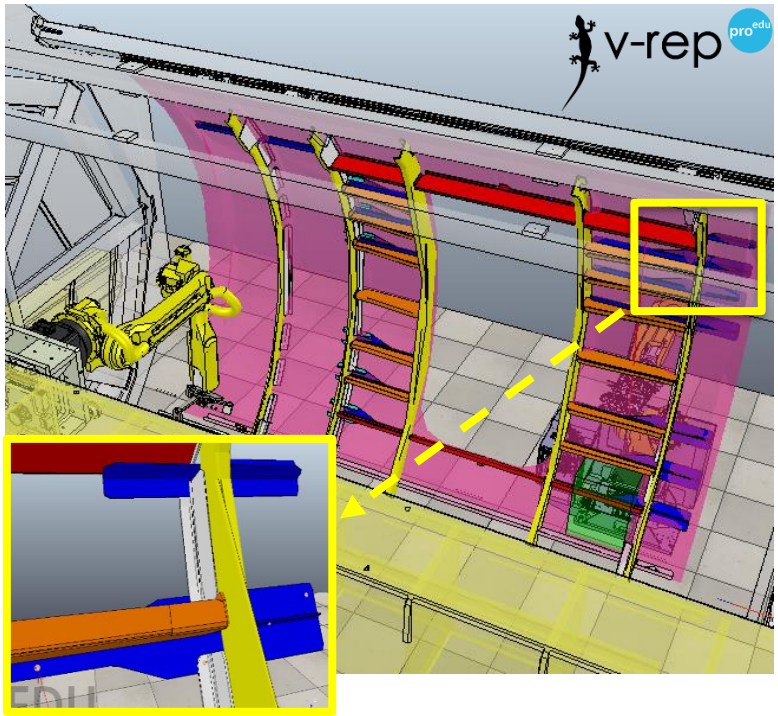
Outline

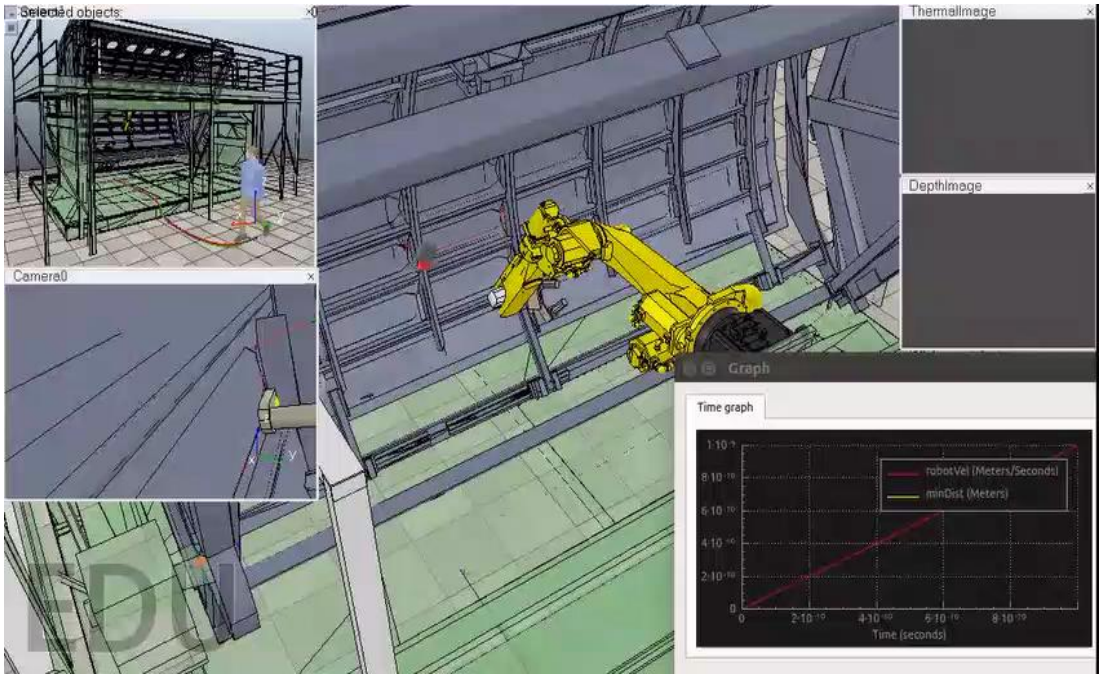
- The LABOR project: HRC Module
  - Objectives
  - Proposed approach
- Human detection and tracking
  - Segmentation pipeline
  - Sensor fusion and CNN
  - Human-robot separation distance
- Feed rate override computation
  - Thermal point cloud
  - Fuzzy control logic
- Experimental results
  - HRC Module architecture
  - Algorithm validation

The LABOR project: HRC Module

Objectives

- Real-time collaborative algorithm to increase robotized assembly productivity
  - reliable human worker detection
  - robot speed control based on risk assessment
  - human safety preservation while keeping high productivity
  - compliance with the current **ISO 10218-1/2** and **TS 15066**, which controls the robot speed based on the separation distance between the robot and the worker





The LABOR project: HRC Module
Proposed approach

HUMAN DETECTION AND TRACKING

- *Convolutional Neural Network (CNN):* depth and thermal data are merged to avoid false positives
- *Point-cloud approach:* the human cluster which is the closest to the robot is identified to compute the separation distance

FEED RATE OVERRIDE COMPUTATION

- *Speed and Separation Monitoring (SSM)*

$$S = \alpha\,[(v_H T_R + v_H T_S) + (v_R T_R)] + (B) + (C + Z_R + Z_S)$$

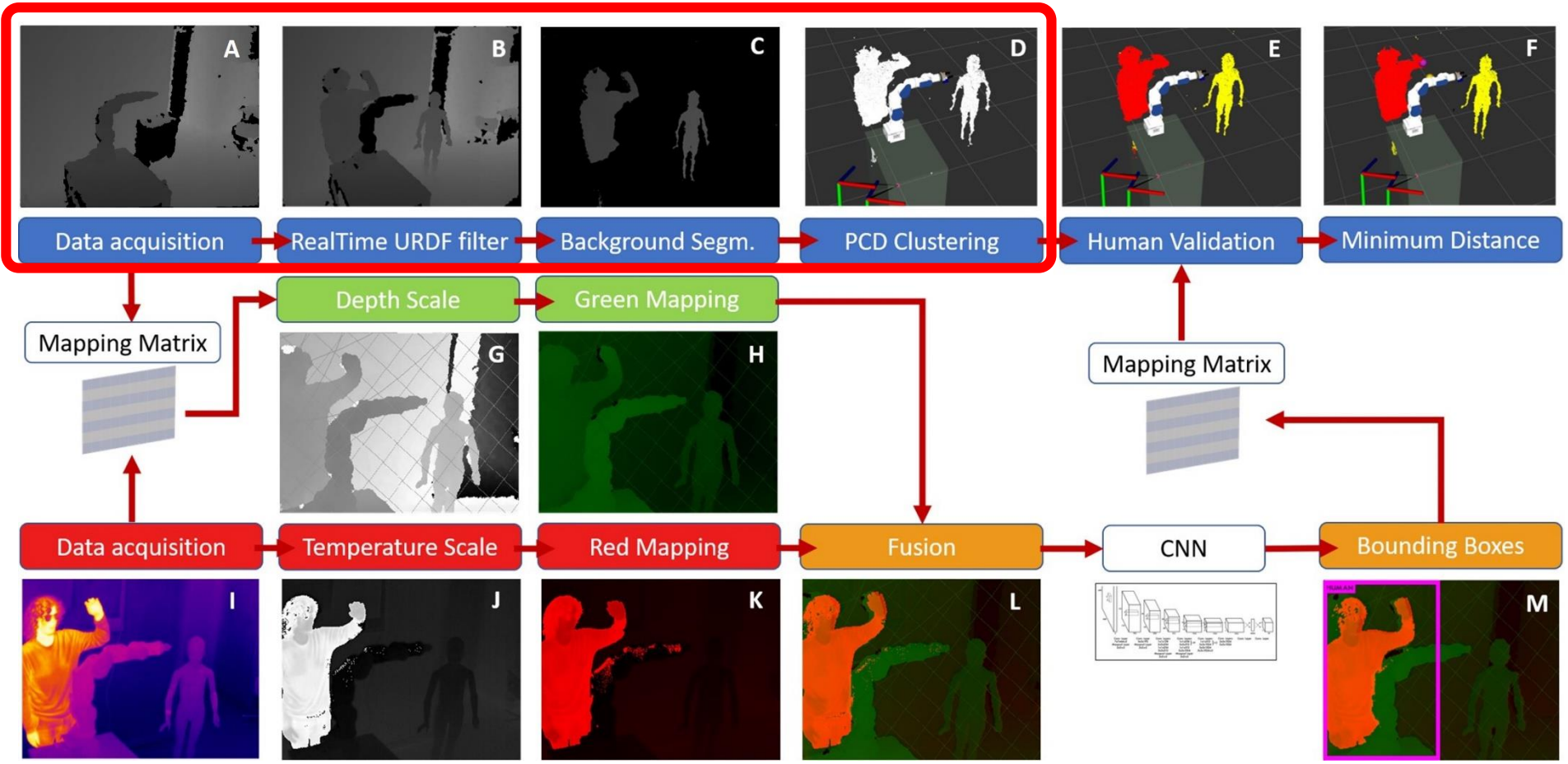
v_H and v_R: human speed (v_H) and robot speed (v_R) are computed in real-time

