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Advisor and Co-funder at Qolo Inc.

ICRA 2022
IEEE International Conference on Robotics and Automation

Metrics and Safety for Autonomous Robot Navigation

Disclaimer: DP is a shareholder of Qolo Inc.

Robots to supplement / palliate to human disabilities

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Robots to supplement / palliate to human disabilities

EPFL

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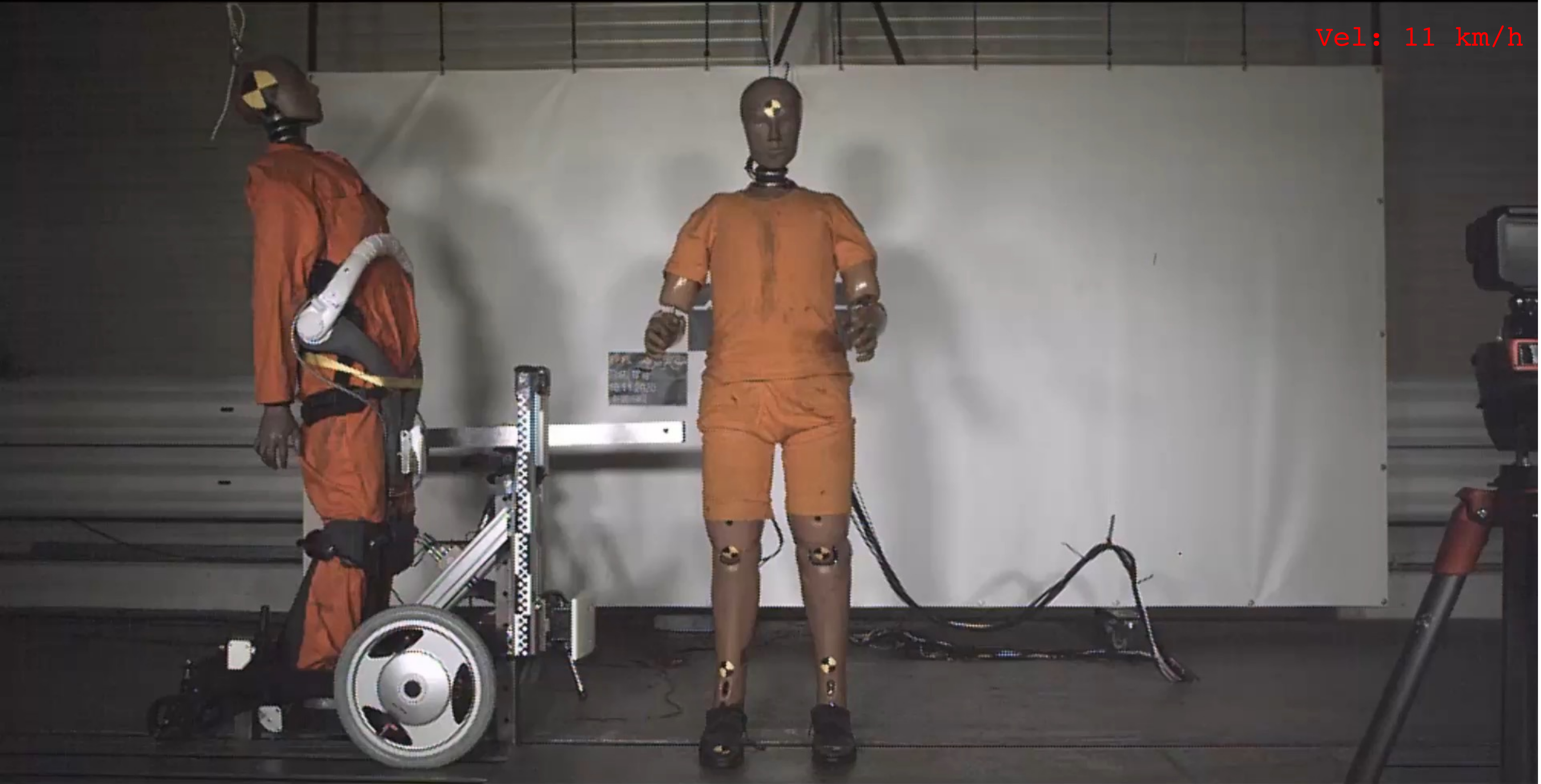
Robots – Could be a risk for humans



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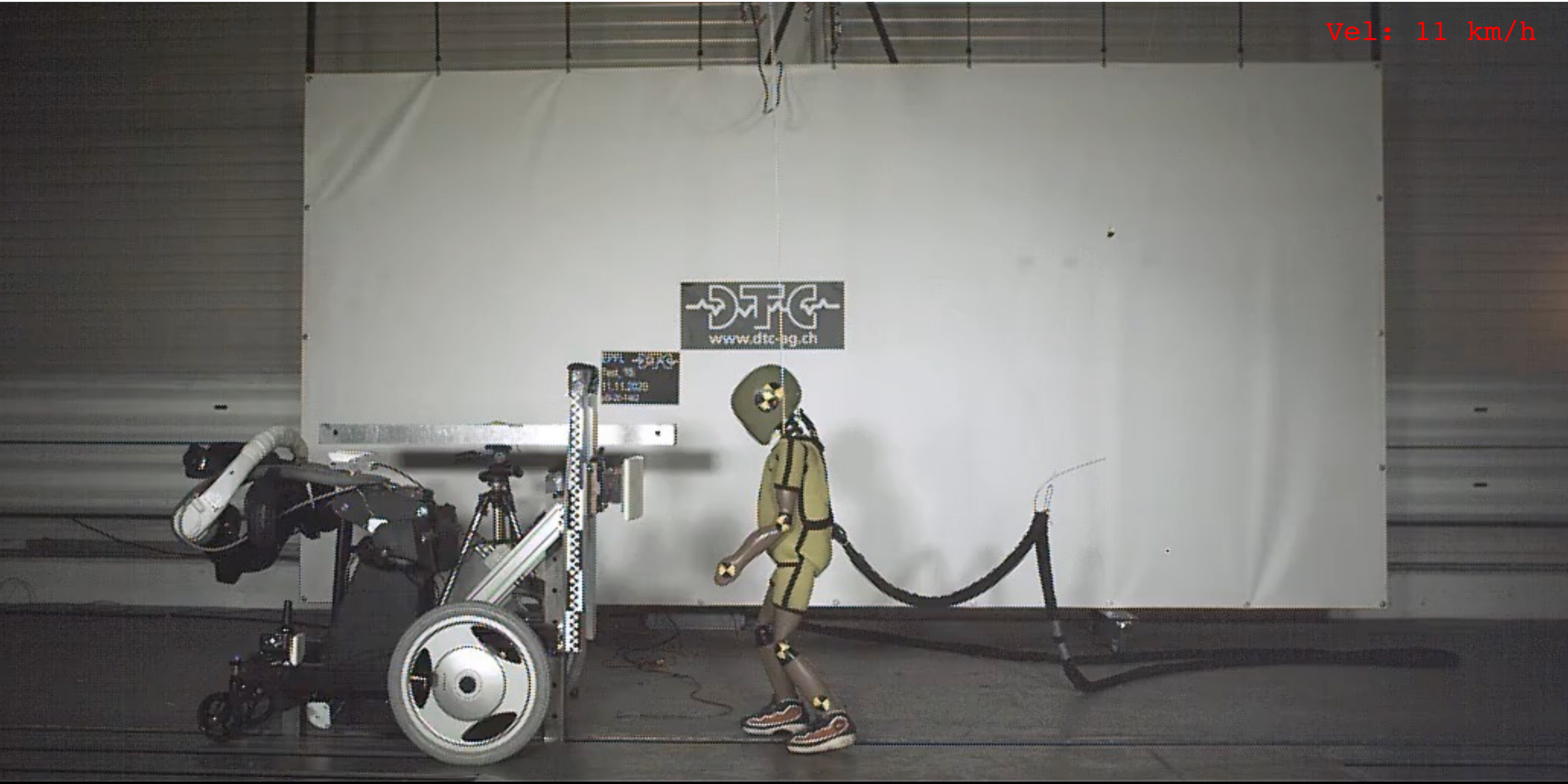
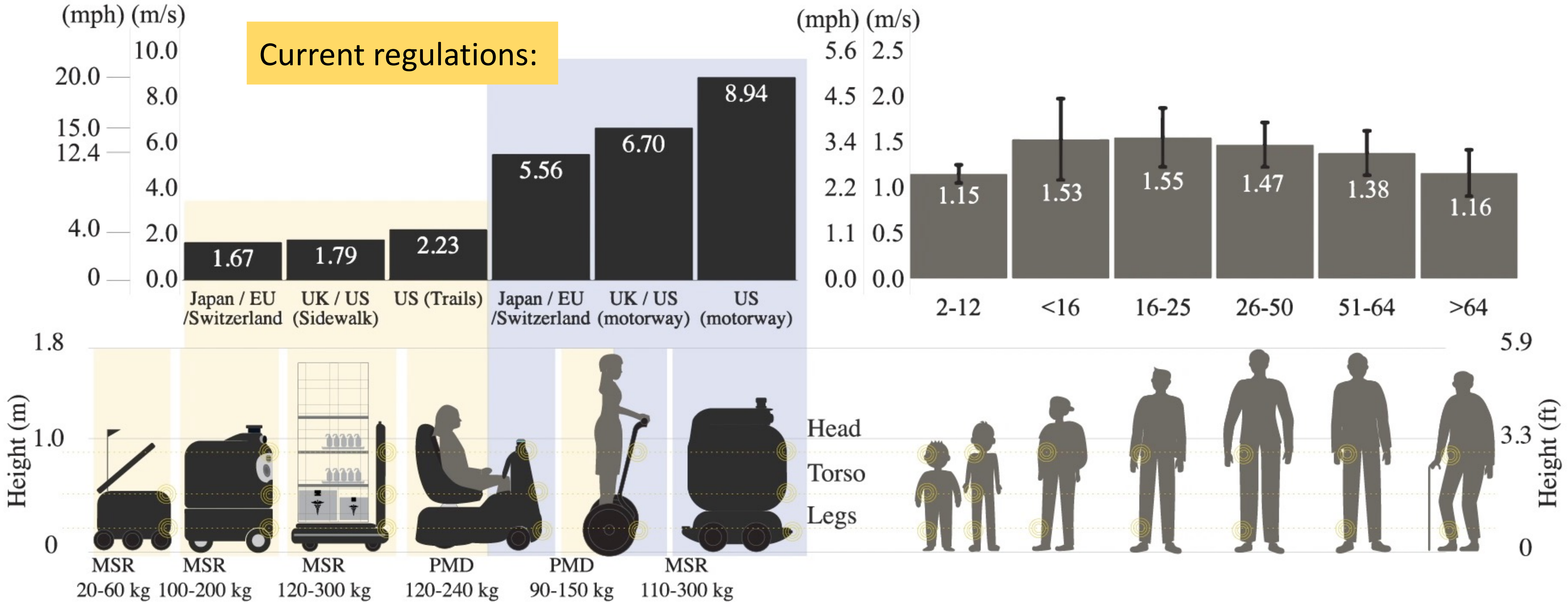


Robots – Could be a risk for humans

Current regulations:



