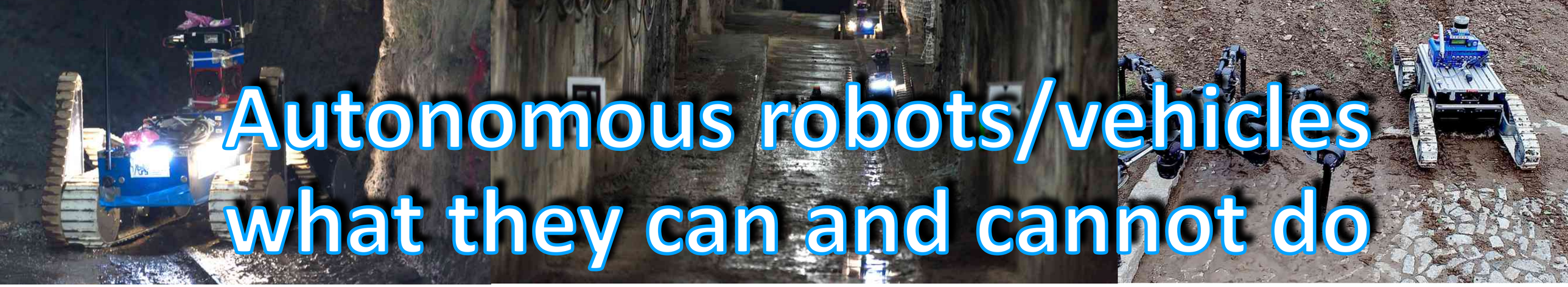


Autonomous robots/vehicles what they can and cannot do

Tomáš Svoboda, Karel Zimmermann, Jan Faigl, Tomáš Krajník, Martin Saska.
PhD, master, bachelor students …
svobodat@fel.cvut.cz, https://cmp.felk.cvut.cz/~svoboda/

Czech Technical University in Prague, Center for Robotics and Autonomous Systems
http://robotics.fel.cvut.cz/

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

DARPA

Valeo

GAČR
GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Robotic vehicles are(?) all around

- https://aiforgood.itu.int/event_tags/robotics/
- agriculture (yet <<<< than normal machines)
- what they can do, now?
- what they will do, tomorrow?

robotic delivery - Starship

https://www.starship.xyz/

robotic delivery Amazon Scout

https://www.aboutamazon.com/news/transportation/meet-scout

transportation

https://auve.tech/

Mercedes Self Driving Bus Official Commercial Mercedes Future Bus 2016 Autonomous Bus

very long history

History of self-driving cars. (2022, August 23). In Wikipedia. https://en.wikipedia.org/wiki/History_of_self-driving_cars

ARGO and the MilleMiglia in Automatico

Completely designed and implemented by VisLab, the ARGO prototype vehicle is the first autonomous passenger car exhaustively tested for more than 2000 km (94% of which in autonomous mode) on Italian highways, together with regular traffic. ARGO is considered one of the milestones of vehicular robotics worldwide (see Wikipedia).