α: risk assessment (FUZZY CONTROL LOGIC)

- *Robot speed adaptation:*
  - real-time estimation of the minimum protective distance, S
  - real-time risk assessment analysis through an AI system that reasons about
    - the computed separation distance, d
    - the human-robot moving directions
    - the thermal information to distinguish points belonging to the body surface from any tools held by the worker

Human detection and tracking

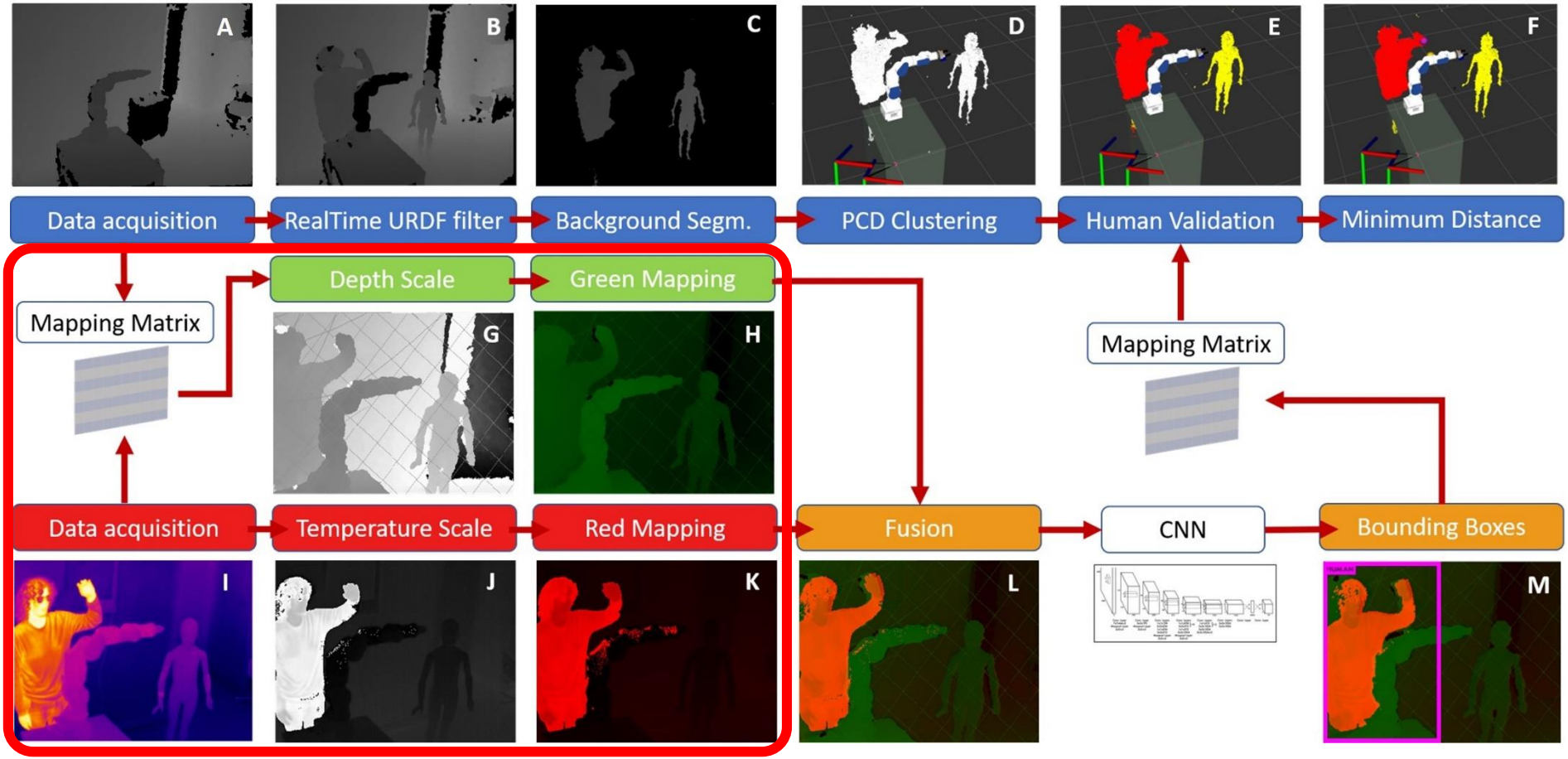
Segmentation pipeline



- The static background is subtracted from the depth image and the *Euclidean cluster extraction* method is performed to identify all the clusters in the foreground

A Multimodal Perception System for Detection of Human Operators in Robotic Work Cells*, M. Costanzo, G. De Maria, **G. Lettera, D. Perrone and C. Natale