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CROWDBOT

ICRA 2022
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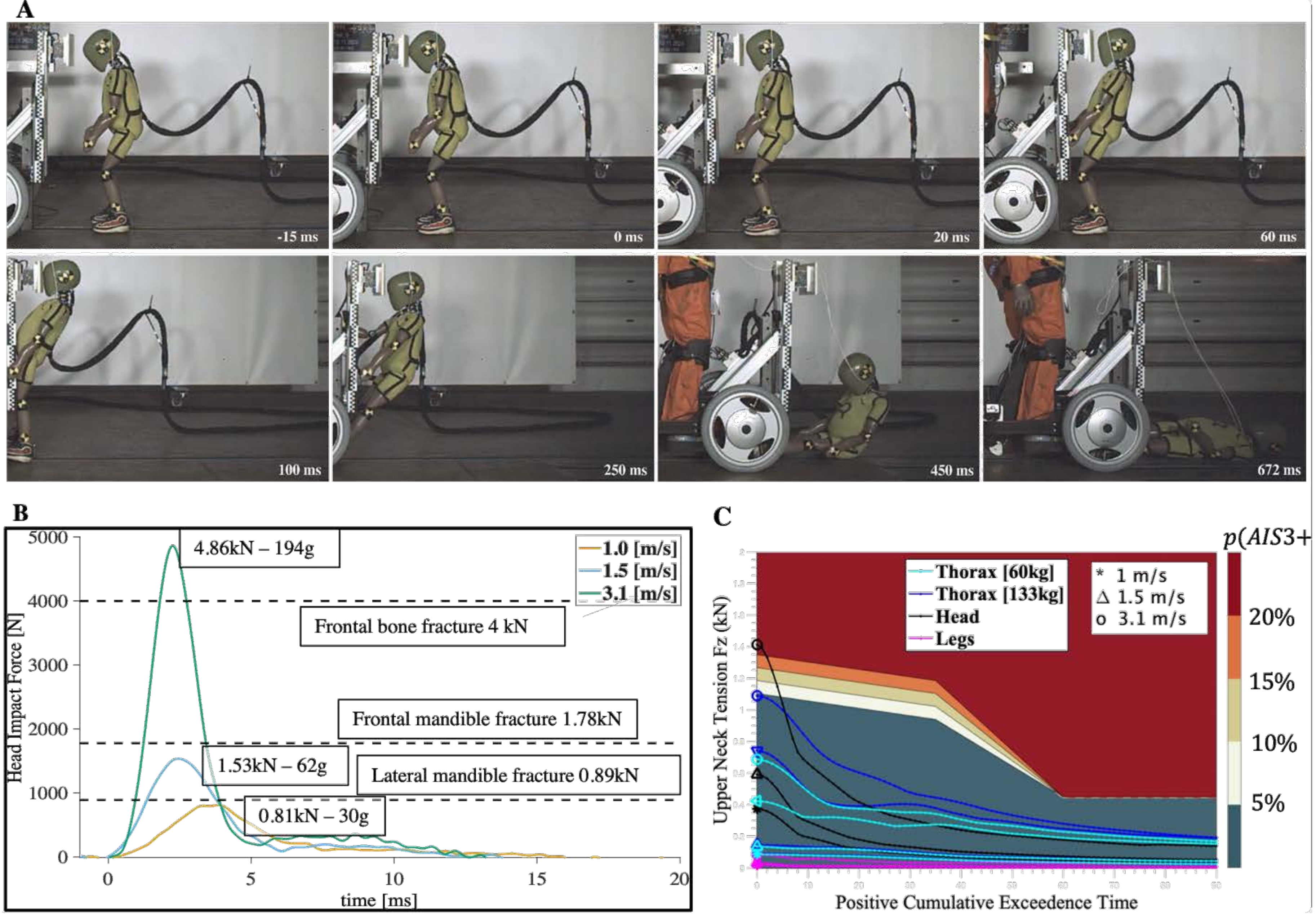
Safety Metrics in Social Navigation

Chest Impact with Child Dummy Q3

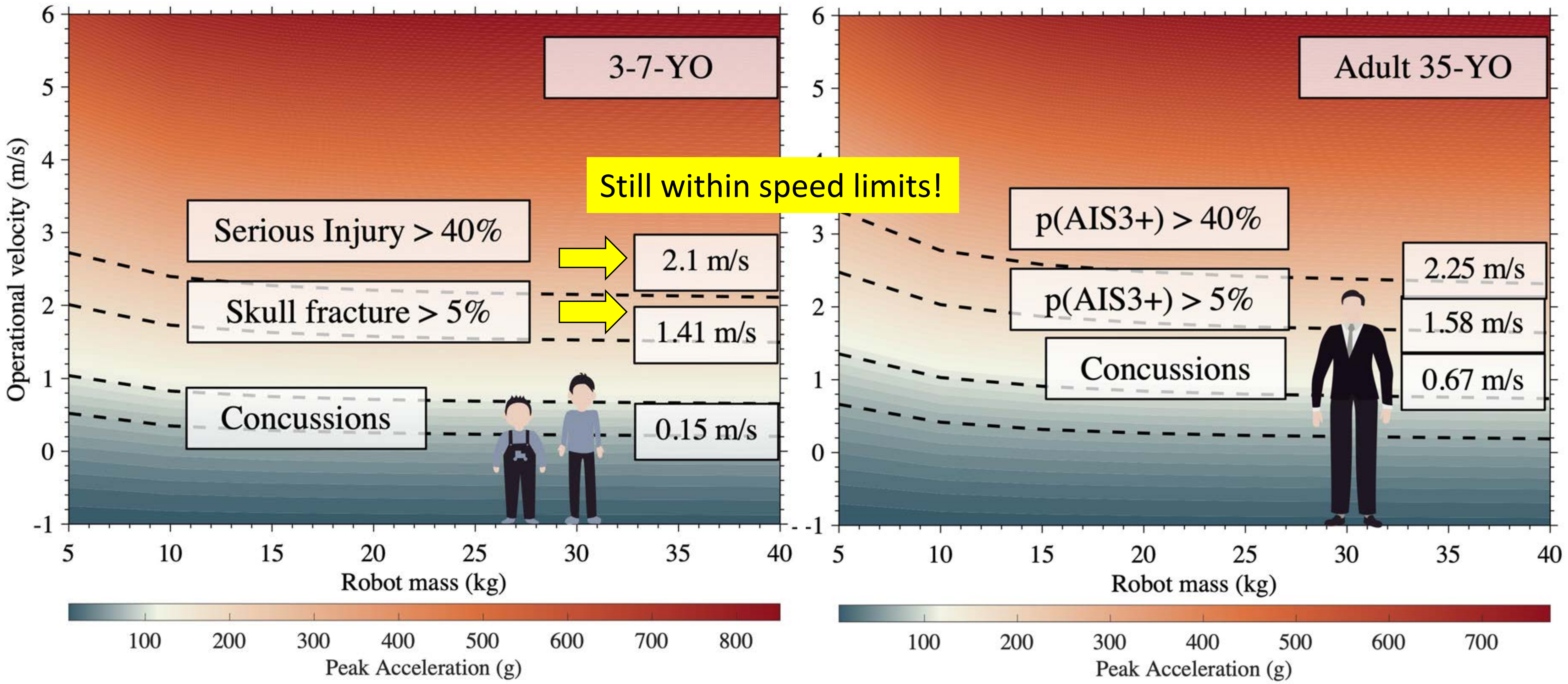
Robot weight: 133 kg

Speed: 3.1 m/s (11 km/h) (6.9 mph)



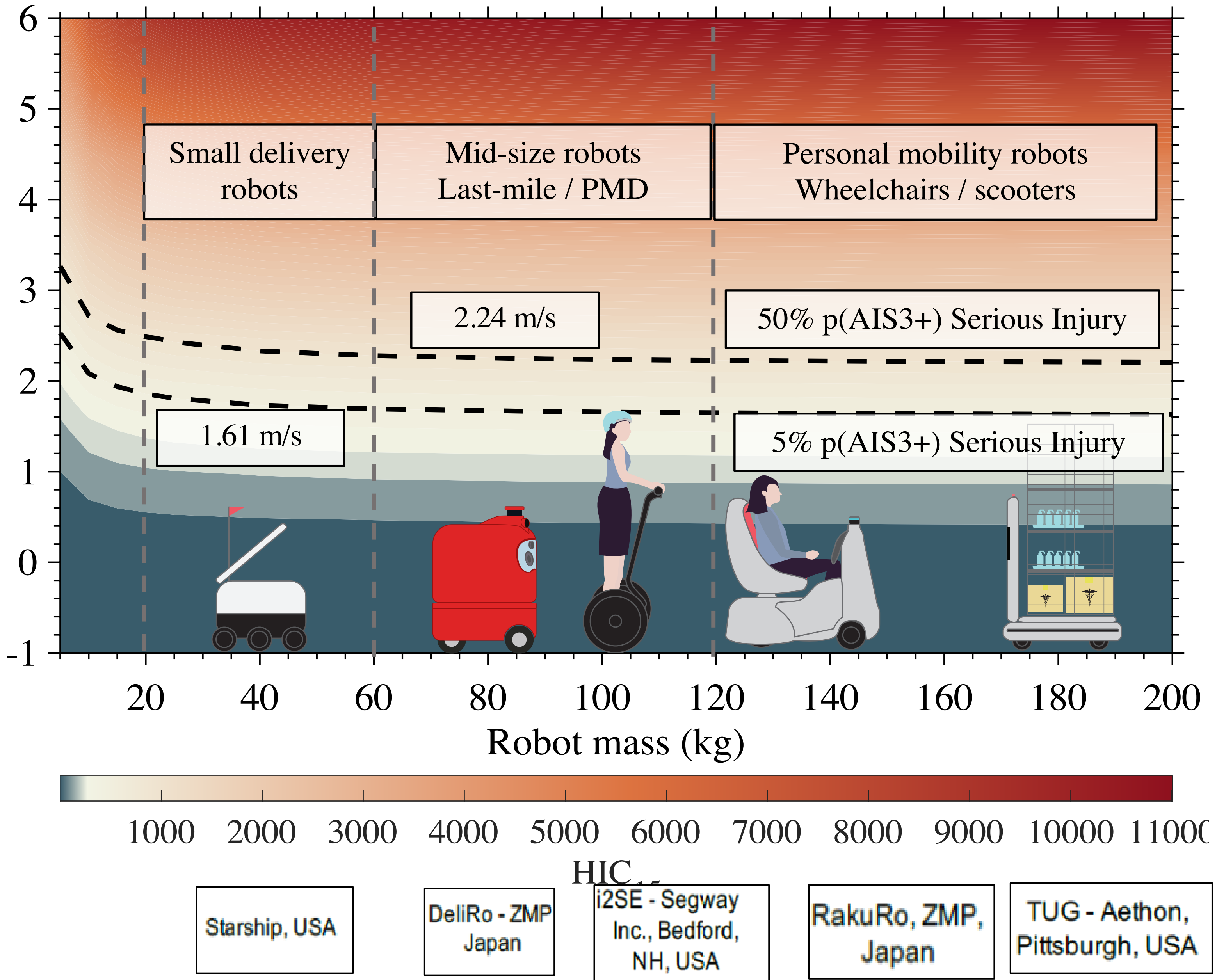
Paez-Granados, D., & Billard, A. (2022). Crash test-based assessment of injury risks for adults and children when colliding with personal mobility devices and service robots. *Nature Scientific Reports*, *12*(5285), 1–13. DOI:10.1038/s41598-022-09349-9

Robots – Could be a risk for humans

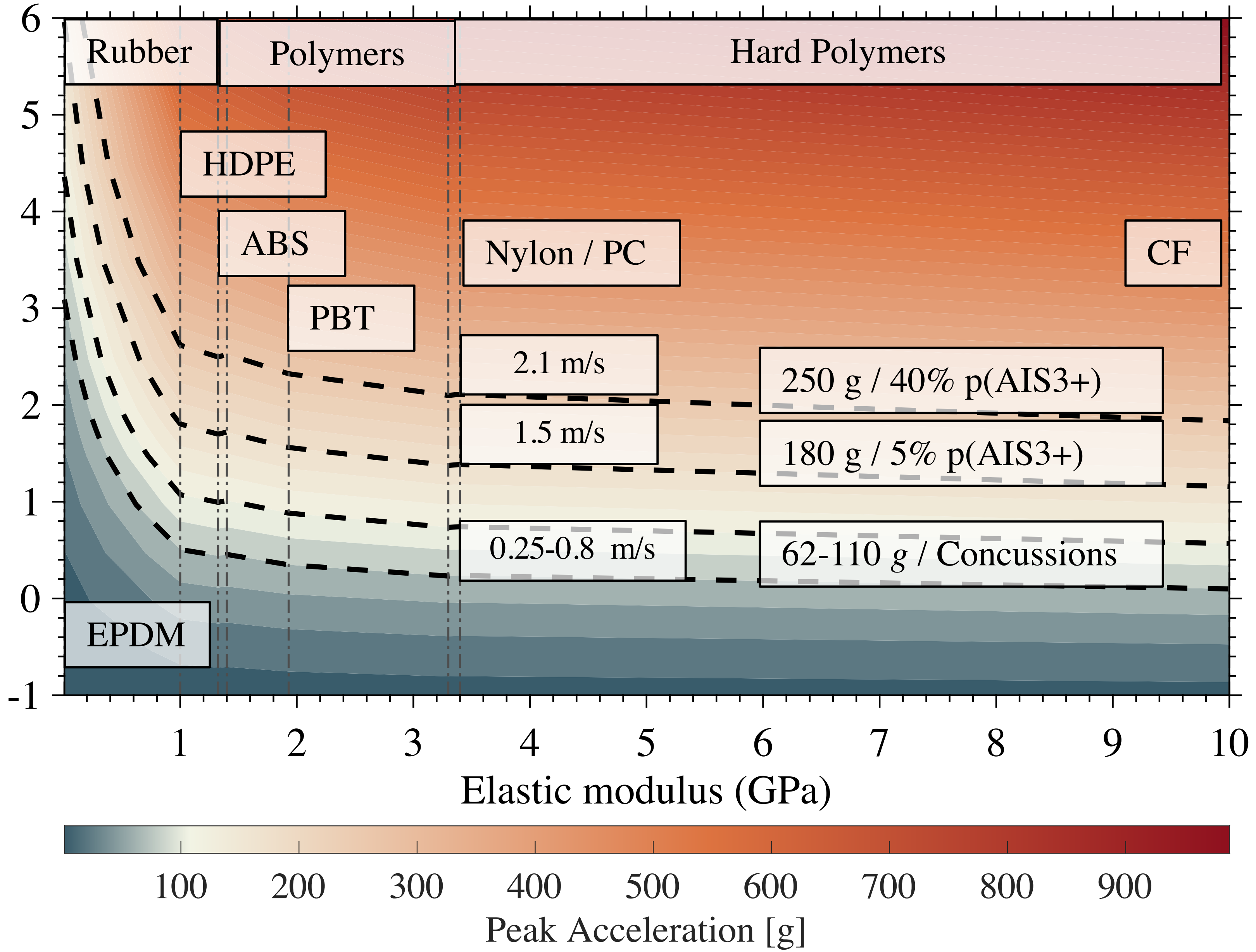


**Accounting for a pedestrian speed of 1.5 m/s*

Robots – Could be a risk for humans



Robots – Could be a risk for humans



Secondary Injuries from Ground Impact Child and Adult

Robot weight: 133 kg

- You could limit the speed.
- You could reduce the mass.
- You could use compliant hulls.