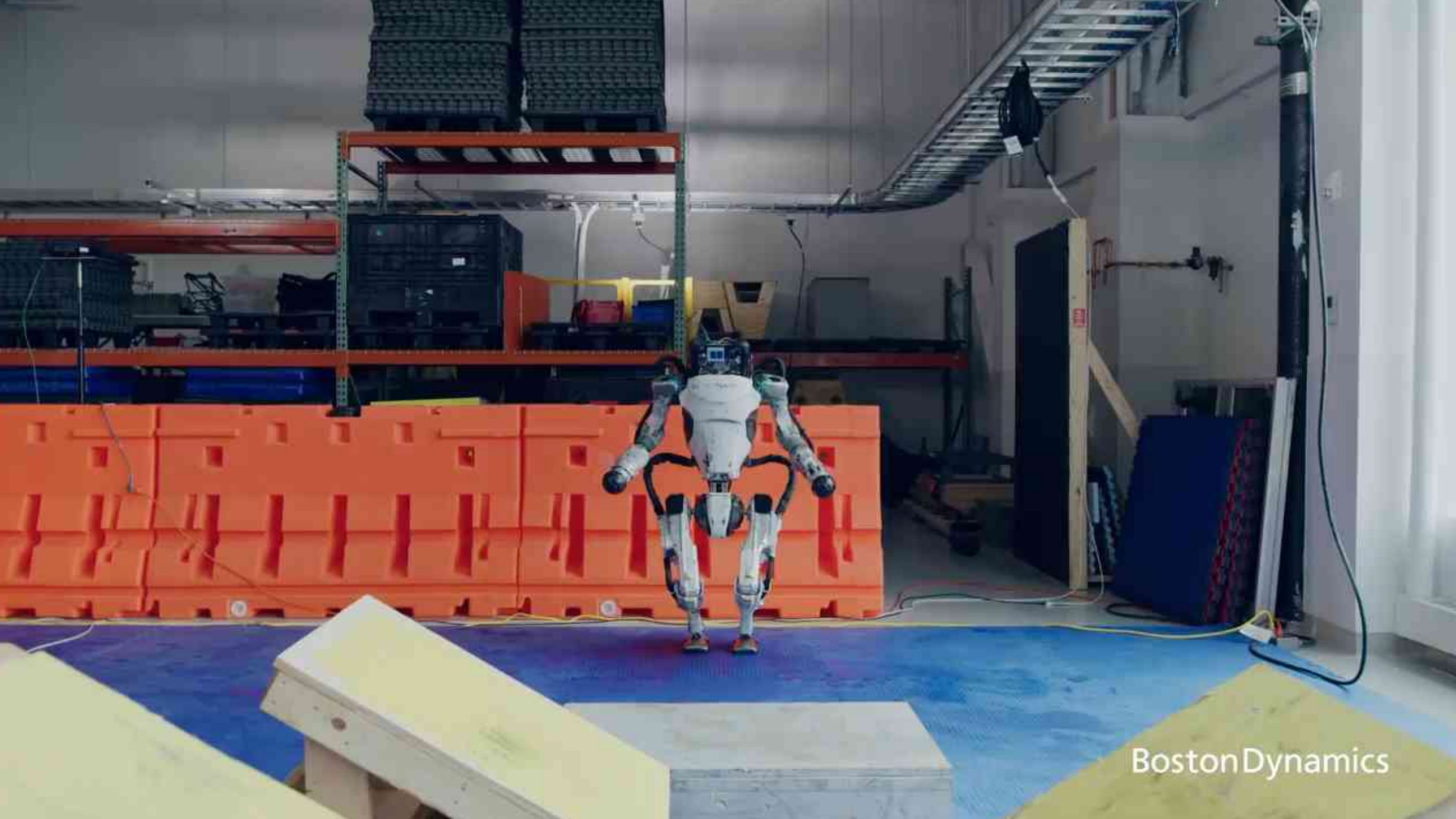
Autonomous verhicles are all around

...

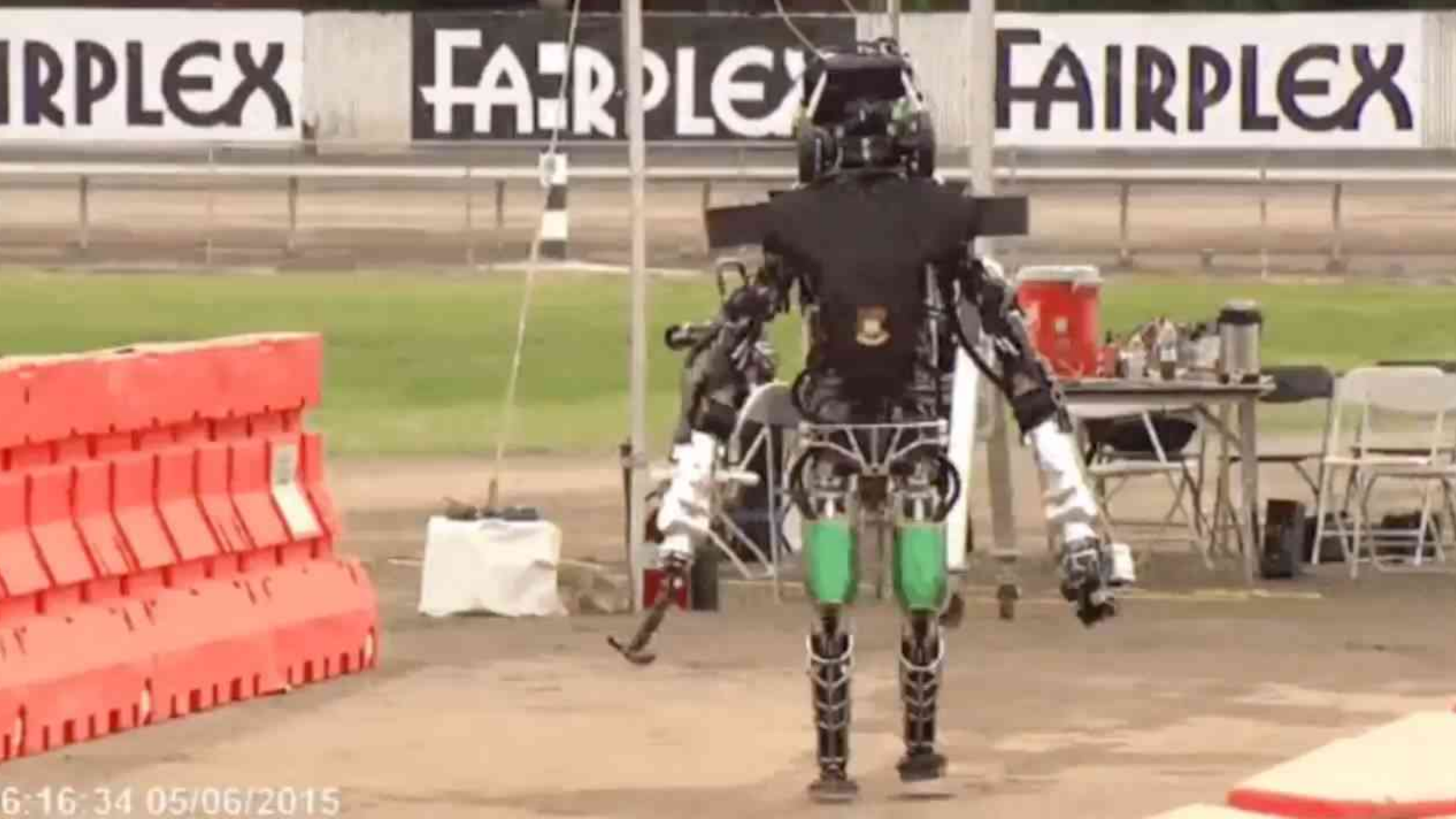
YouTube

What you mostly see

...