Human detection and tracking
Sensor fusion and CNN

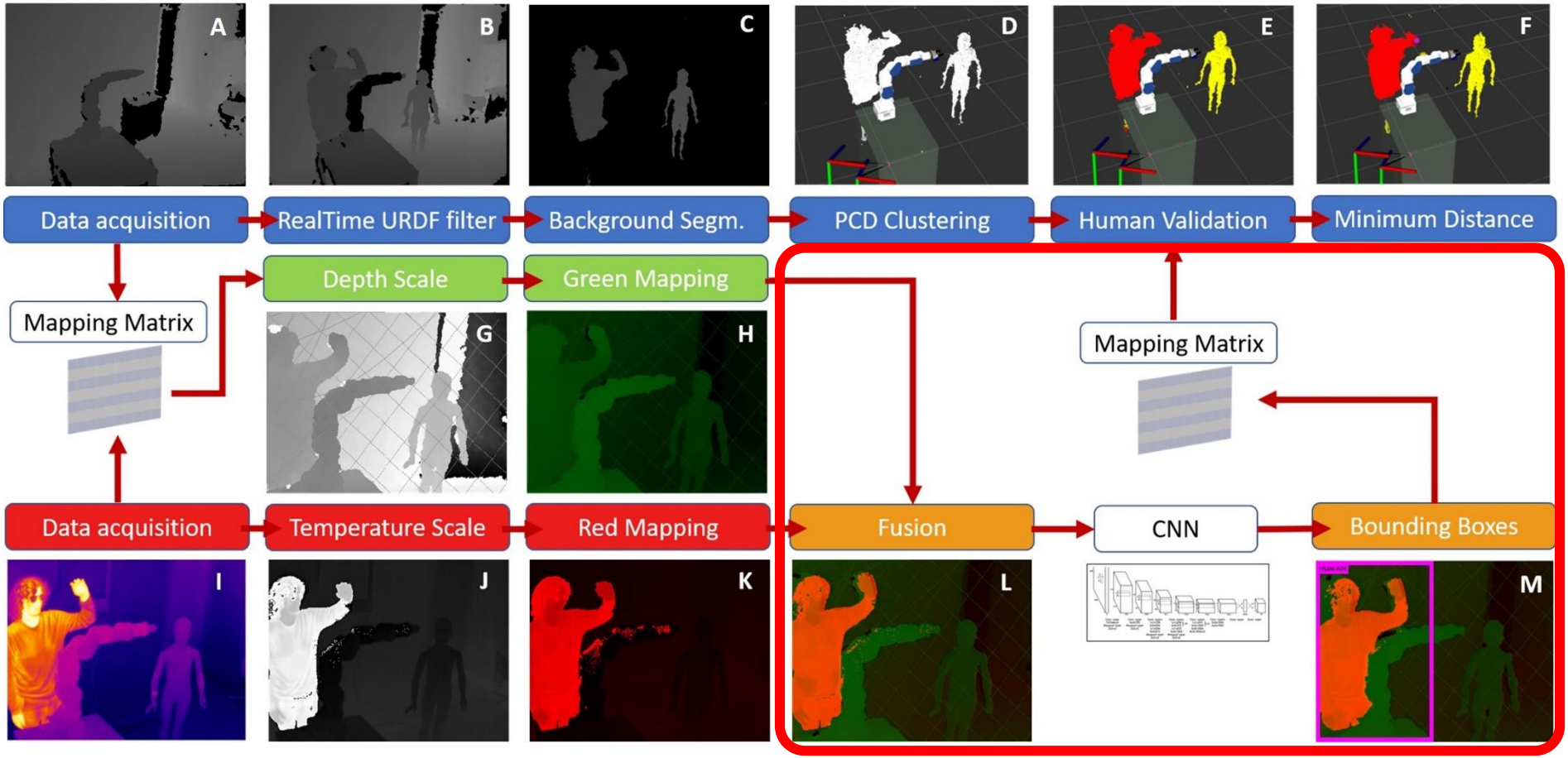


- The sensor fusion of the depth image and the thermal image is carried out by using a mapping algorithm that produces an RGB image containing depth values on the green channel and thermal data on the red one

A Multimodal Perception System for Detection of Human Operators in Robotic Work Cells*, M. Costanzo, G. De Maria, **G. Lettera, D. Perrone and C. Natale

Human detection and tracking

Sensor fusion and CNN

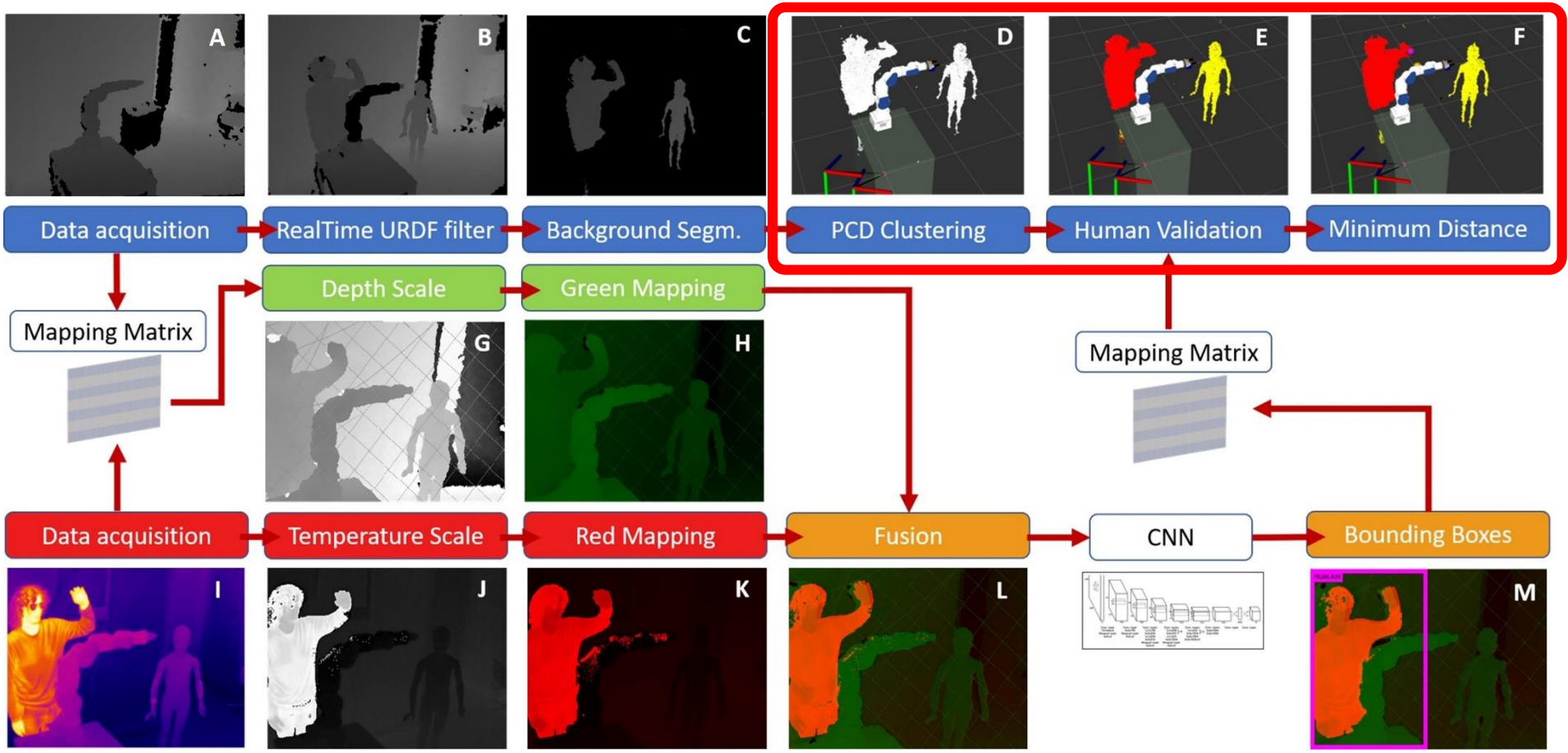


- The fused image is then classified by the YOLO deep neural network to recognize the humans in the work cell, identifying a magenta bounding box around each detected human

A Multimodal Perception System for Detection of Human Operators in Robotic Work Cells*, M. Costanzo, G. De Maria, **G. Lettera, D. Perrone and C. Natale

Human detection and tracking

Human-robot separation distance

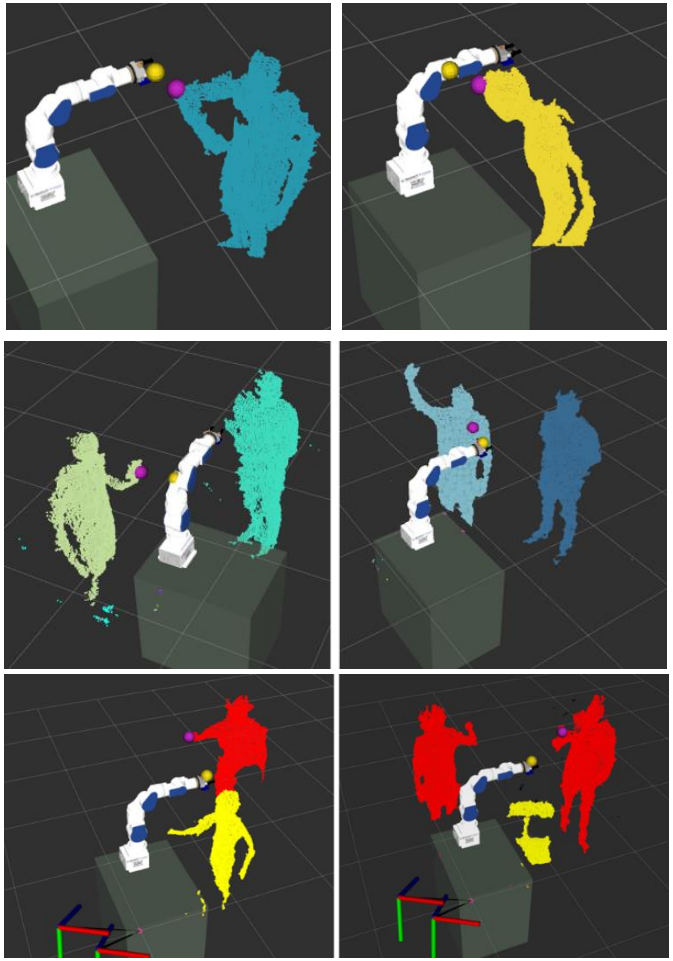


- The last step, the *Human Validation Check*, computes the human-robot separation distance between the robot and the point-cloud clusters validated as 'Human' by the CNN