But most importantly, you do want to avoid collisions!

To avoid collisions, robots need to understand their environments.

Paez-Granados, D., Billard, A. Crash test-based assessment of injury risks for adults and children when colliding with personal mobility devices and service robots. Nature Scientific Reports 12, 5285 (2022). DOI:10.1038/s41598-022-09349-9

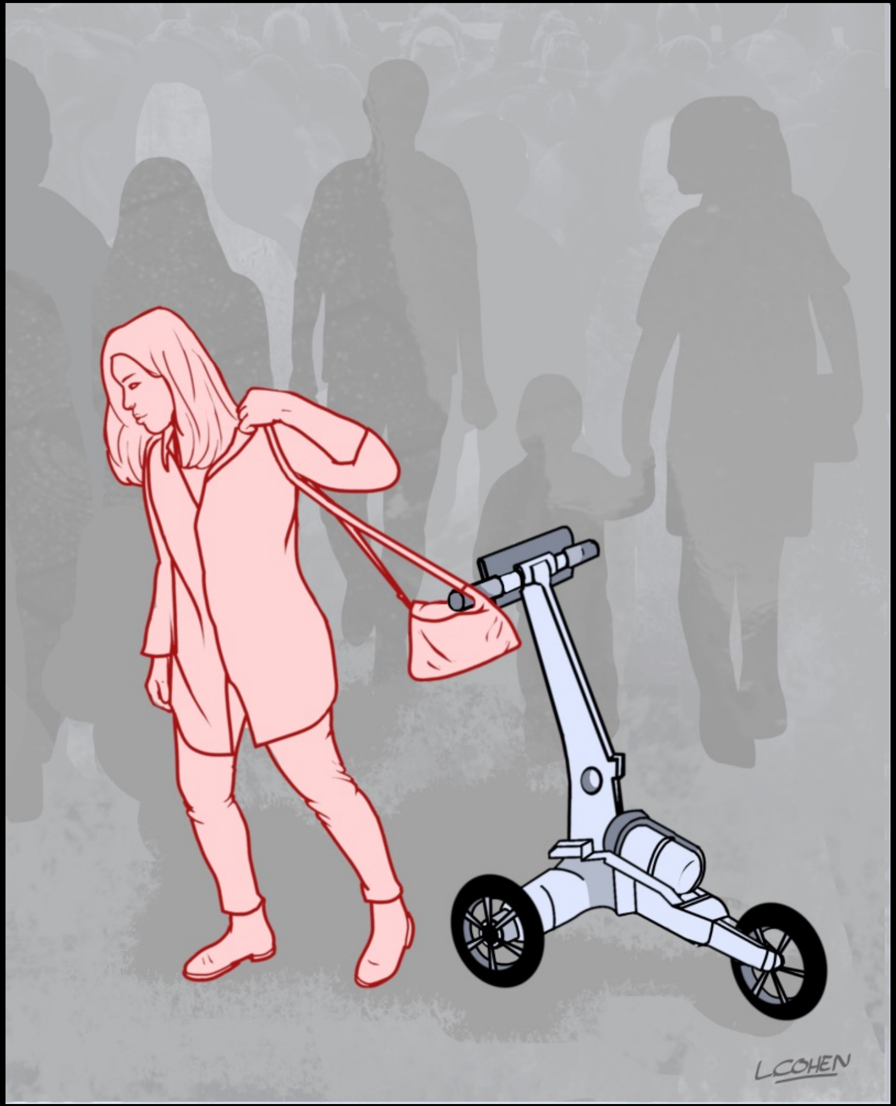

CLER
Bershka
STARBUCKS COFFEE
CLER
CLER
Bershka
coop
OCHSNER SHOES
coop

Understanding the crowd!

Illustrations: Laura Cohen

Smart robots that can interact with humans safely

Model the behavior and types of pedestrians



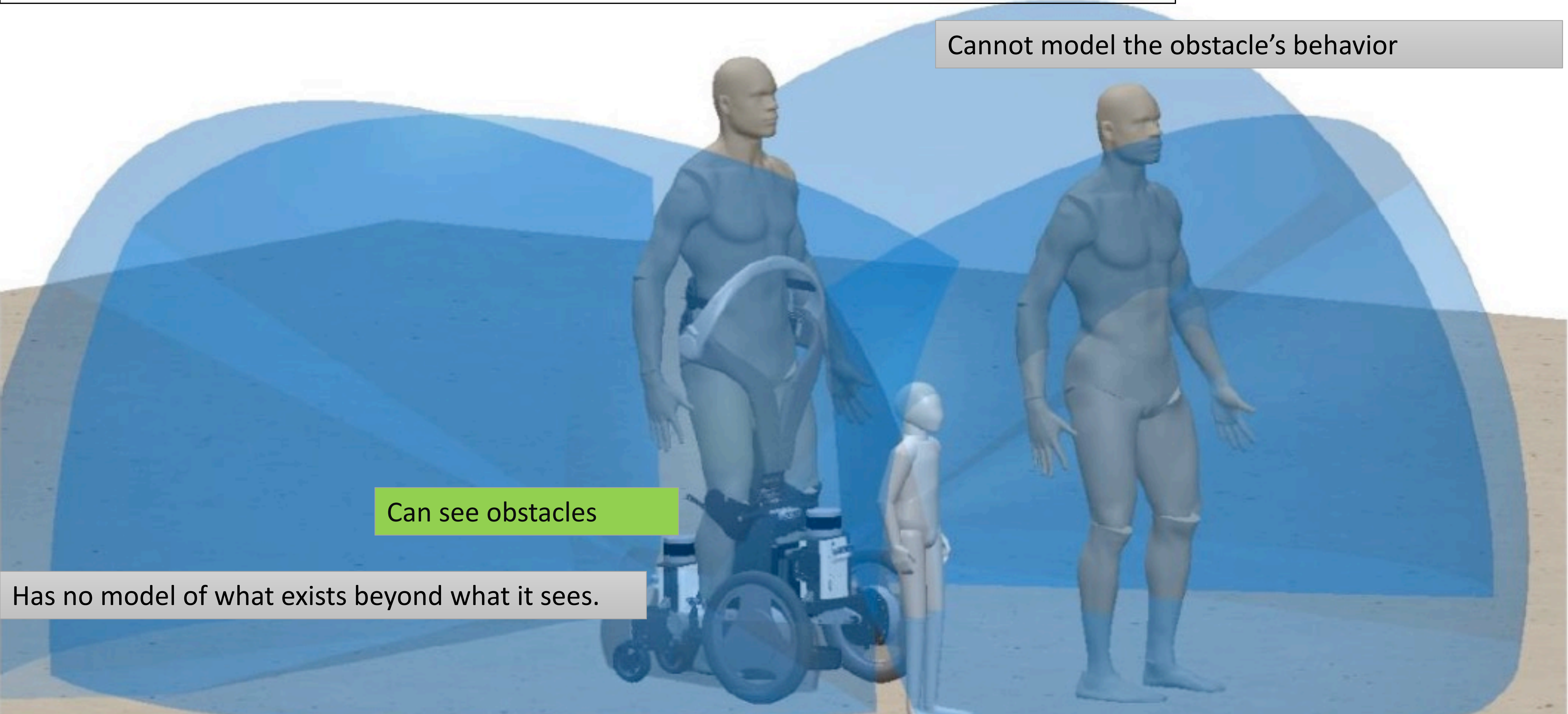
Illustrations: Laura Cohen

Bystanders variety: pedestrians, bicycles, scooter, wheelchairs, vehicles

Smart robots that can interact with humans safely

What is the Level of robot’s understanding?