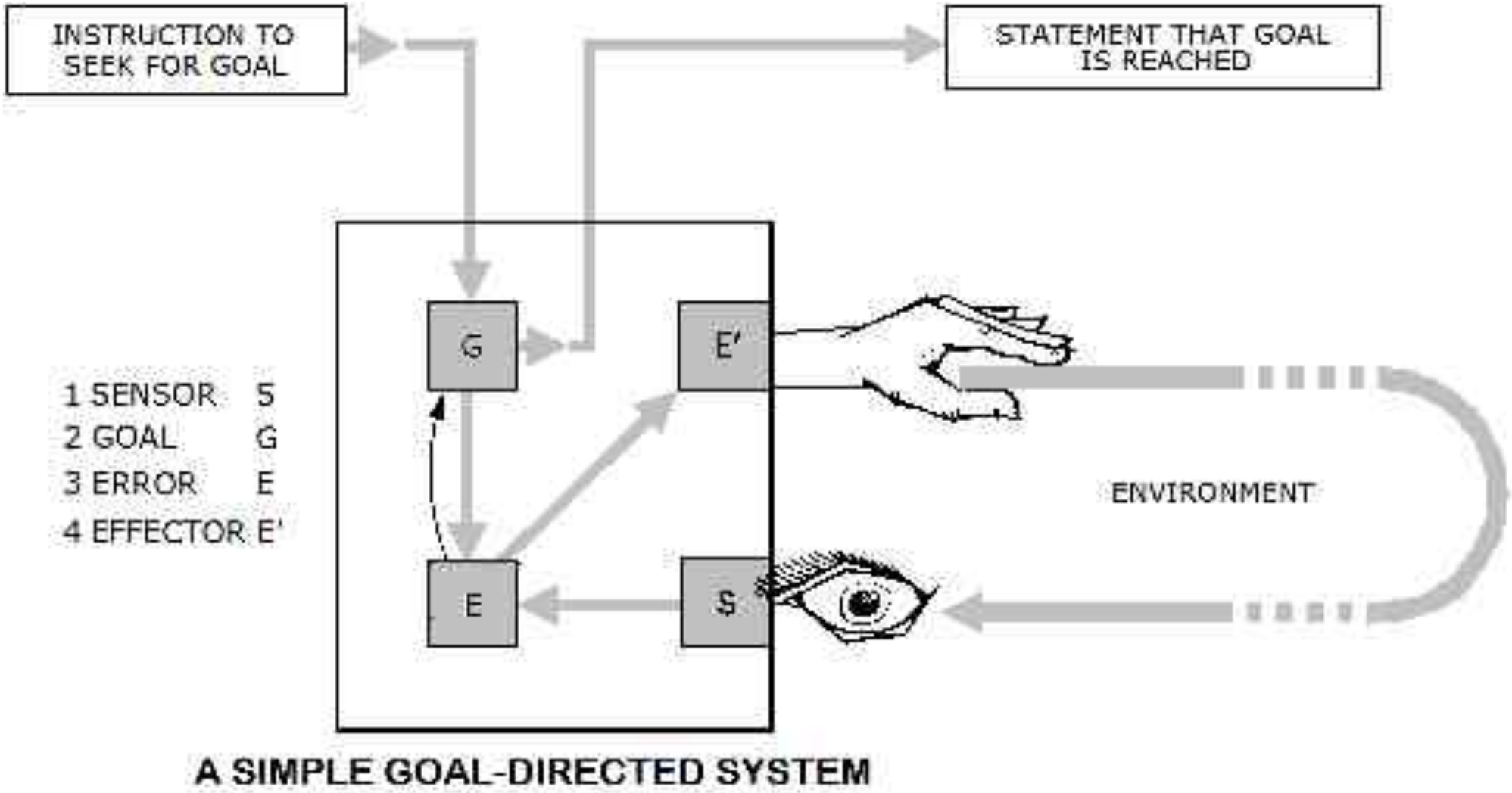

Boston Dynamics

What you mostly do not see …


FAIRPLEX
FAIRPLEX
FAIRPLEX
6:16:34 05/06/2015

Real deployments still very limited

(our) AI in robotics - goal-directed system



A SIMPLE GOAL-DIRECTED SYSTEM