A Multimodal Perception System for Detection of Human Operators in Robotic Work Cells*, M. Costanzo, G. De Maria, **G. Lettera, D. Perrone and C. Natale

Human detection and tracking
Human-robot separation distance

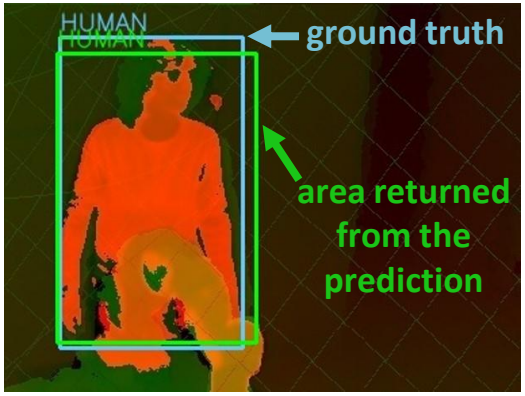
- The identification of the points at minimum distance, one belonging to the robot (P_R, yellow sphere) and one belonging to the operator (P_H, purple sphere) is immediate



$$P_H \in \mathcal{H}, P_R \in \mathcal{R} | \; d(P_H, P_R) < d(P'_H, P'_R) \quad \forall \; P'_H \in \mathcal{H}, P'_R \in \mathcal{R}$$

- Whole surface of human operators
- Whole robot kinematic chain/volume
- More than one human workers

CNN ACCURACY: MEAN AVERAGE PRECISION (maP)



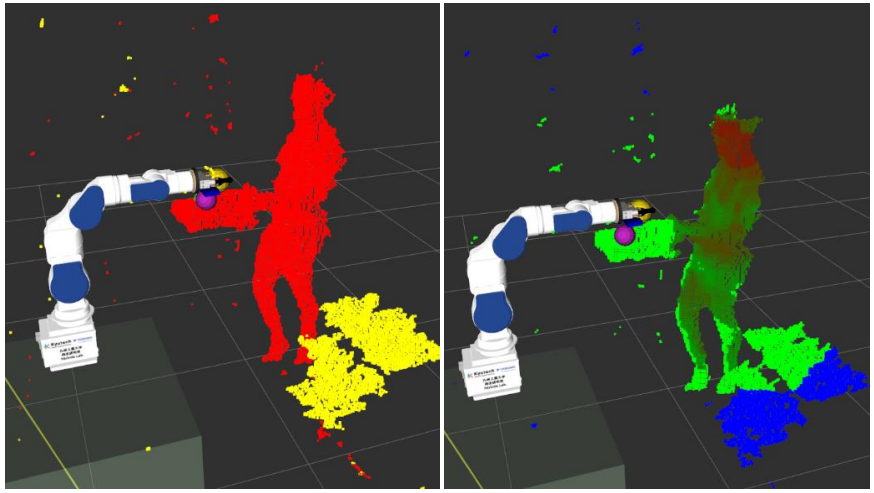
CNN	mAP %	FP%	FN%
D-CNN	65.09	36.87	17.53
T-CNN	62.76	64.35	4.37
DT-CNN	57.54	2.47	11.85

A Multimodal Perception System for Detection of Human Operators in Robotic Work Cells*, M. Costanzo, G. De Maria, **G. Lettera, D. Perrone and C. Natale

Feed rate override computation

Thermal point cloud & Fuzzy control logic

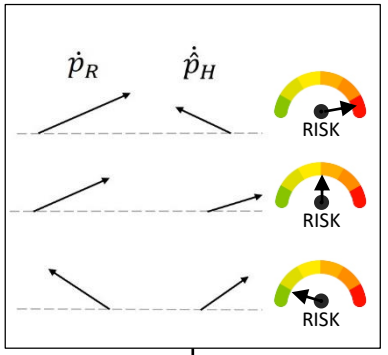
THERMAL POINT CLOUD



ARTIFICIAL INTELLIGENCE SYSTEM

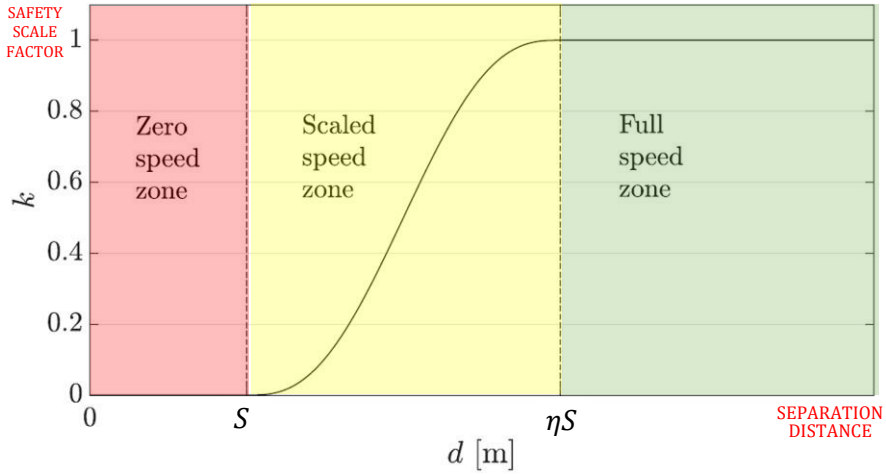
$$S = \alpha\,[(v_H T_R + v_H T_S) + (v_R T_R)] + (B) + (C + Z_R + Z_S)$$

ANTECEDENT			CONSEQUENT
$\dot{d}$	$\dot{p}_R^T \dot{p}_H^T$	T_{human}	α
N	-	-	H
P	N	-	S
P	P	-	M
-	-	Yes	H
-	-	No	S



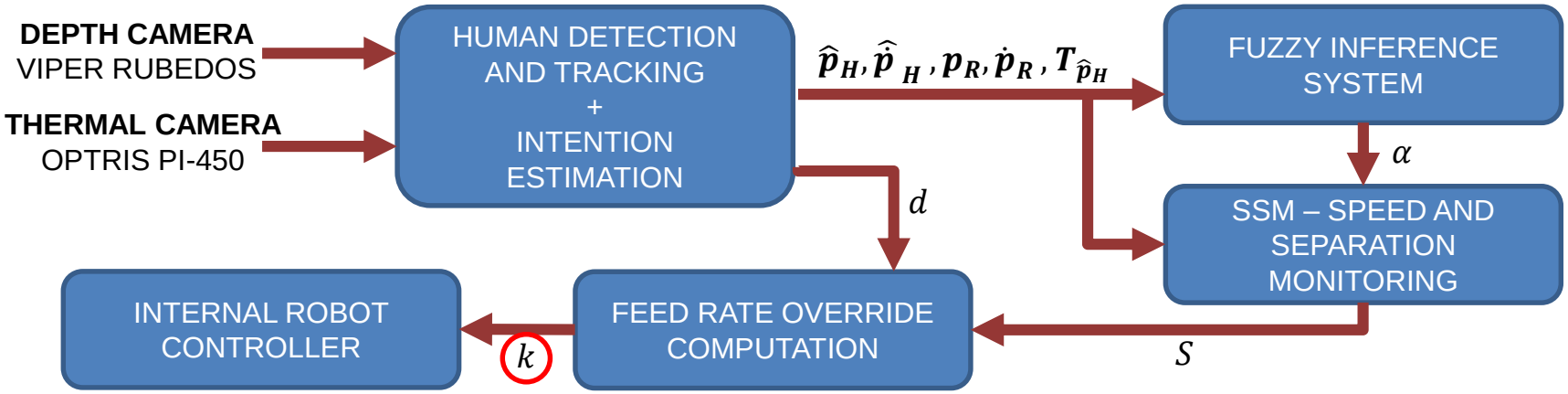
PROGRESS BAR

- Not all the points of a human cluster could belong to the body surface
- The worker could hold a proper tool for his manual operation, i.e., a drilling or a sealing tool, a screwdriver, a hammer
- Thermal information can distinguish the points belonging to the tool from those of the human body inside a single cluster