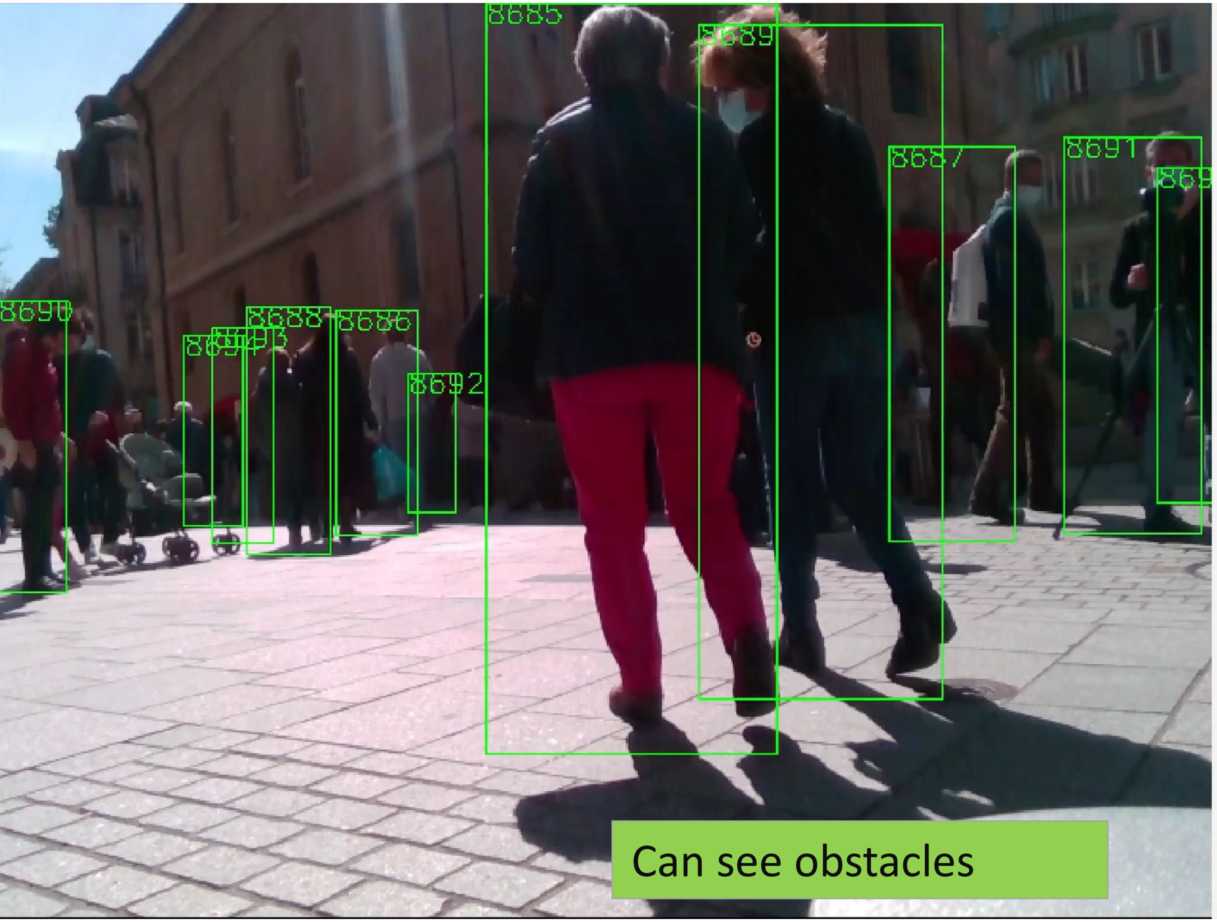
Cannot model the obstacle’s behavior

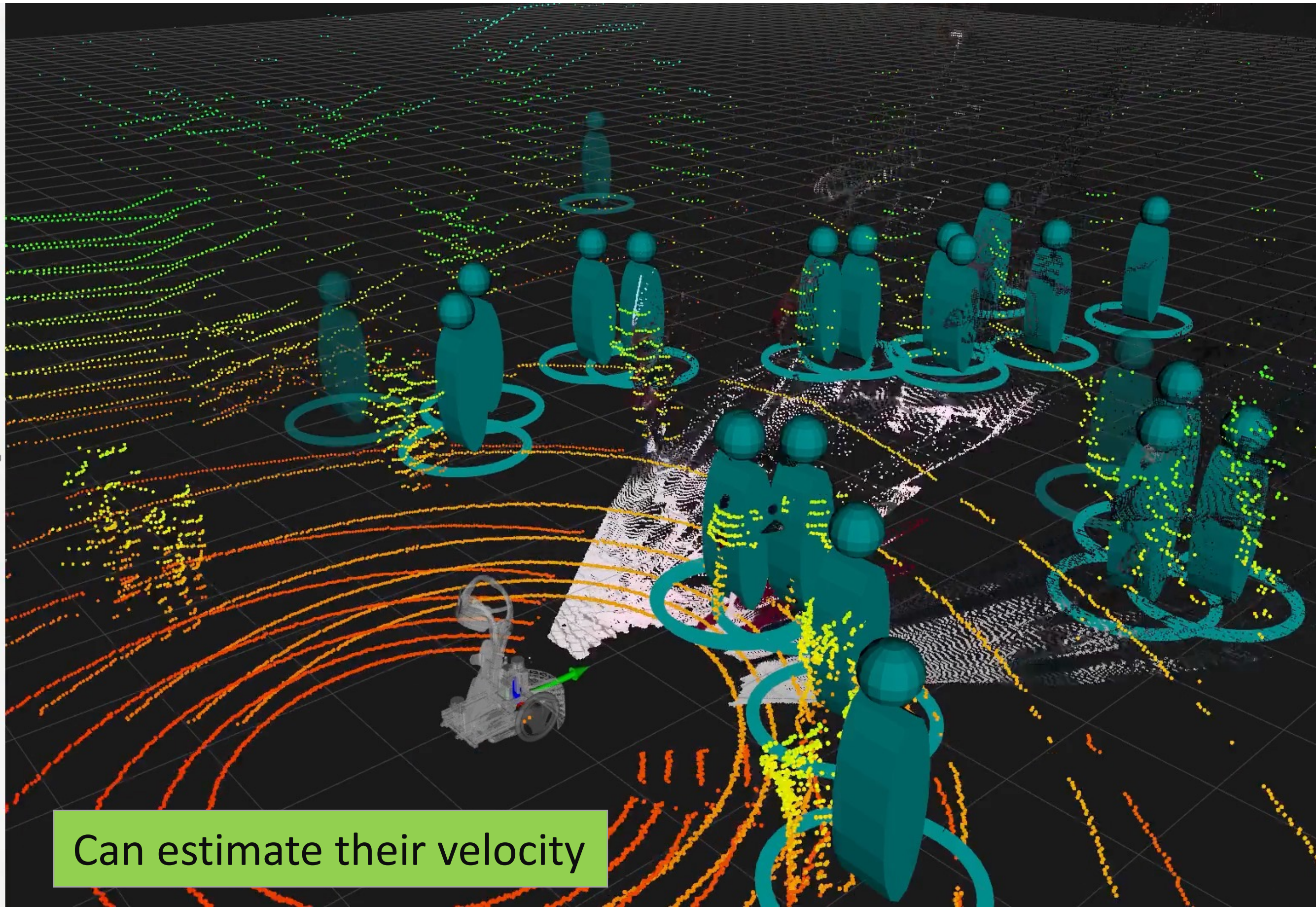


Can see obstacles

Has no model of what exists beyond what it sees.

Smart robots that can interact with humans safely





Real time Robot’s Egocentric view:

Smart robots that can interact with humans safely

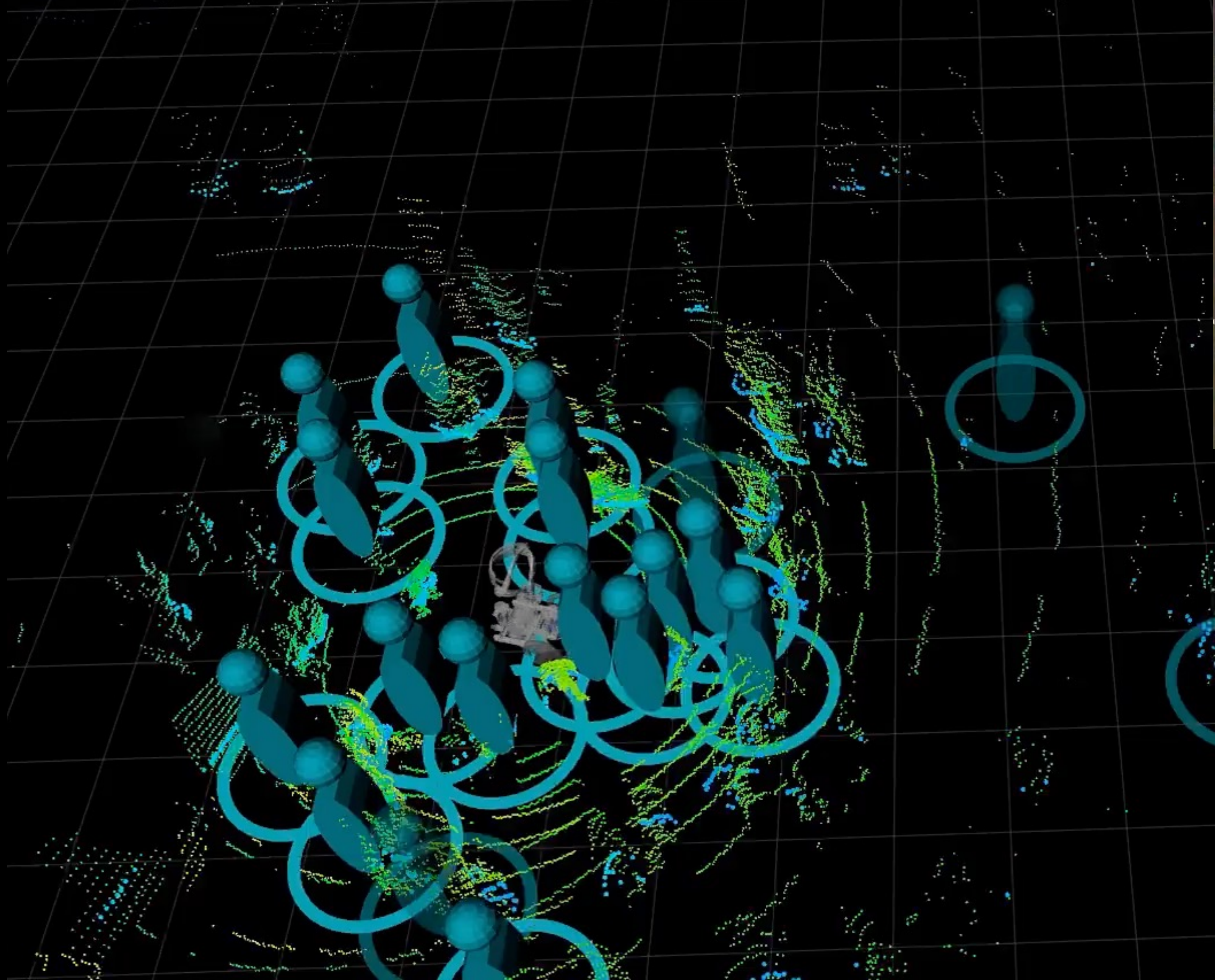
EPFL

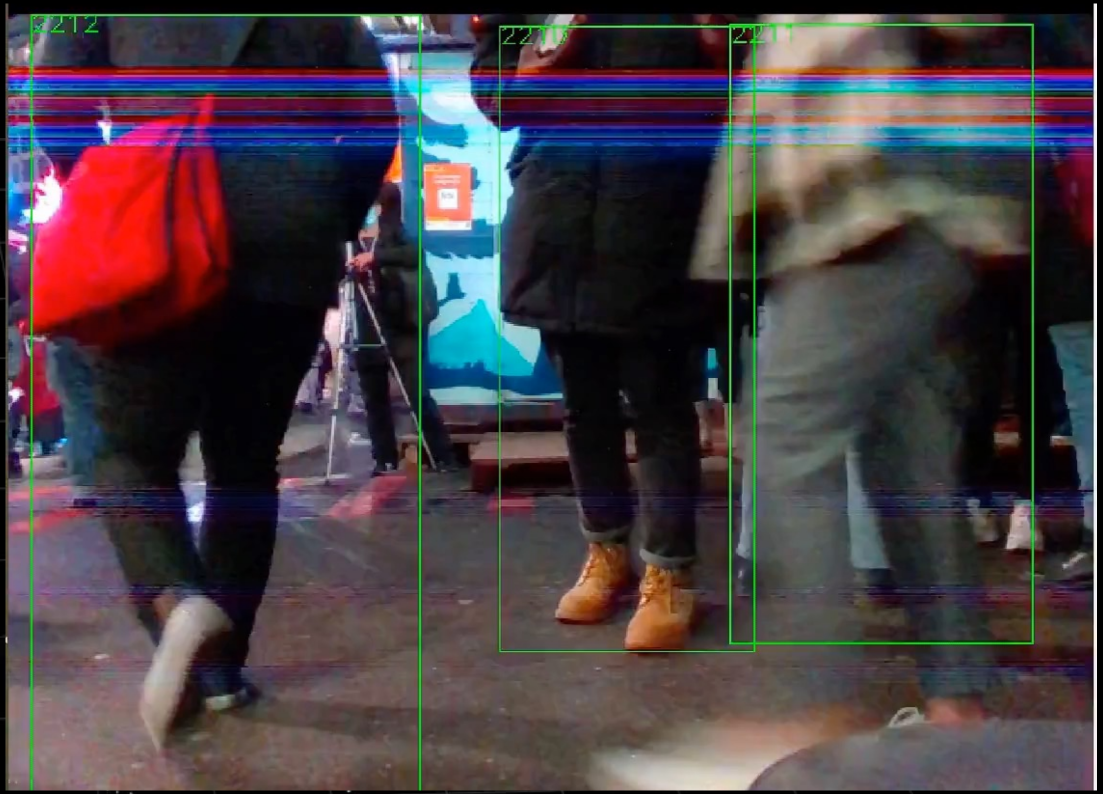
CROWDBOT

Understand the Crowd!