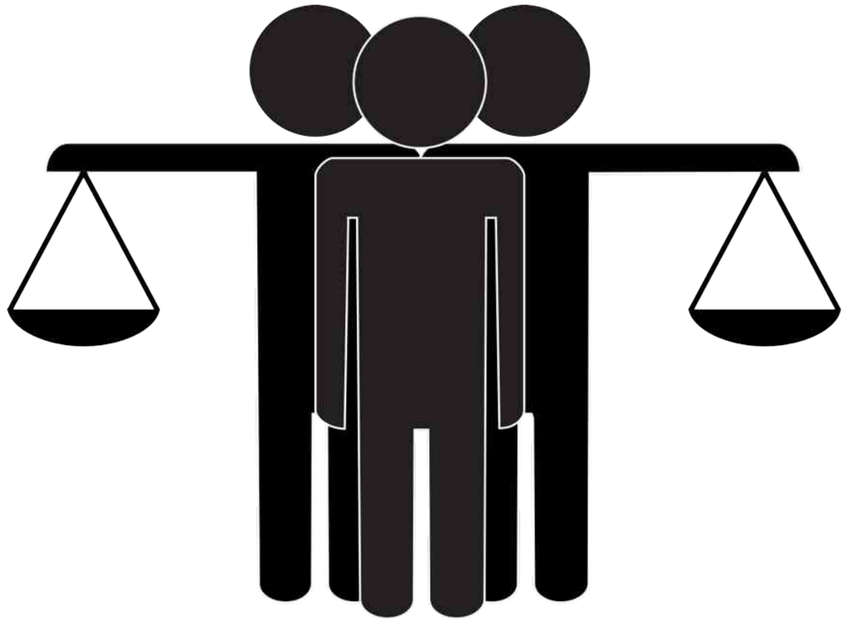
1

Robot: hardware AND software

[1] Figure from http://www.cybsoc.org/gcyb.htm

Me/You:
How would you know your system is good (or not)?

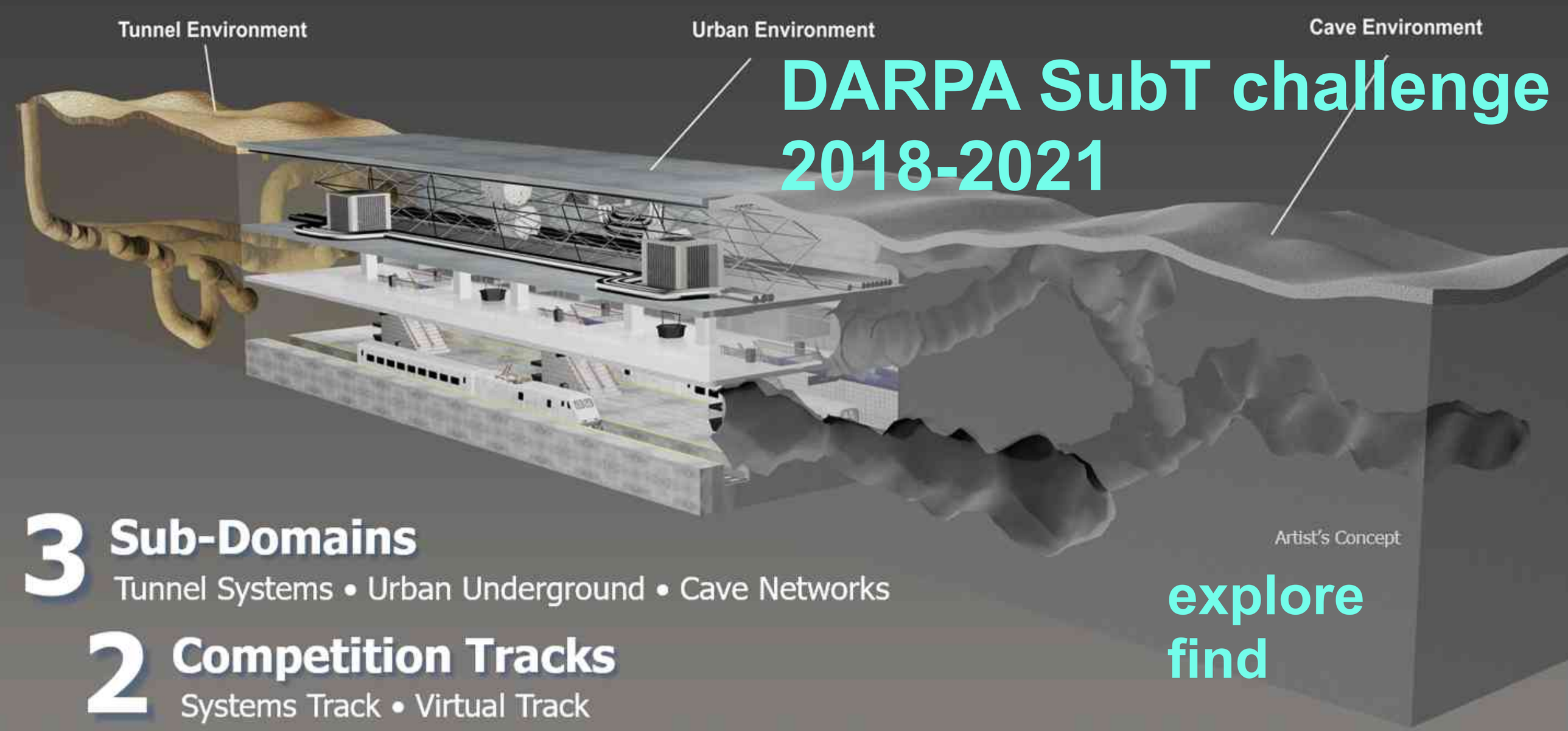
Agency/Government:
What is the current State of the Art?