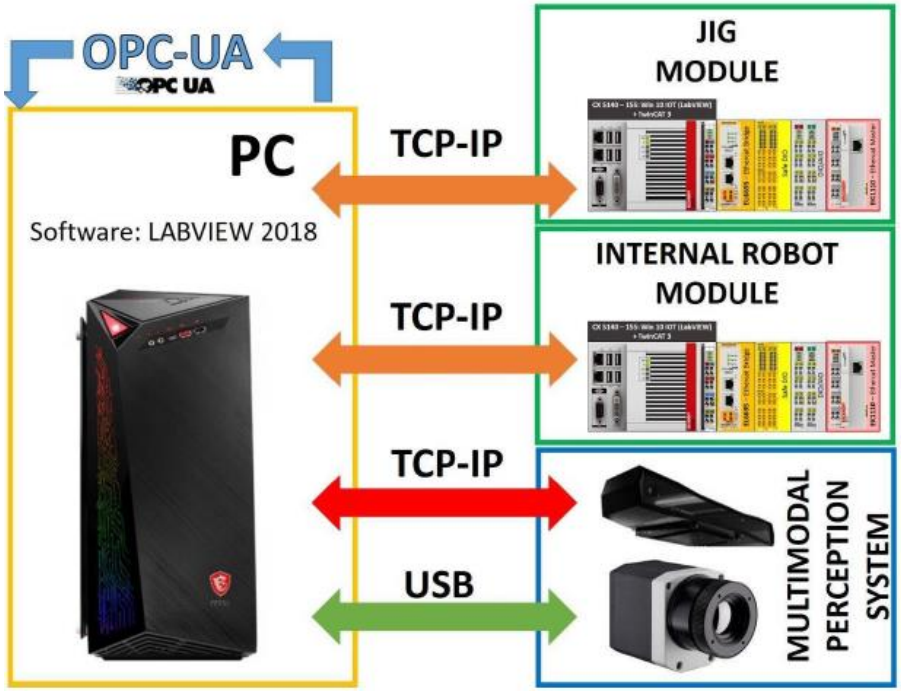


A fuzzy inference approach to control robot speed in human-robot shared workspaces,* A. Campomaggiore, M. Costanzo, **G. Lettera and C. Natale

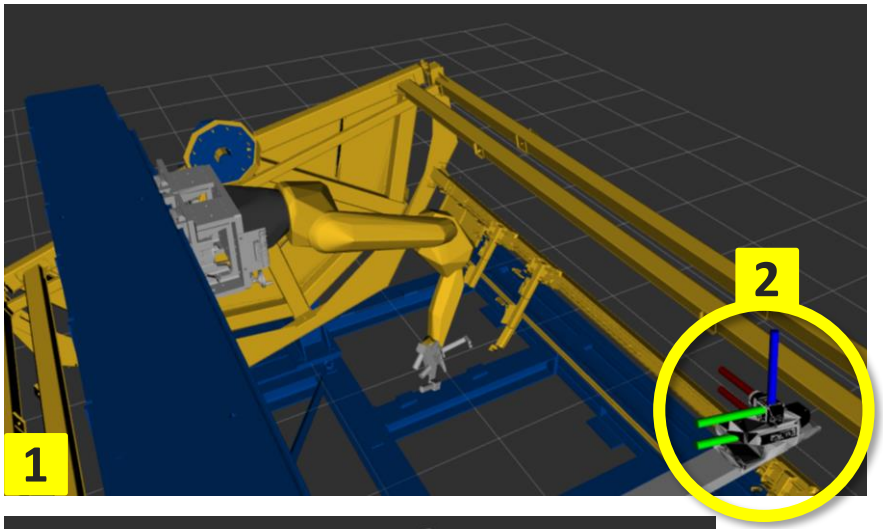
Experimental results
HRC Module architecture

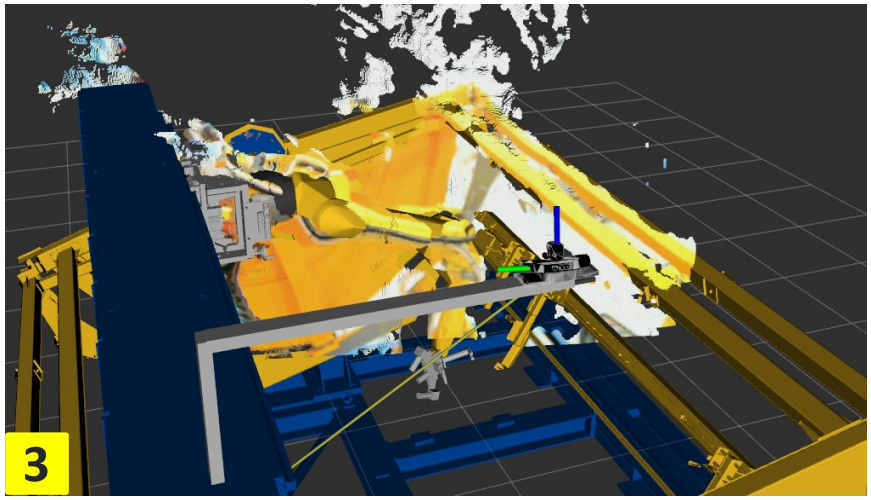


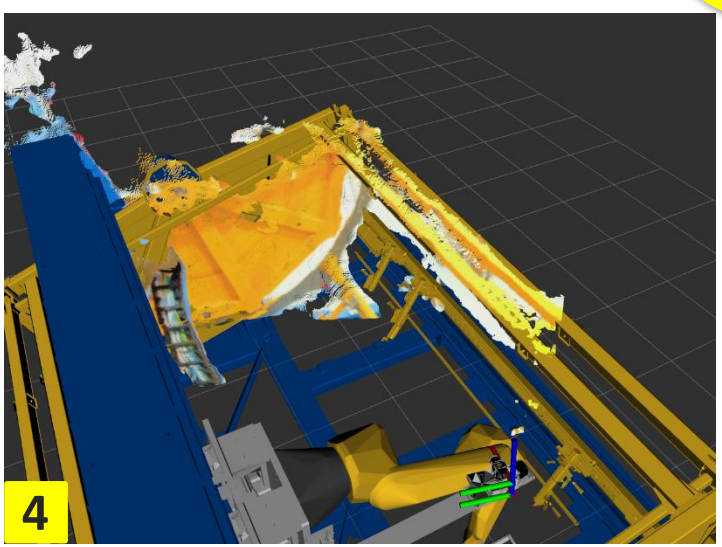
- $\hat{p}_H$: human point at minimum distance from the robot
- $\dot{\hat{p}}_H$: estimated human point speed
- p_R: robot point at minimum distance from the operator
- $\dot{p}_R$: robot point speed
- $T_{\hat{p}_H}$: temperature of $\hat{p}_H$
- α: hazard evaluation factor
- S: minimum protective separation distance
- d: separation distance between p_R and $\hat{p}_H$
- k: feed rate override