Smart robots that can interact with humans safely

Predict with limited visibility

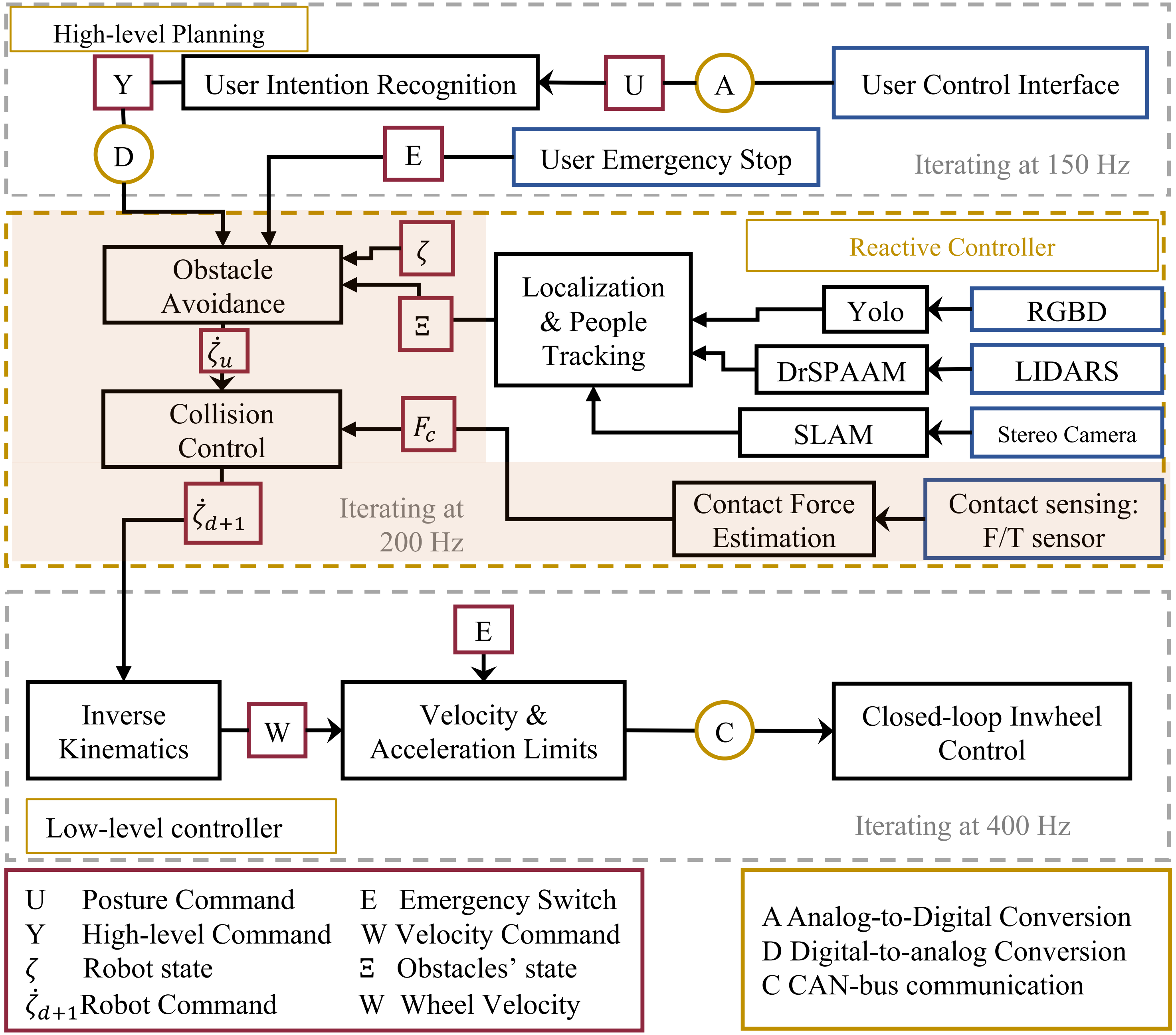




Metrics in Social Navigation

Unified Framework for pre- and post-Collision Control

Paez-Granados, D., Gupta, V., & Billard, A. (2022). Unfreezing Social Navigation : Dynamical Systems based Compliance for Contact Control in Robot Navigation. *IEEE International Conference on Robotics and Automation (ICRA)*, *1*(1), 1–7



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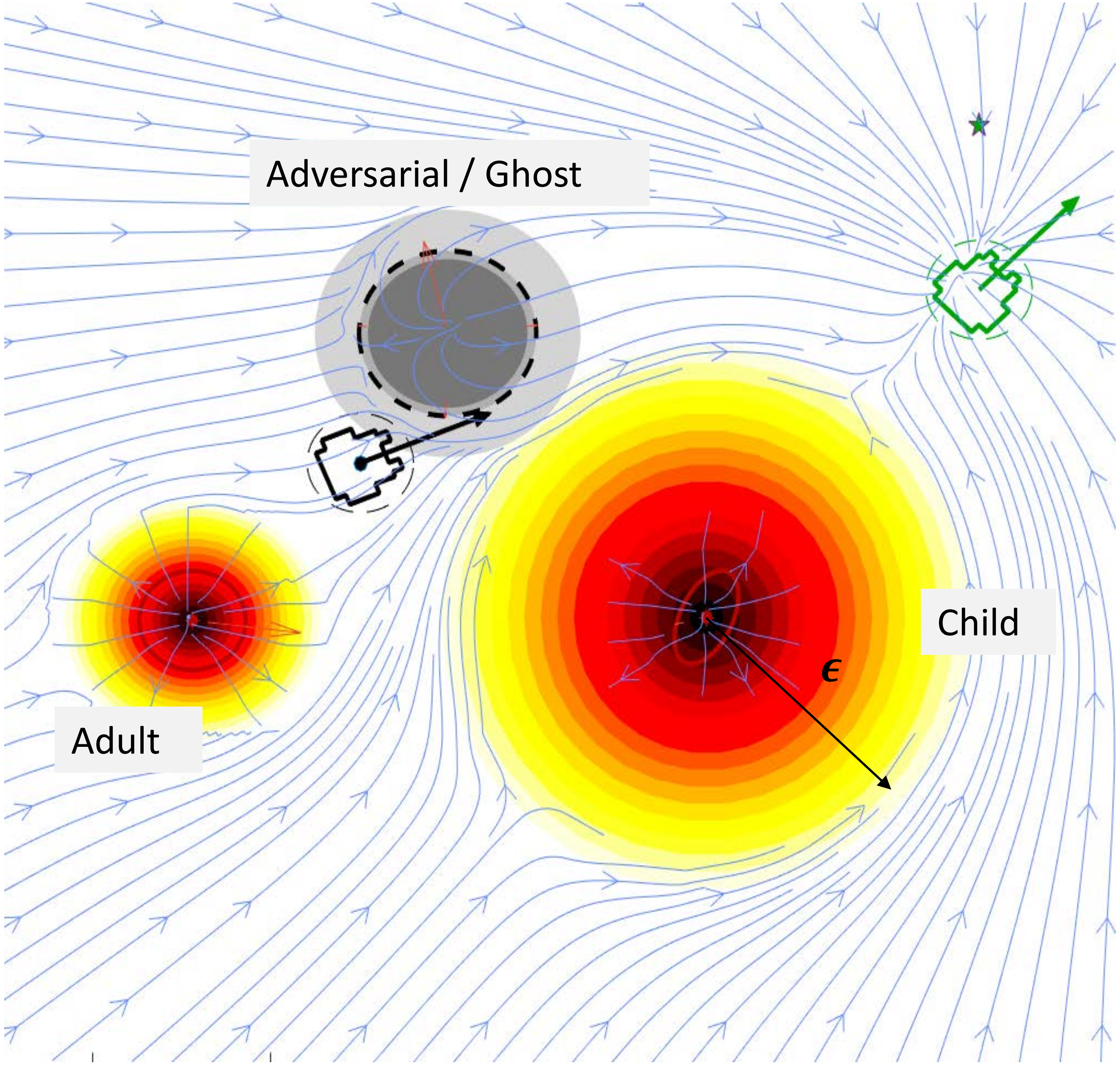

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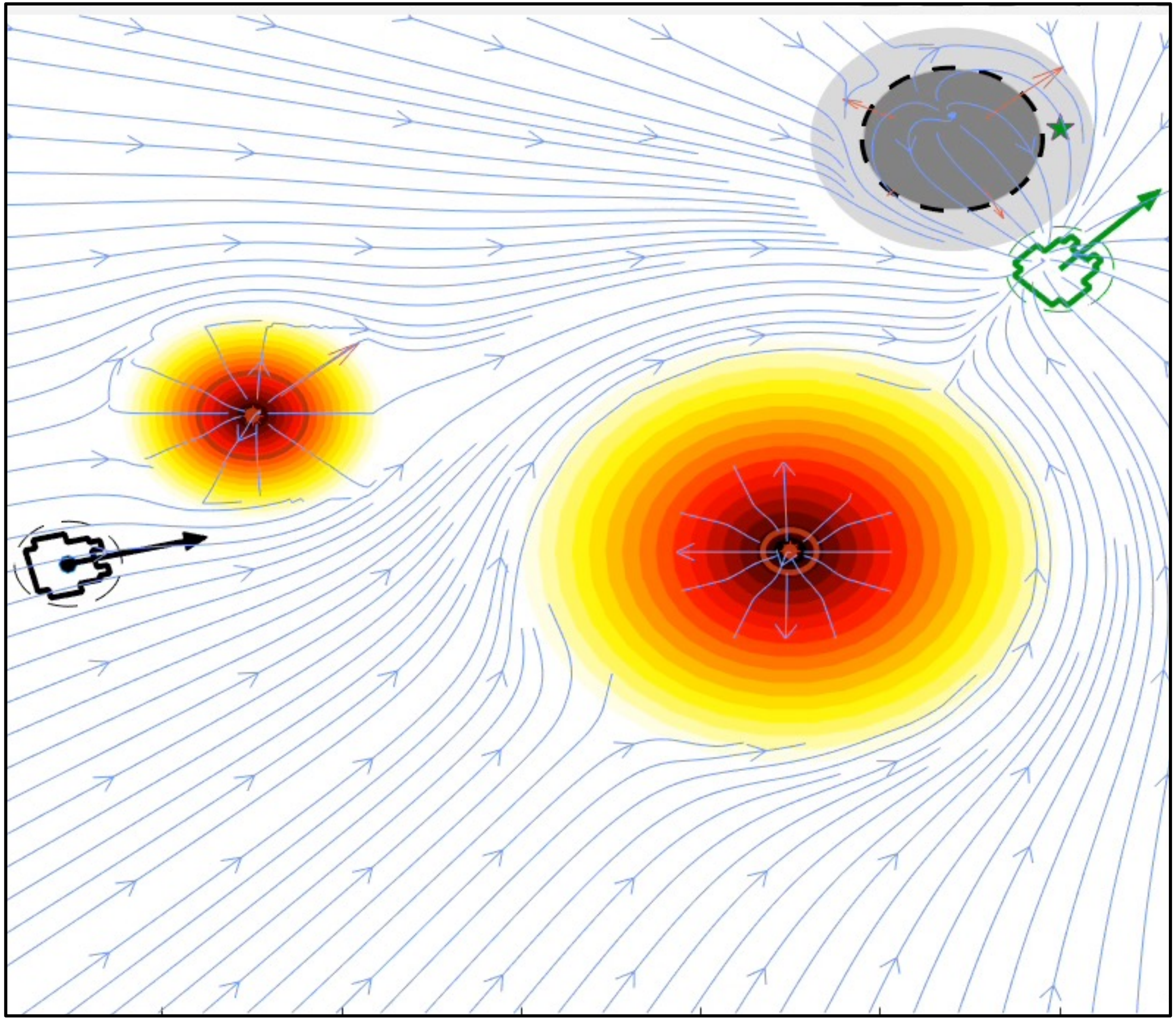
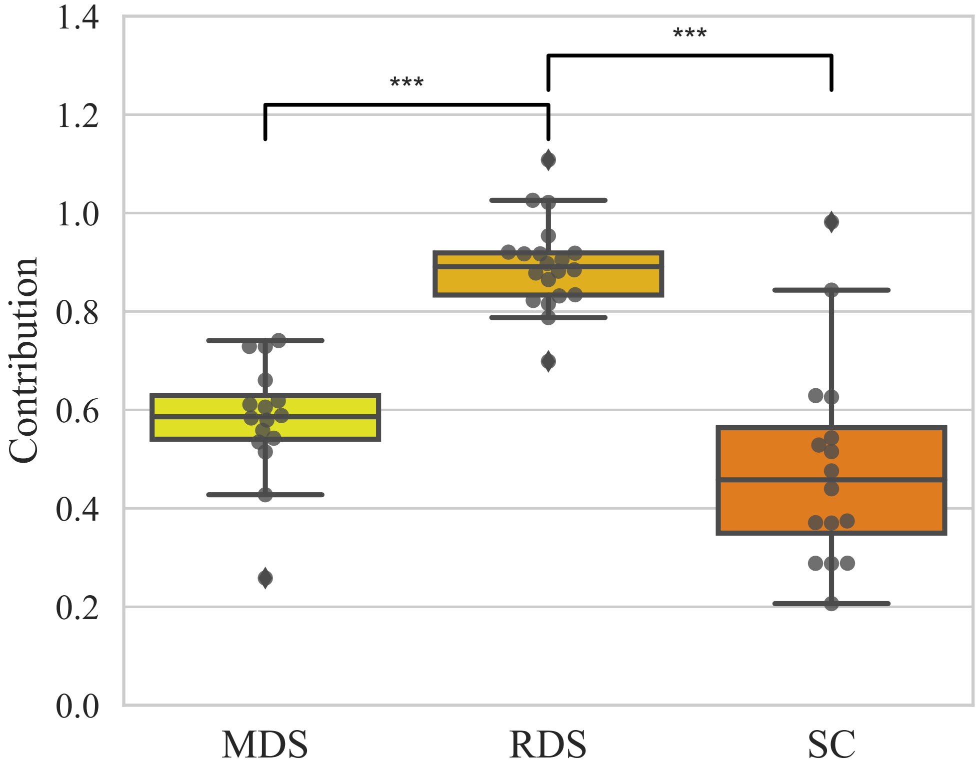
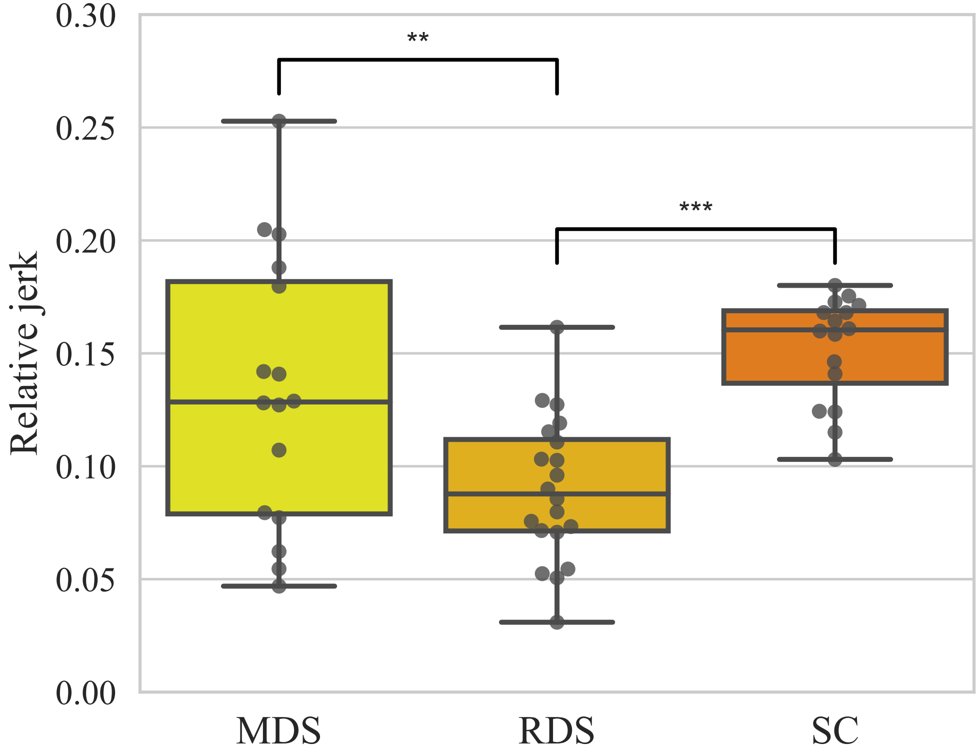