DARPA Grand Challenge 2004, 2005

DARPA Urban Challenge 2007

DARPA Robotics (humanoid) challenge 2012-2015



DARPA SubT challenge 2018-2021

Artist's Concept

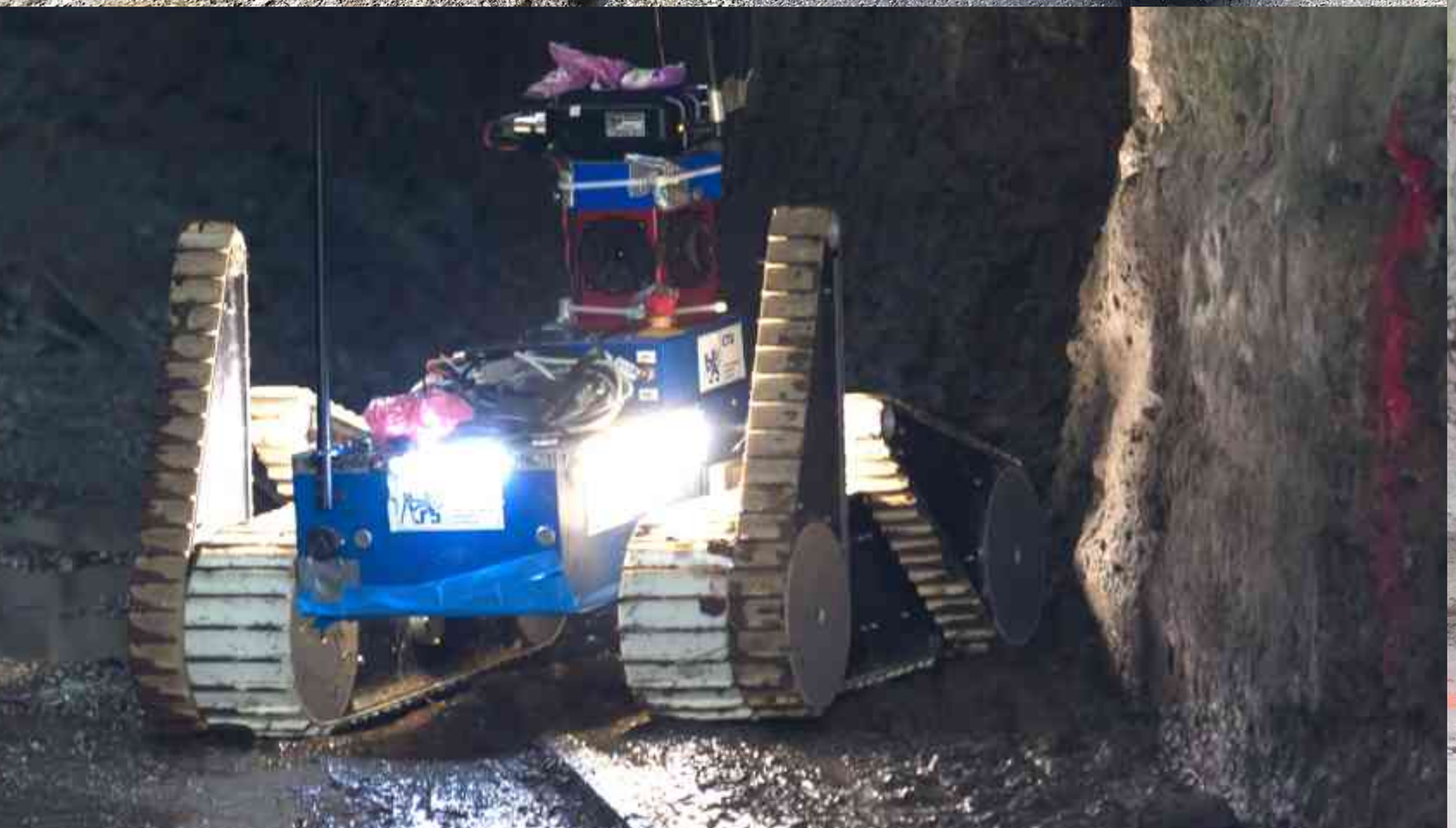
3 Sub-Domains
Tunnel Systems • Urban Underground • Cave Networks