- *Digital model of the LABOR work cell*

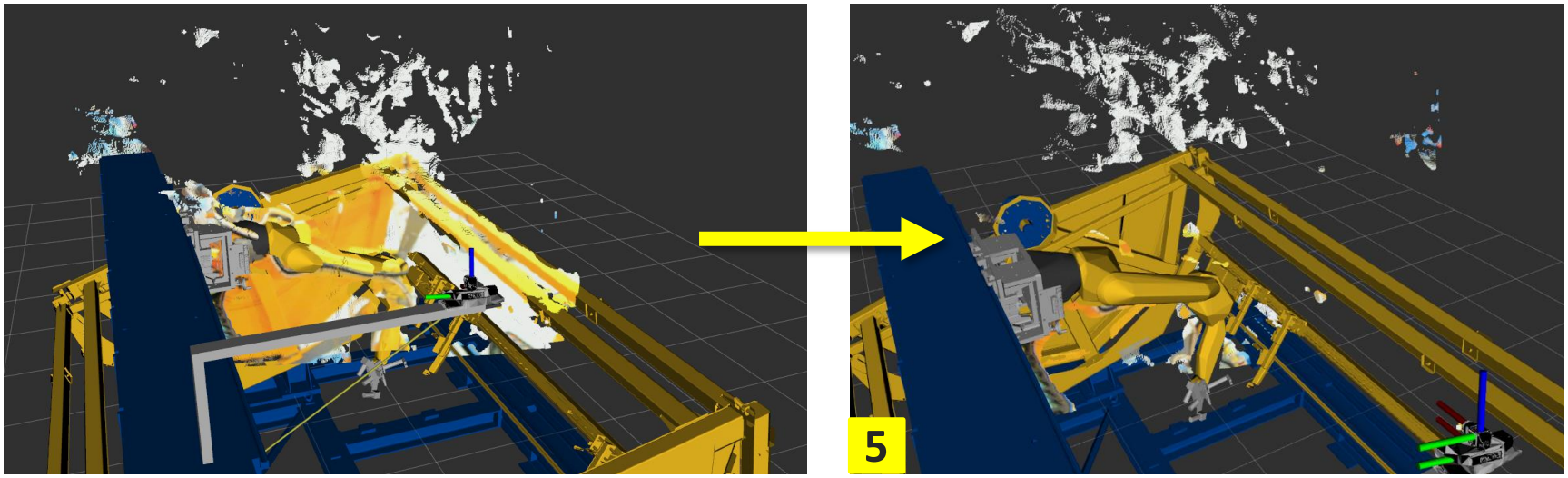


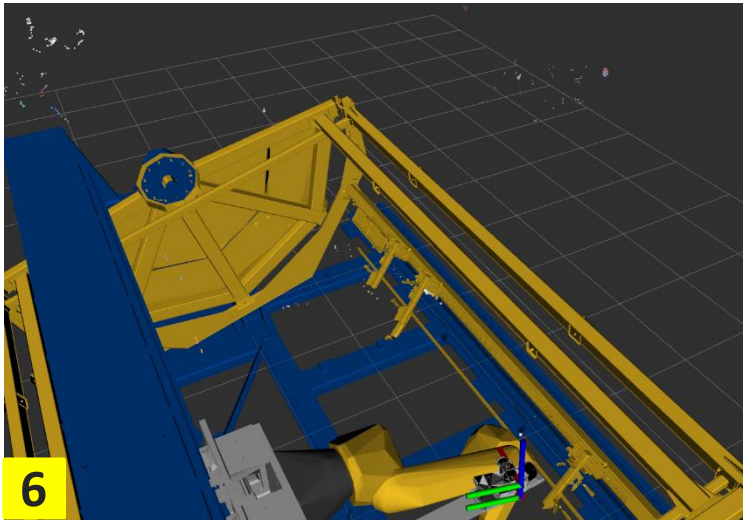




- Development of the digital model of the LABOR cell in ***RViz viewer*** 1
- Estimation of the depth camera pose through the extrinsic calibration procedure developed in ***Matlab*** 2
- Overlaying of the sensor data (3D point-cloud) on the digital model in real-time 3 4

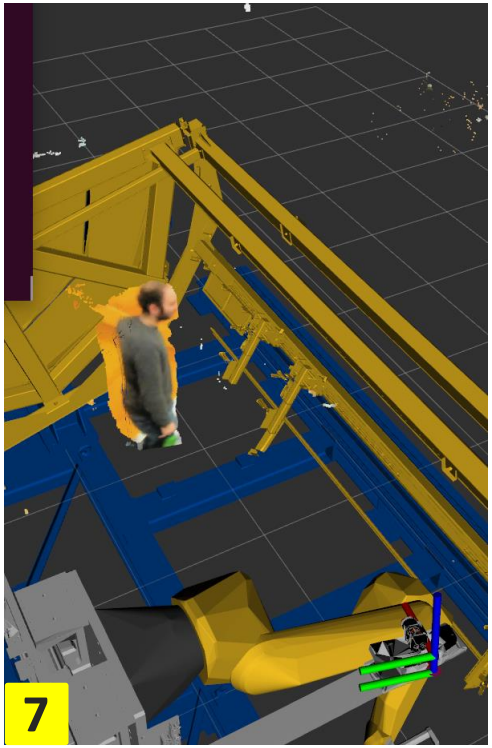
- *Background Segmentation*

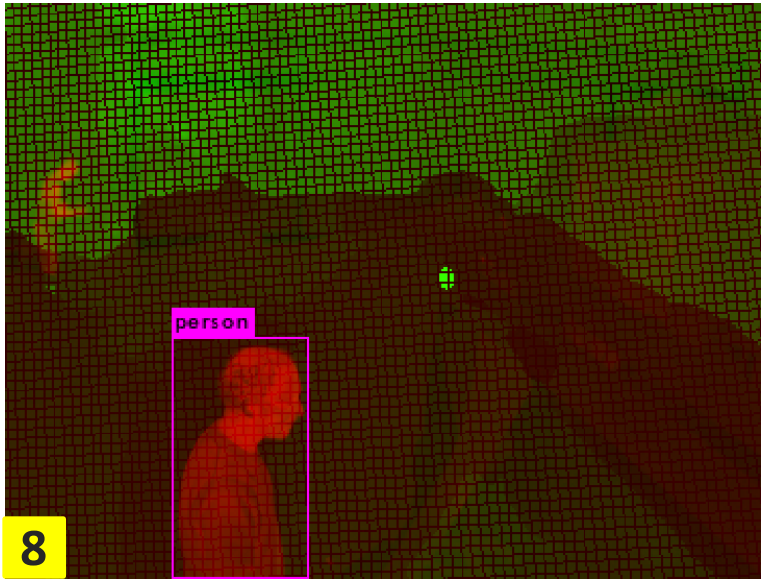


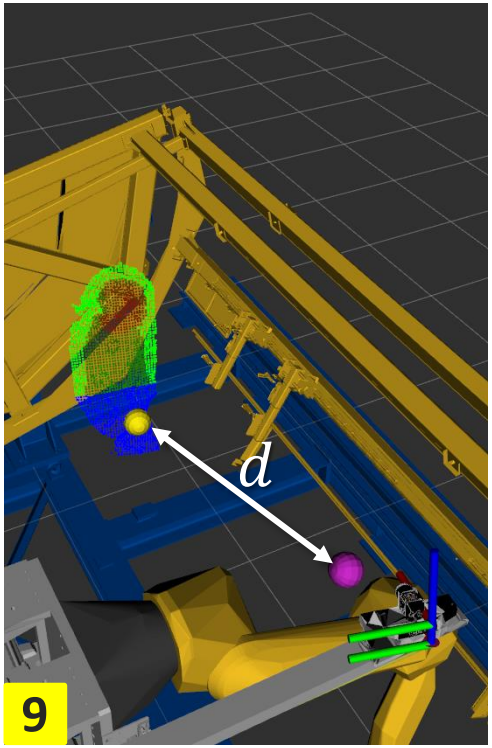


- The *Background Segmentation* step is executed to filter the static background of the observed scenario 5
- When the internal robot moves into the collaborative scenario, its volume is filtered through the *RealTime URDF Filter* module 6