Autonomy versus shared control

CONTROLLER CONTRIBUTION



MOTION JERK

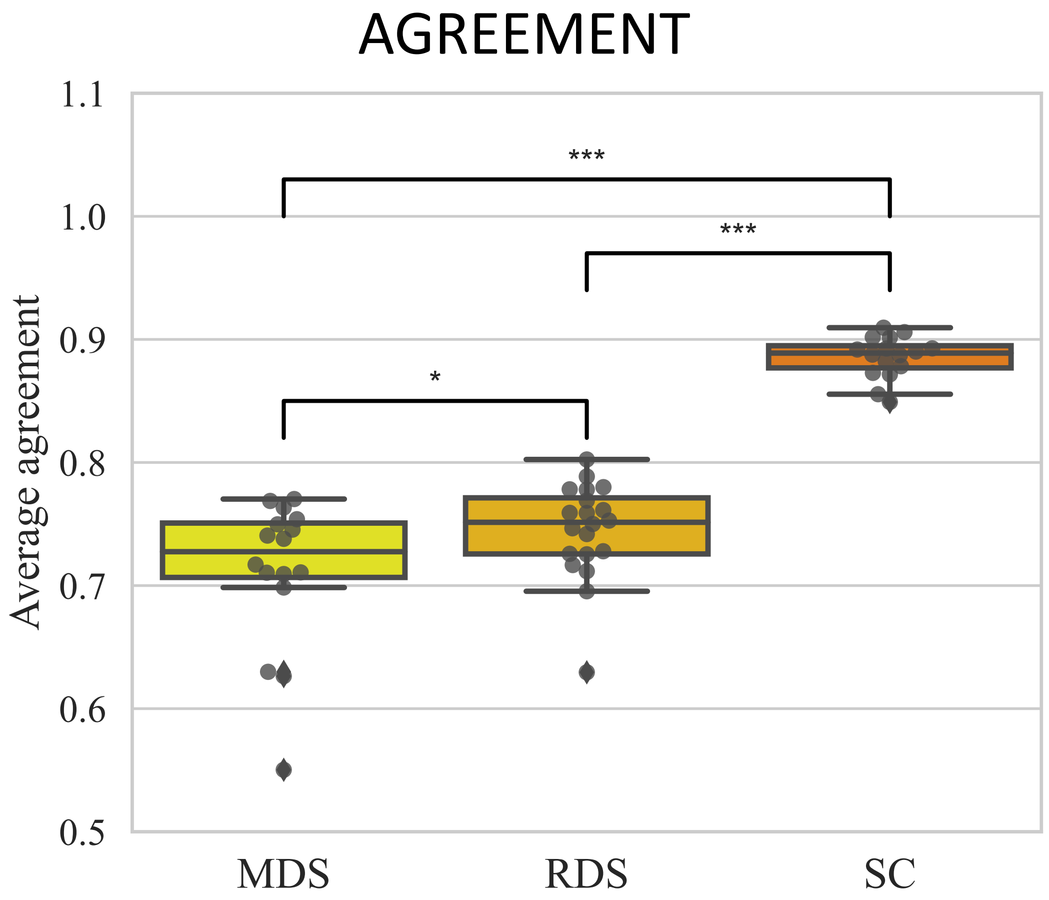


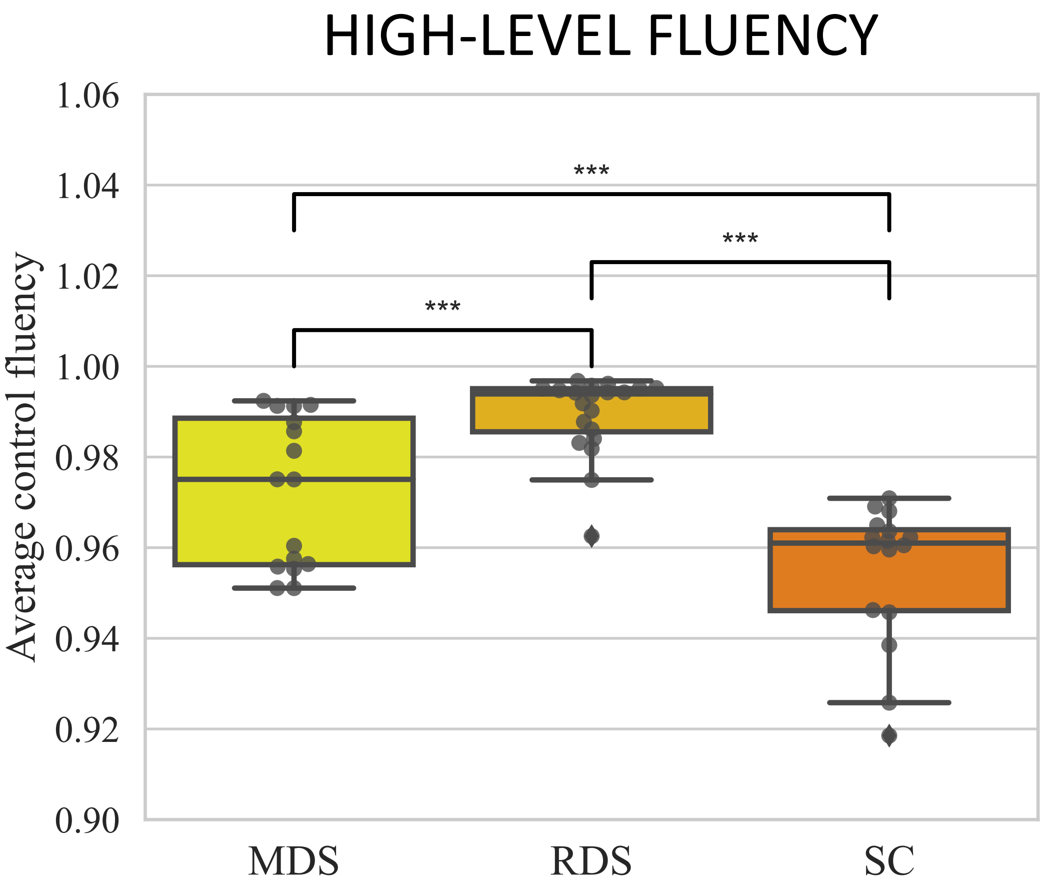
Number of tests compared:

- MDS: **15** / 18
- RDS: **20** / 30
- Shared control (SC): **17** / 45

ANOVA results
* → $p < 0.1$
** → $p < 0.05$
*** → $p < 0.05$

Autonomy versus shared control





Number of collisions:

- MDS: 2
- RDS: 2
- Shared Control (SC): 3

ANOVA results
* → $p < 0.1$
** → $p < 0.05$
*** → $p < 0.05$

Autonomy versus shared control

Number of tests compared:

- MDS: **15** / 18
- RDS: **20** / 30
- Shared control (SC): **17** / 45

Measurable from egocentric data

CONTROLLER COMPARISON IN MID DENSITY CROWDS

Metrics	Controller		
	MDS	**RDS**	**Shared control**
Avg. crowd density	0.12 ± 0.03	0.13 ± 0.03	0.12 ± 0.03
Max crowd density	0.45 ± 0.08	0.47 ± 0.12	0.51 ± 0.14
Min distance	1.19 ± 0.16	1.08 ± 0.18	1.20 ± 0.16
Time to goal	0.28 ± 0.09	0.32 ± 0.10	0.29 ± 0.07
Path length	1.41 ± 0.21	1.34 ± 0.20	1.52 ± 0.52
Jerk	0.13 ± 0.06	0.09 ± 0.03	0.15 ± 0.02
Contribution	0.58 ± 0.12	0.89 ± 0.09	0.49 ± 0.21
Avg. fluency	0.97 ± 0.02	0.99 ± 0.01	0.95 ± 0.02
Avg. agreement	0.71 ± 0.06	0.74 ± 0.04	0.89 ± 0.02
Virtual collision	3.50 ± 2.71	7.05 ± 7.92	4.25 ± 3.11
Actual collision	2/16	2/20	3/16