2 Competition Tracks
Systems Track • Virtual Track

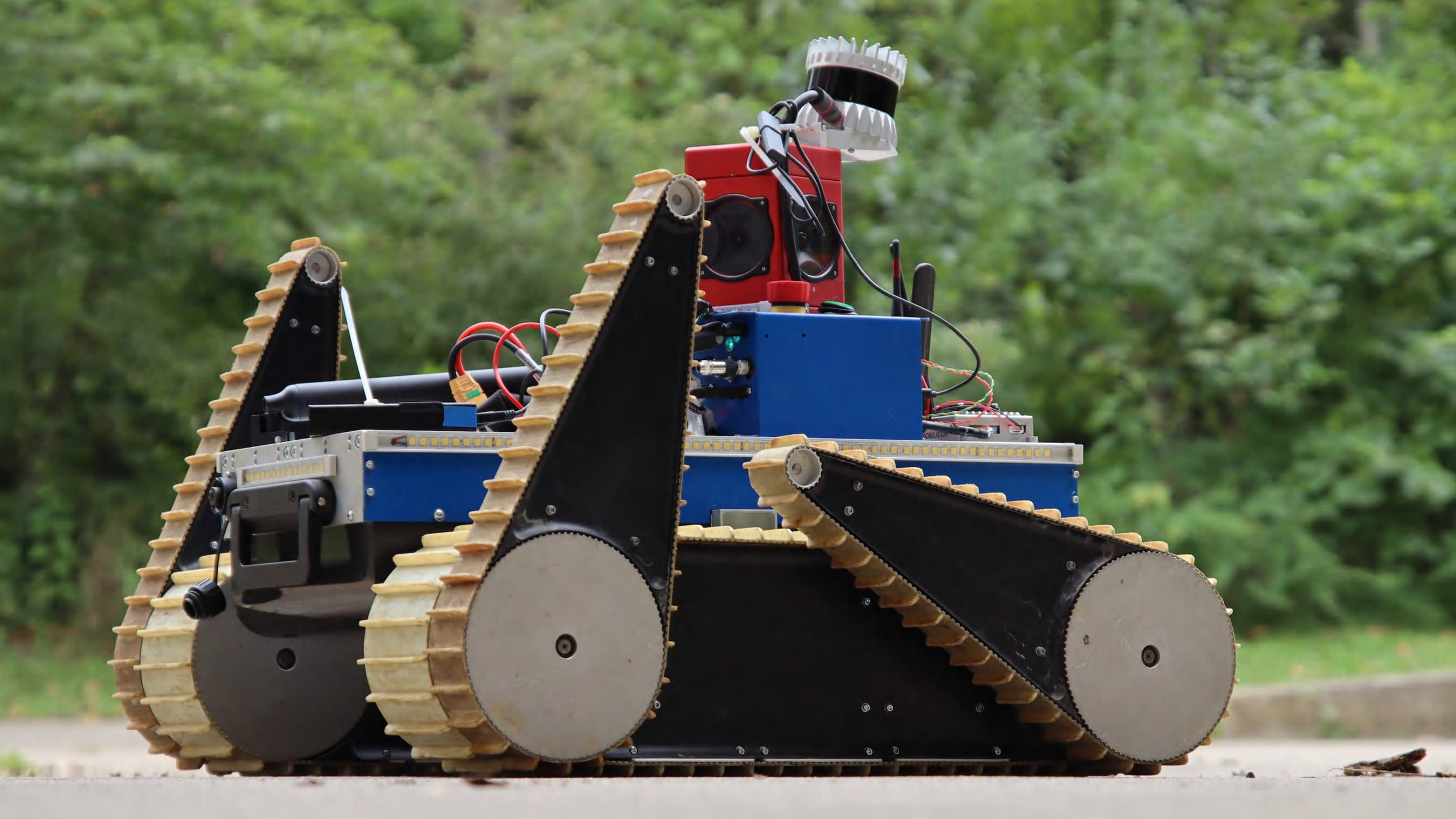
1 Revolutionary Vision
Create breakthrough technologies and capabilities for underground operations