- *Human Validation*

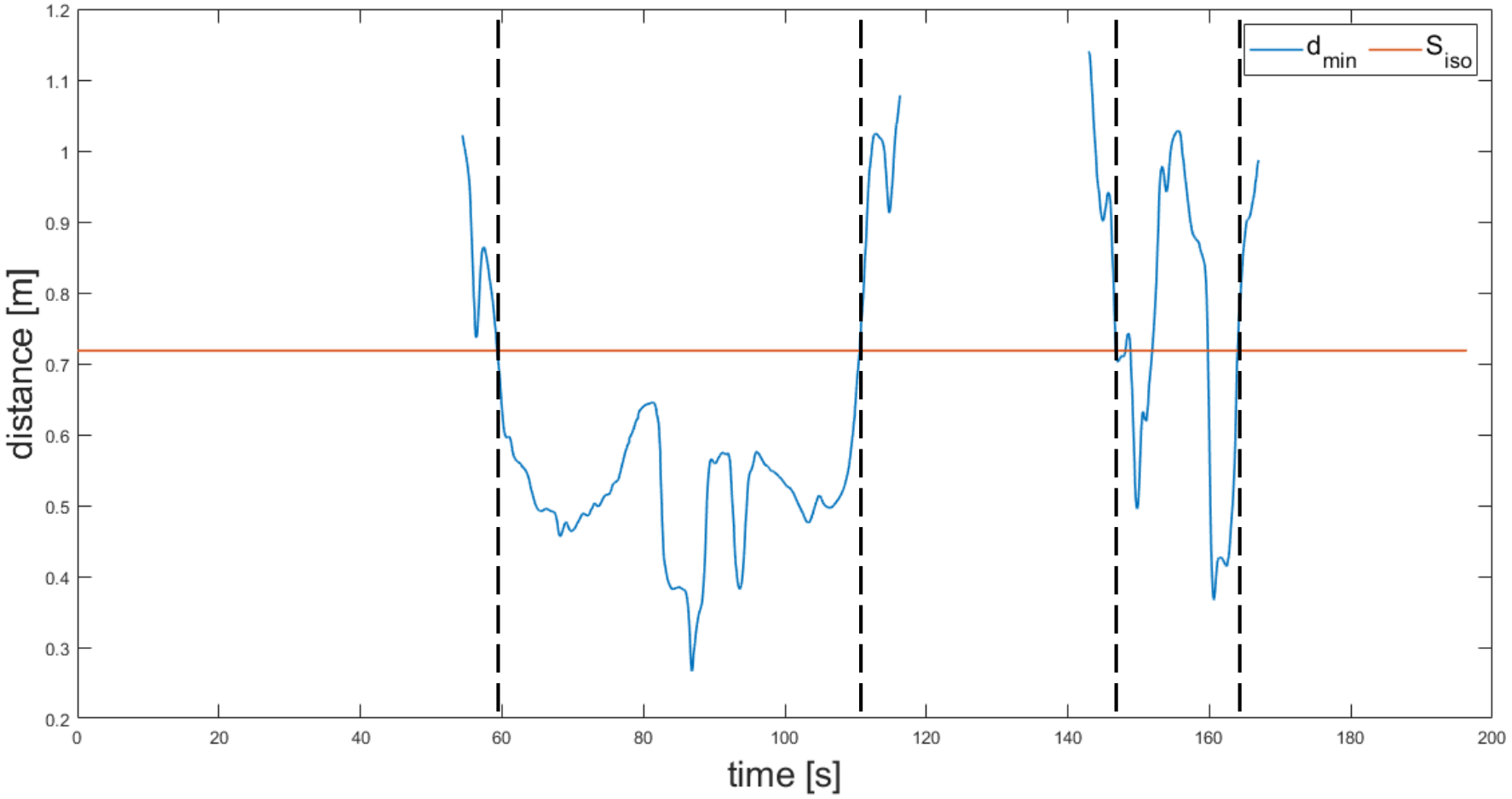






- The *Euclidean cluster extraction* step clearly identifies the dynamic cluster 7
- The *YOLO DT-CNN* detects and tracks the human operator 8
- The *Human Validation* step computes the separation distance 9