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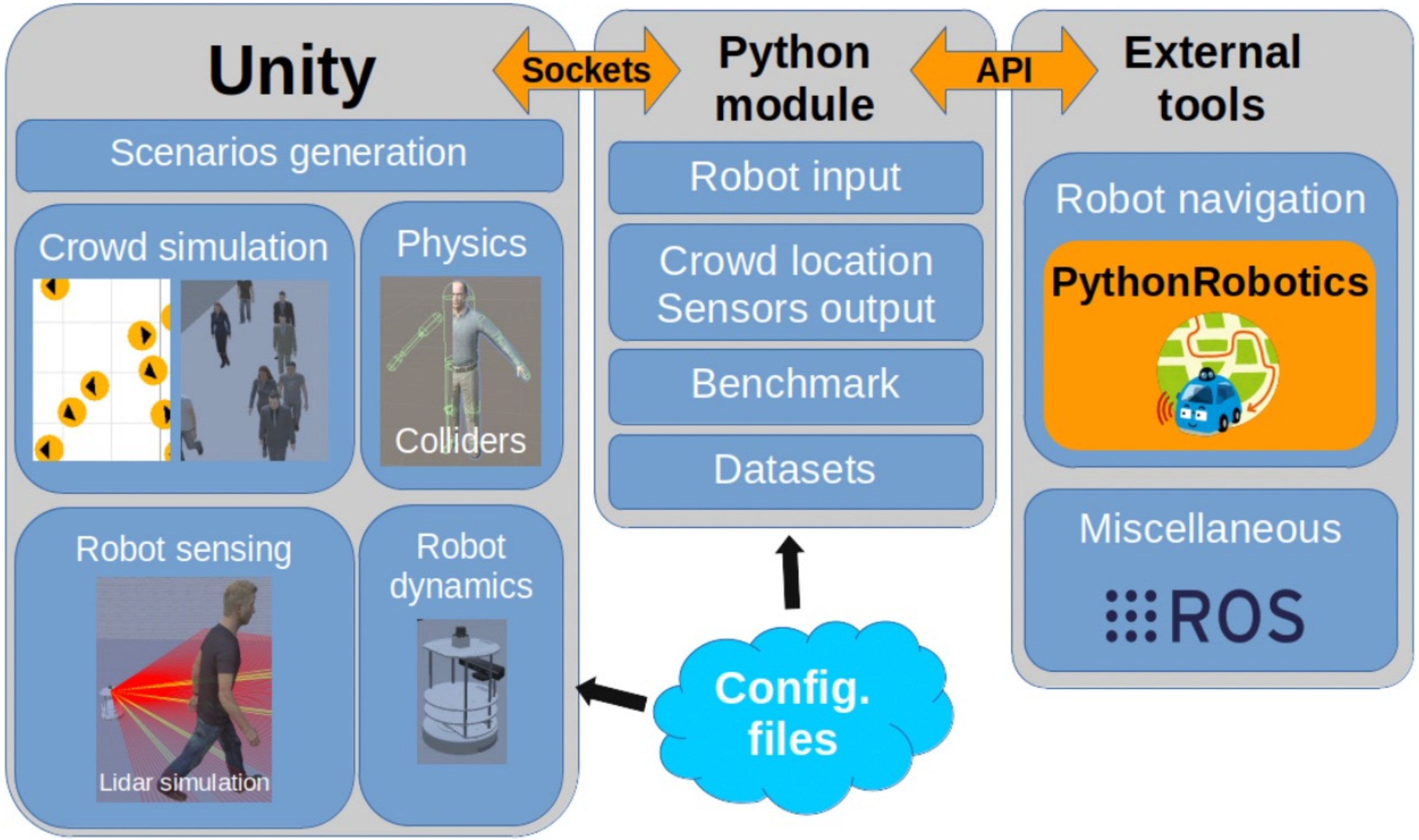
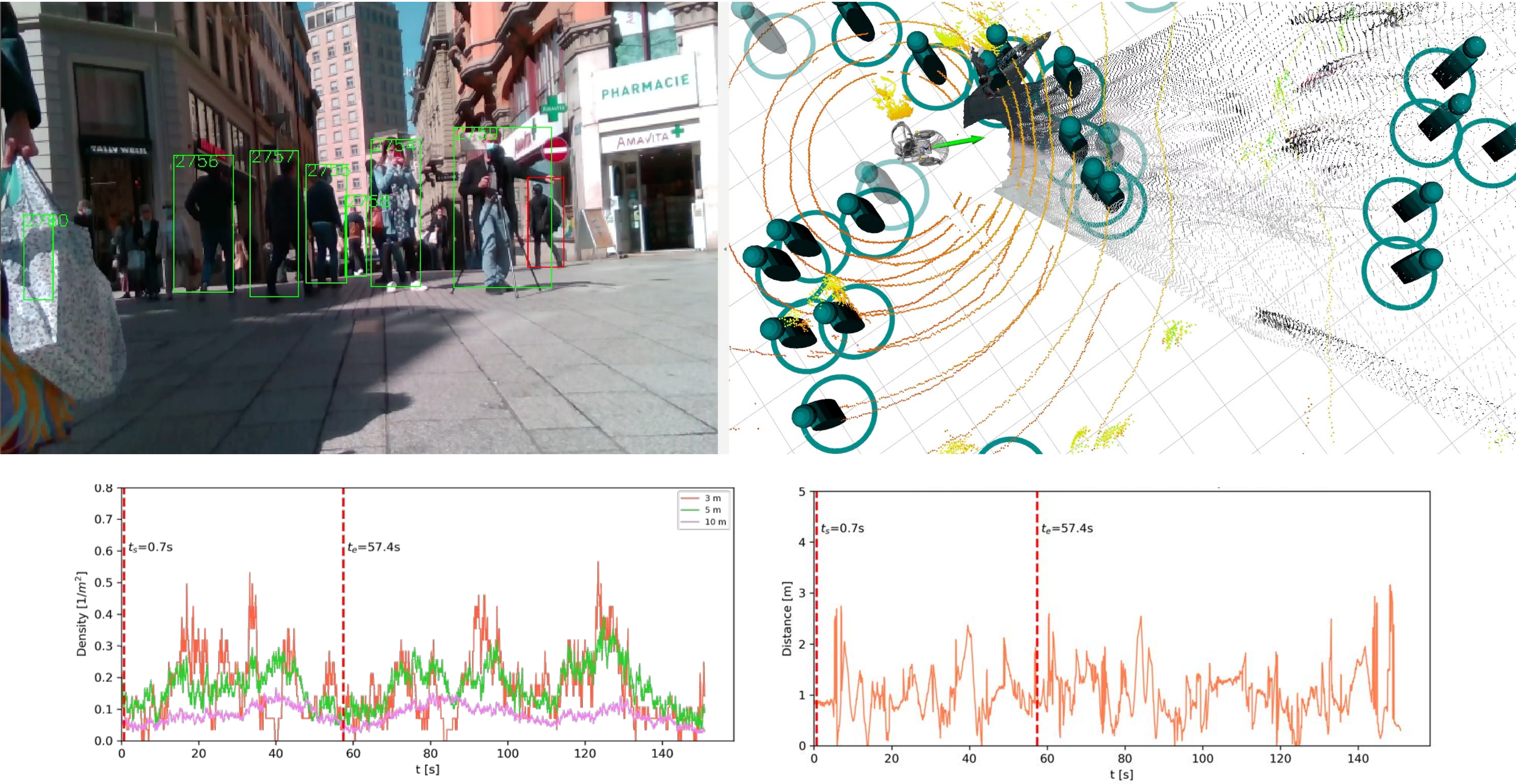
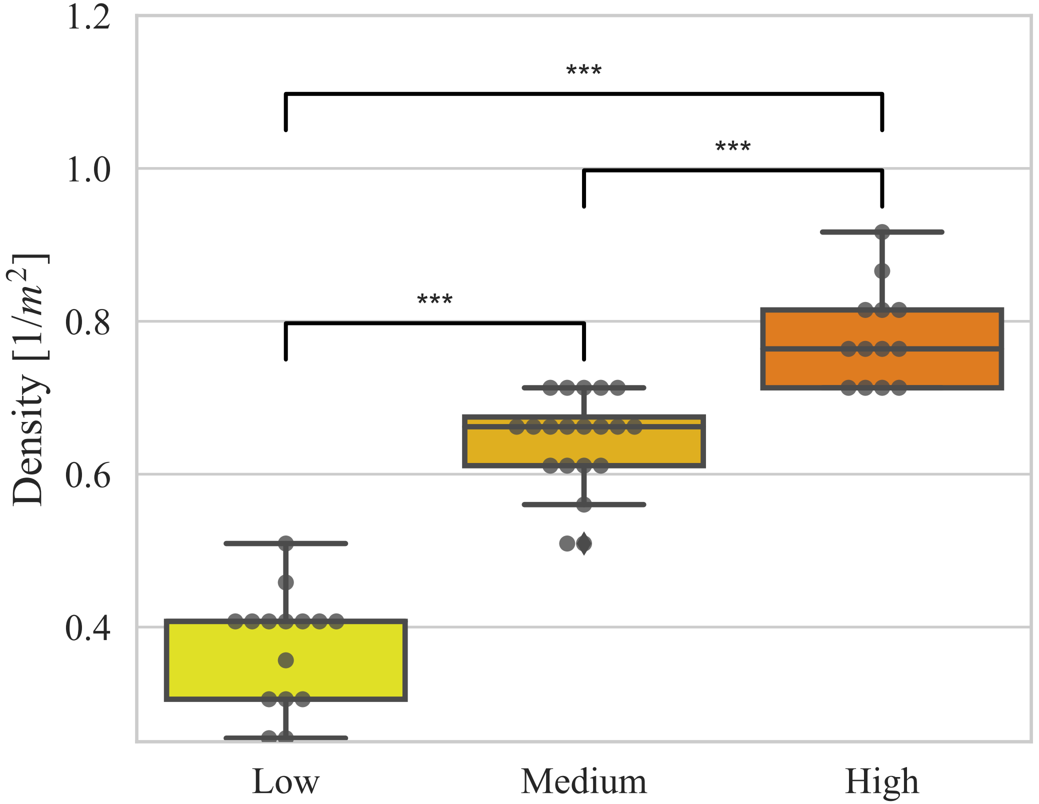


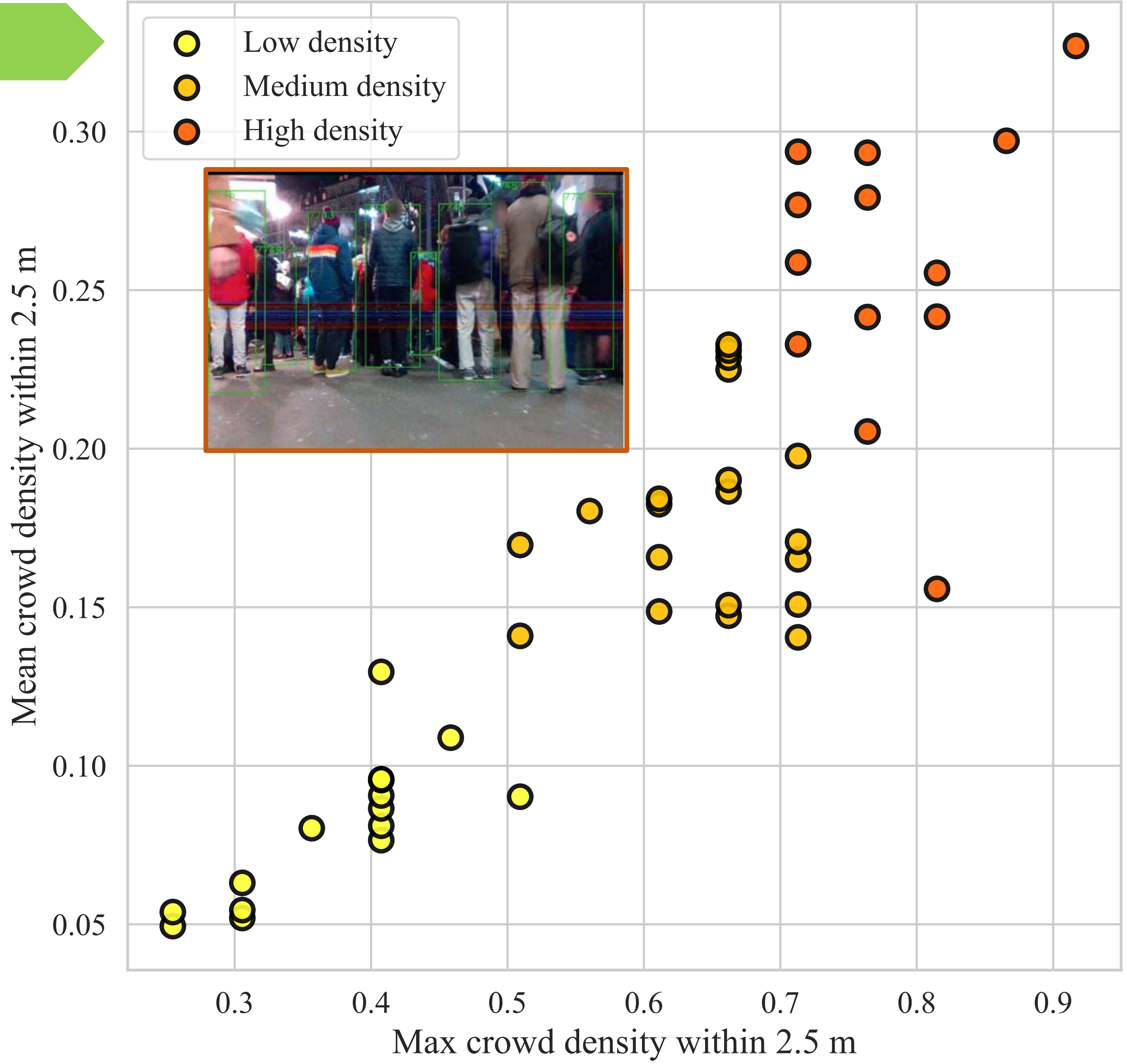
Grzeskowiak, F., Gonon, D., Dugas, D., Paez-Granados, D., Chung, J., Nieto, J., Siegwart, R., Billard, A., Babel, M., & Pettré, J. (2021). Crowd against the machine: A simulation-based benchmark tool to evaluate and compare robot capabilities to navigate a human crowd. *IEEE International Conference on Robotics and Automation (ICRA-2021)*. https://doi.org/10.1109/ICRA48506.2021.9561694



2756
2757
2754
2759
PHARMACIE
AMAVITA
3 m
5 m
10 m
t_s=0.7s
t_e=57.4s
Density [1/m^2]
t [s]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
100
120
140
t_s=0.7s
t_e=57.4s
Distance [m]
t [s]
0
1
2
3
4
5
0
20
40
60
80
100
120
140