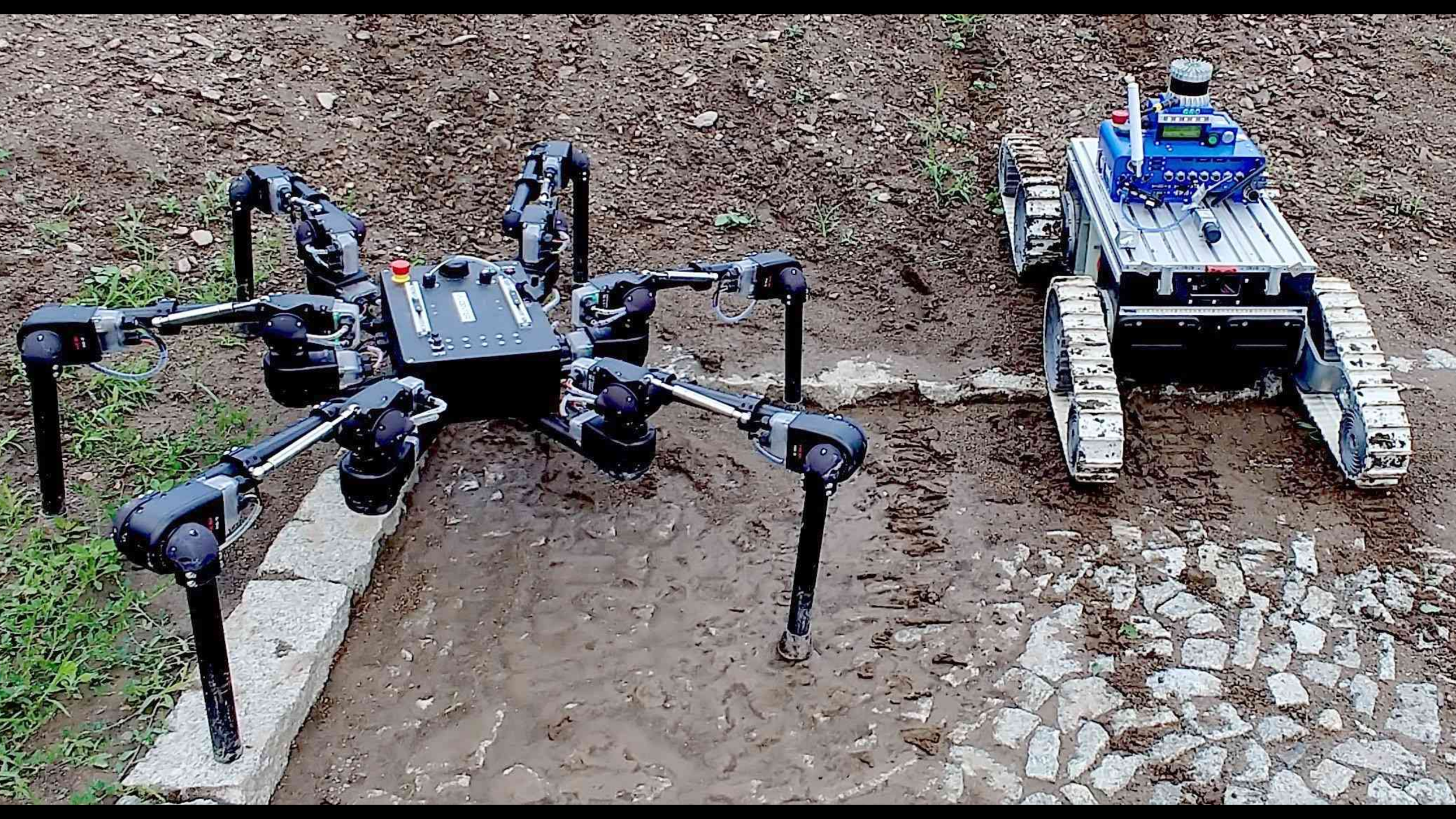
explore
find

Learn More at www.darpa.mil




2
BostonDynamics
GENERAL






4

Rules of the game

- take up from the garages, move to site entrance
- **30 mins** for set-up at the entrance (unpack robots, displays, laptops, get the coordinate systems aligned)
- **60 mins** for the mission - go in, find/reognize and locate objects and report to the DARPA evaluation system
- **only 1 person** allowed to “talk” to machines (if possible at all) and report