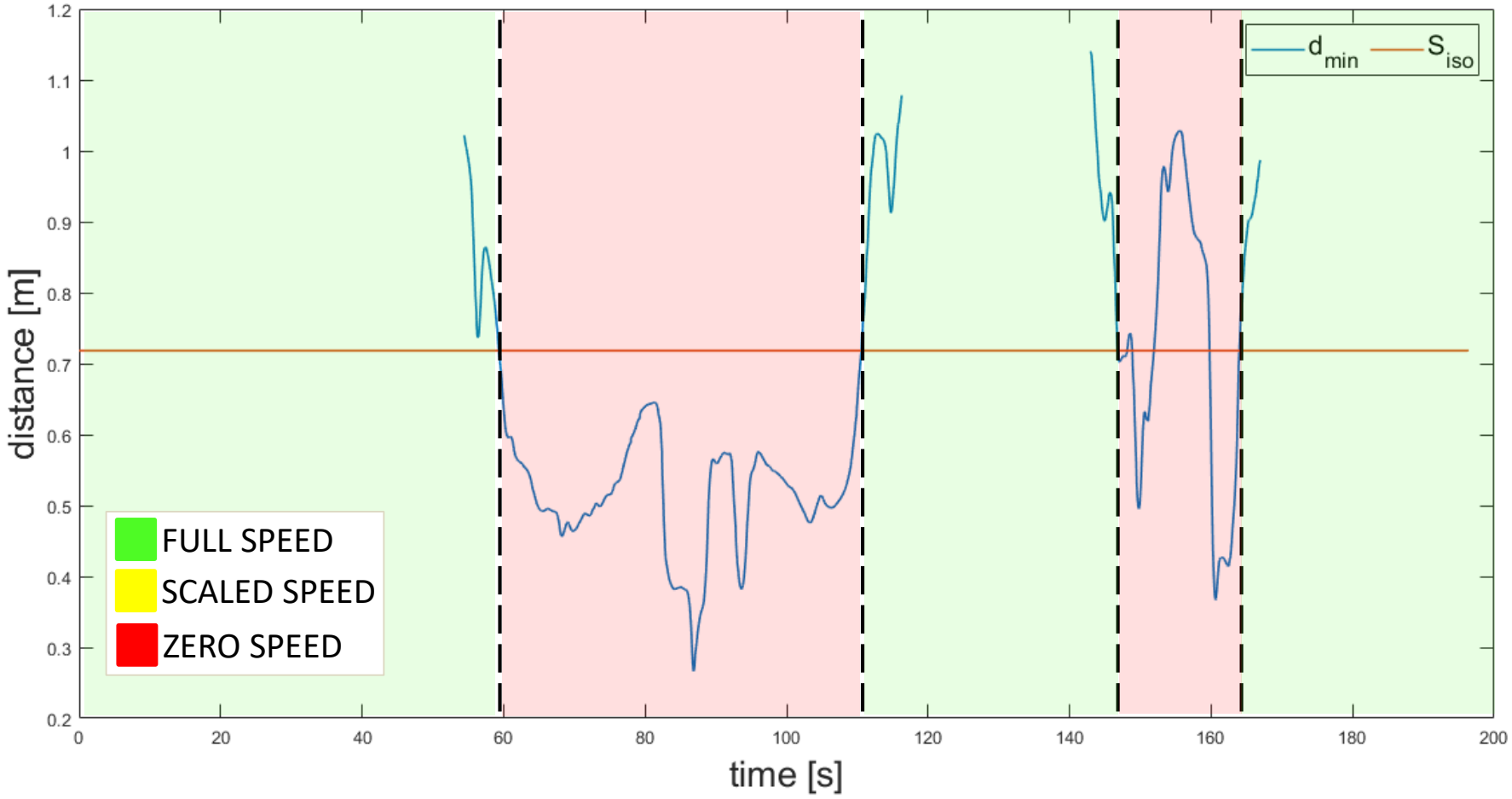
- *Speed scaling factor evaluation*



$$S_{iso} = v_H T_R + v_H T_S + v_R T_R + B + C + Z_R + Z_S$$

$$v_H = 2.0\ \frac{m}{s}; \quad v_R = 0.5\ \frac{m}{s}$$

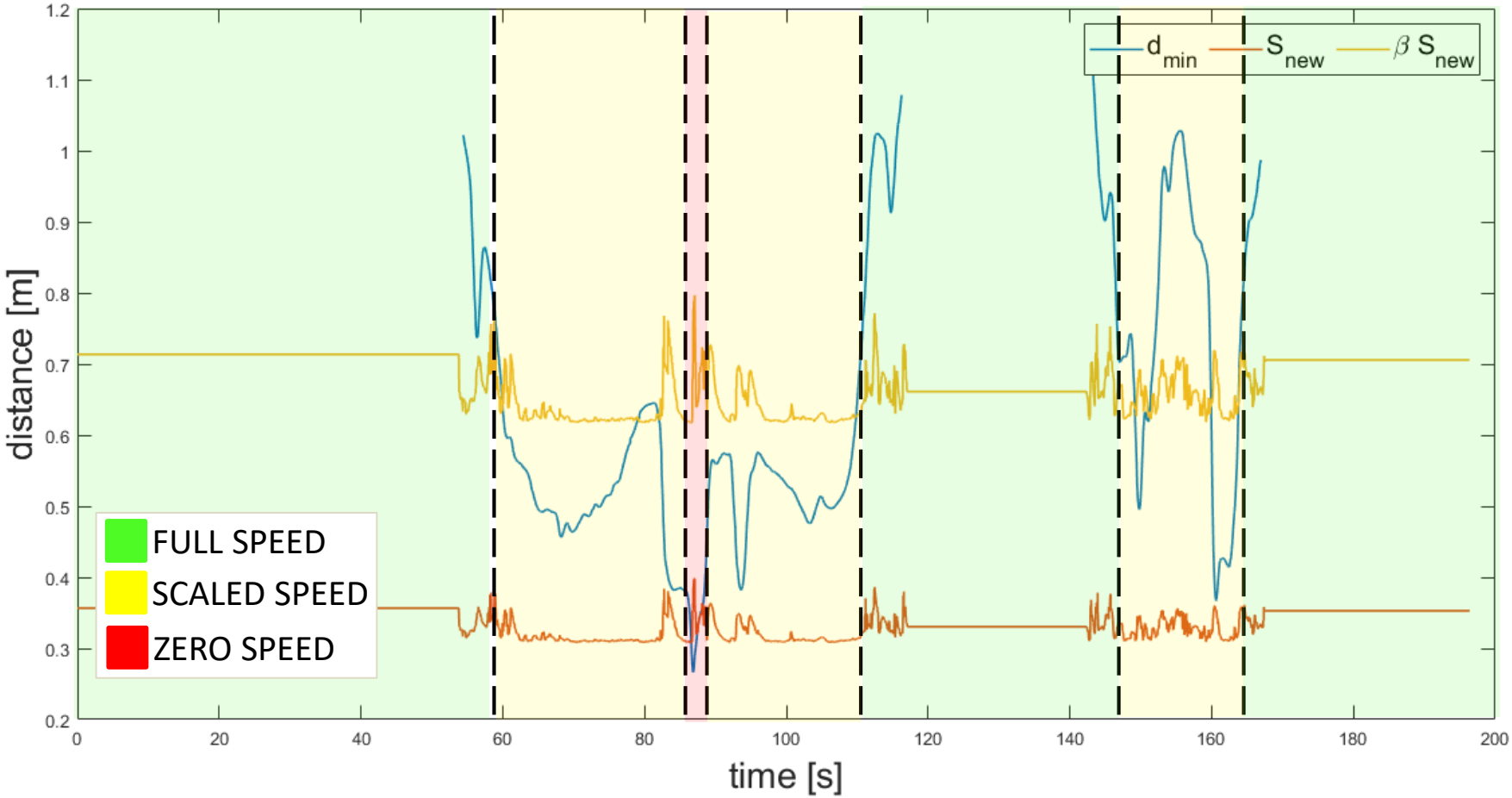
- *Speed scaling factor evaluation*



$$S_{iso} = v_H T_R + v_H T_S + v_R T_R + B + C + Z_R + Z_S$$

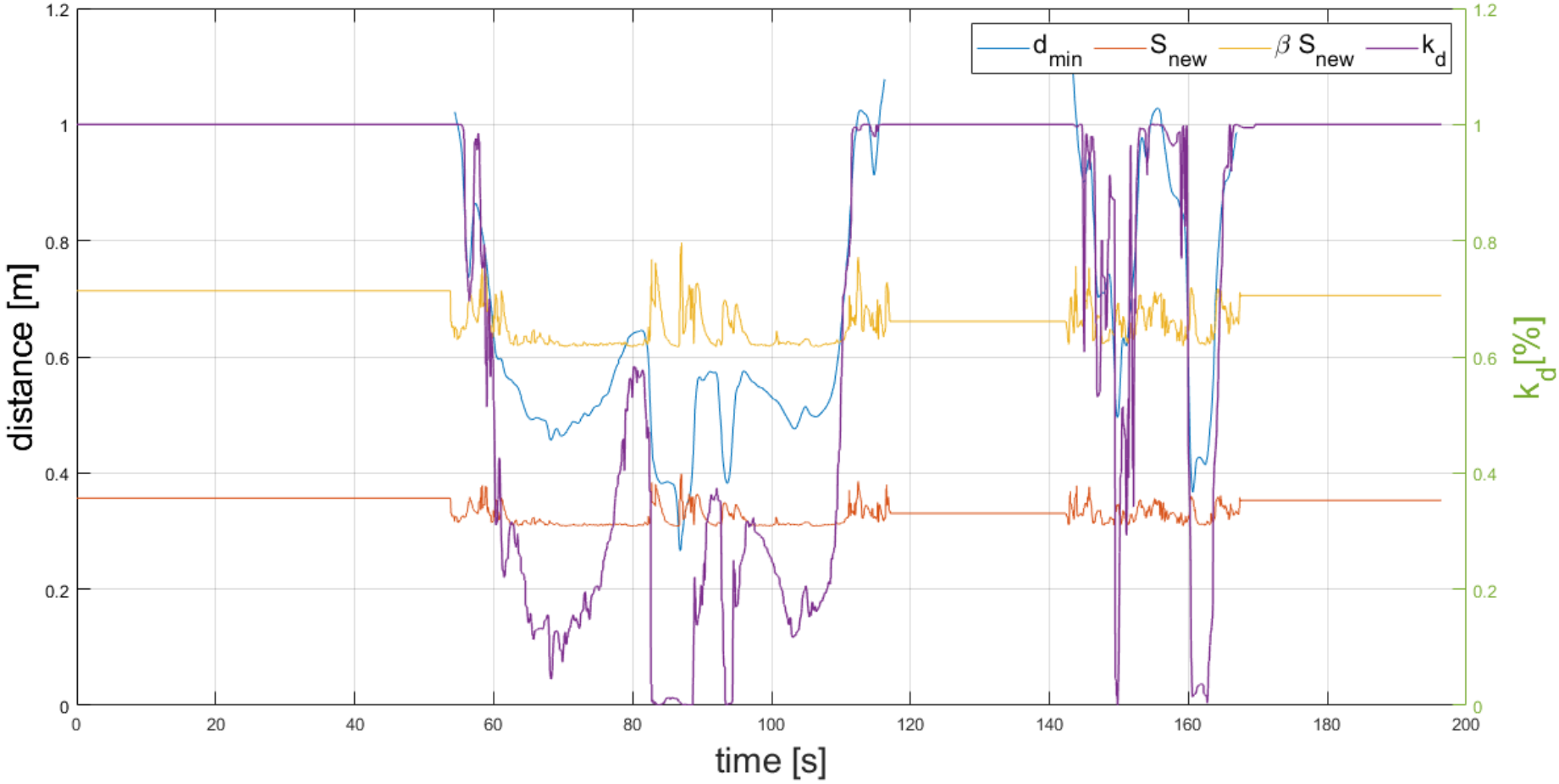
$$v_H = 2.0\ \frac{m}{s}; \quad v_R = 0.5\ \frac{m}{s}$$

- *Speed scaling factor evaluation*



$$S_{new}(t) = \alpha(t)\,\{[v_H(t)T_R + v_H(t)T_S] + v_R(t)T_R\} + B + C + Z_R + Z_S \qquad \alpha \in [0,1]$$

- *Speed scaling factor evaluation*



$$S_{new}(t) = \alpha(t)\,\{[v_H(t)T_R + v_H(t)T_S] + v_R(t)T_R\} + B + C + Z_R + Z_S \qquad \alpha \in [0,1]$$

Thank you

LABOR project has received funding from the European Union's CleanSky Joint Undertaking (CSJU) research and innovation programme under grant agreement No 785419.