Crowd Type and Density





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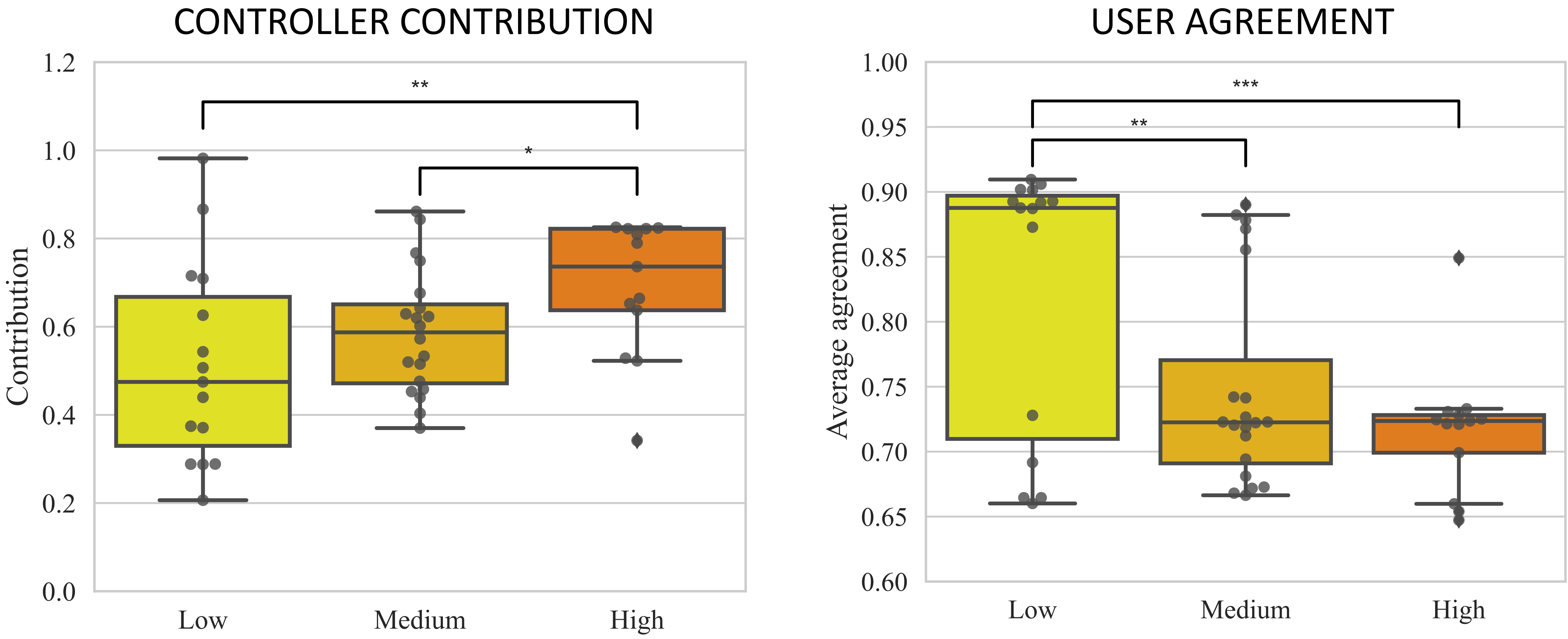

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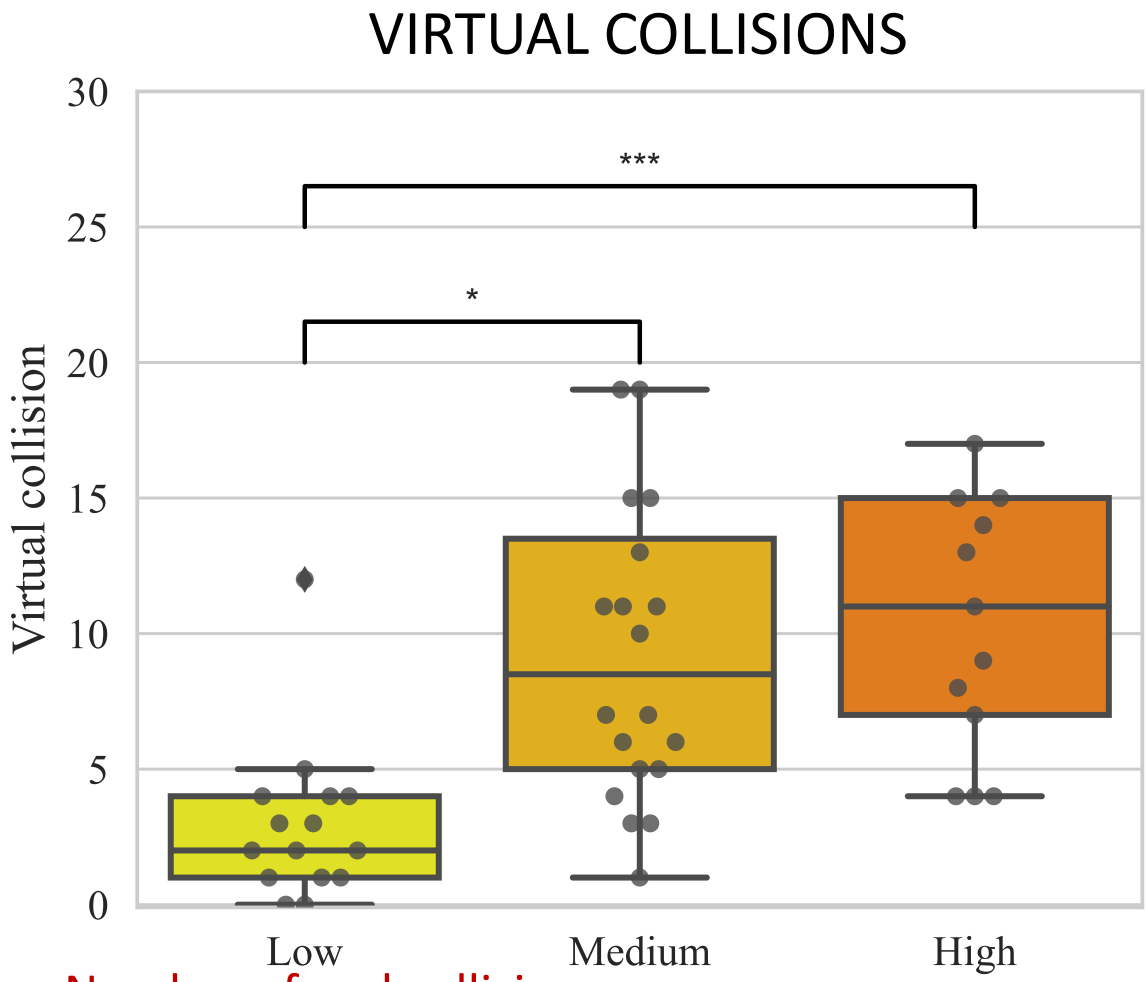

Number of real collisions:

0 3 0

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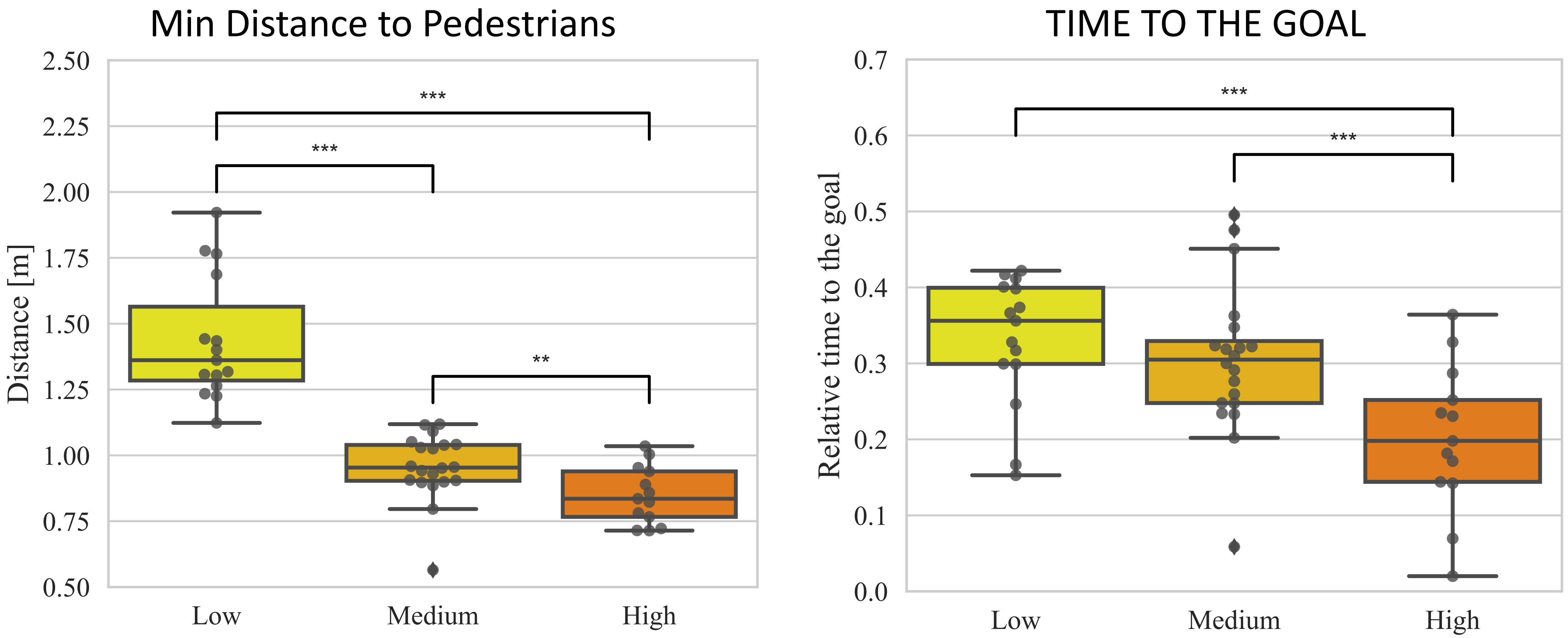

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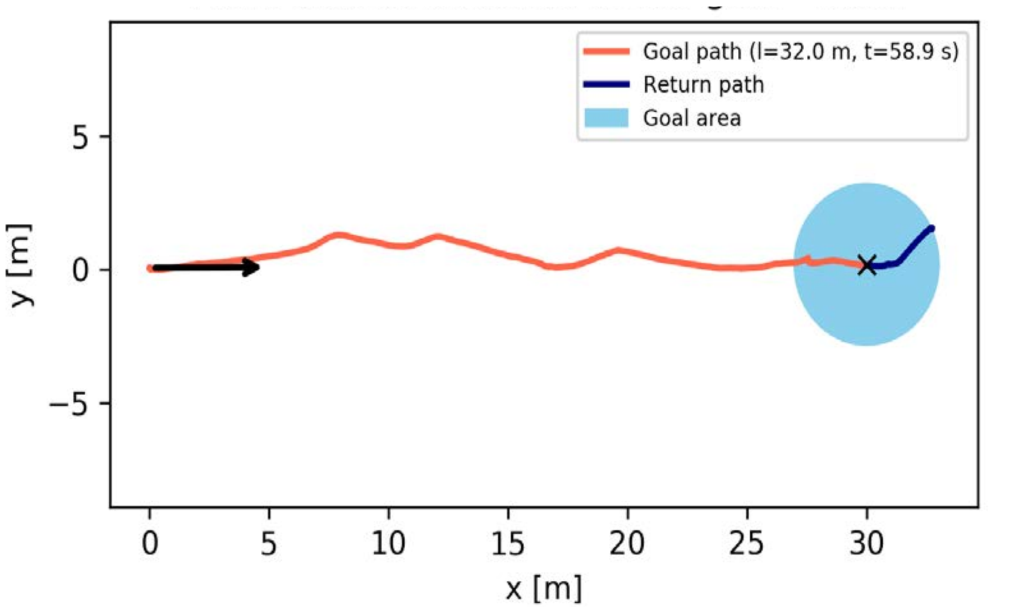
Autonomy versus shared control



	Recorded Data
Recordings	250k frames of 2 x 3D point clouds
Tests	120 recordings
Time	~ 5 hours of data
Traveled distance	~ 12 km
Total raw data	~1.2 Tb

Paez-Granados D., He Y., Gonon D., Huber L., & Billard A., (2021), “3D point cloud and RGBD of pedestrians in robot crowd navigation: detection and tracking." IEEE Dataport, doi: https://dx.doi.org/10.21227/ak77-d722.

Smart robots that can interact with humans safely

How to measure autonomy?

Not ready yet!

Robots understanding of their surrounding too limited

Social Navigation on crowds needs to understand their behavior

We need to evaluate robot's behavior for each applications and society

We need to agree on egocentric feasible metrics for real applications

ISO- 18646 - Robotics — Performance criteria and related test methods for service robots —
ISO/DIS 22737 - Intelligent transport systems — Low-speed automated driving (LSAD) systems for predefined routes

Credits

CROWDBOT

Metrics and Safety for Autonomous Robot Navigation

Dr. Diego Paez-Granados

LASA
Learning Algorithms and Systems Laboratory

ACKNOWLEDGEMENT

Funding

EU H2020 project ”Crowdbot” (779942)

Toyota Mobility Unlimited Challenge (2019-21)

The experiments were approved with an ethical protocol by the human research ethical committee of EPFL

Approval No: HREC-032-2019 / 2021

Collaborators

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Prof. Kenji Suzuki, U. Tsukuba

Prof. Bastian Leibe, RWTH