Time: T-45 mins
TEAM
ECCV16
CTU-CRAS
CHARLIE

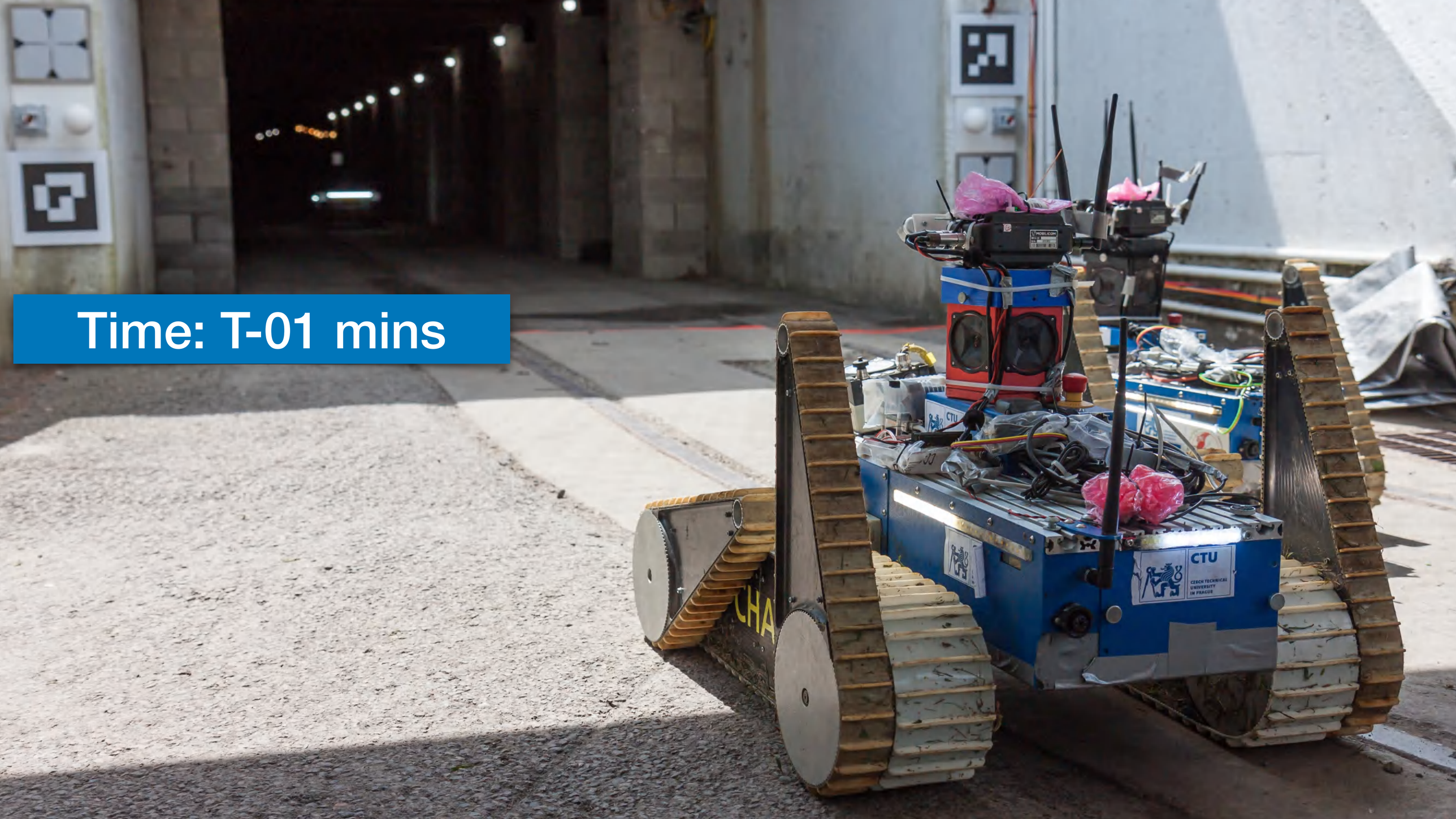

Time: T-35 mins
CTU
CTU


Time: T-32 mins
Electric


Time: T-15 mins
CRAS-09
SUBTERRANEAN CHALLENGE

Time: T-10 mins


Time: T-05 mins
CRAS-12
CTU
DELTA


Time: T-01 mins
CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Mission: 60 minutes

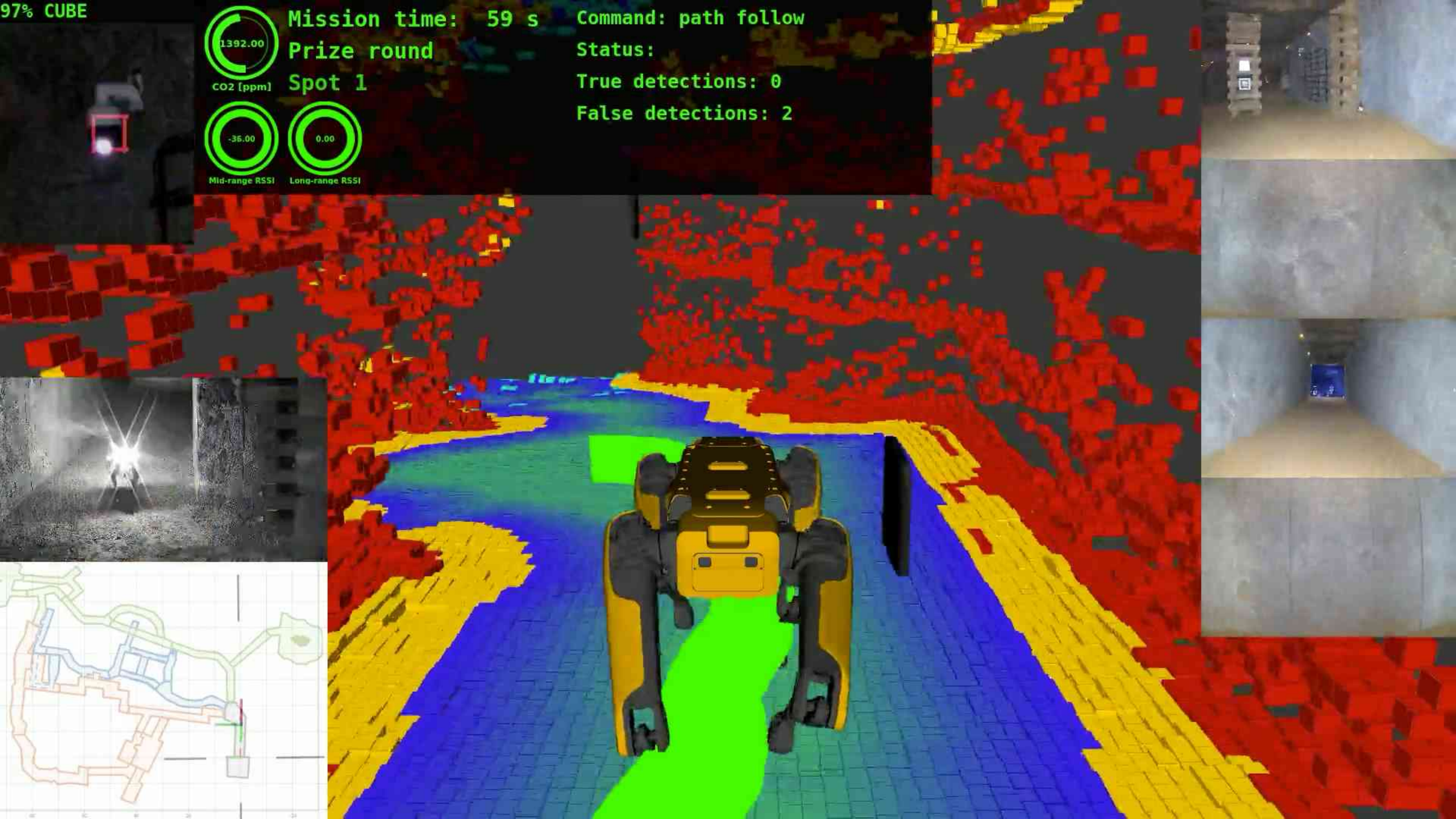

DARPA SubT Urban Circuit, 02/2020

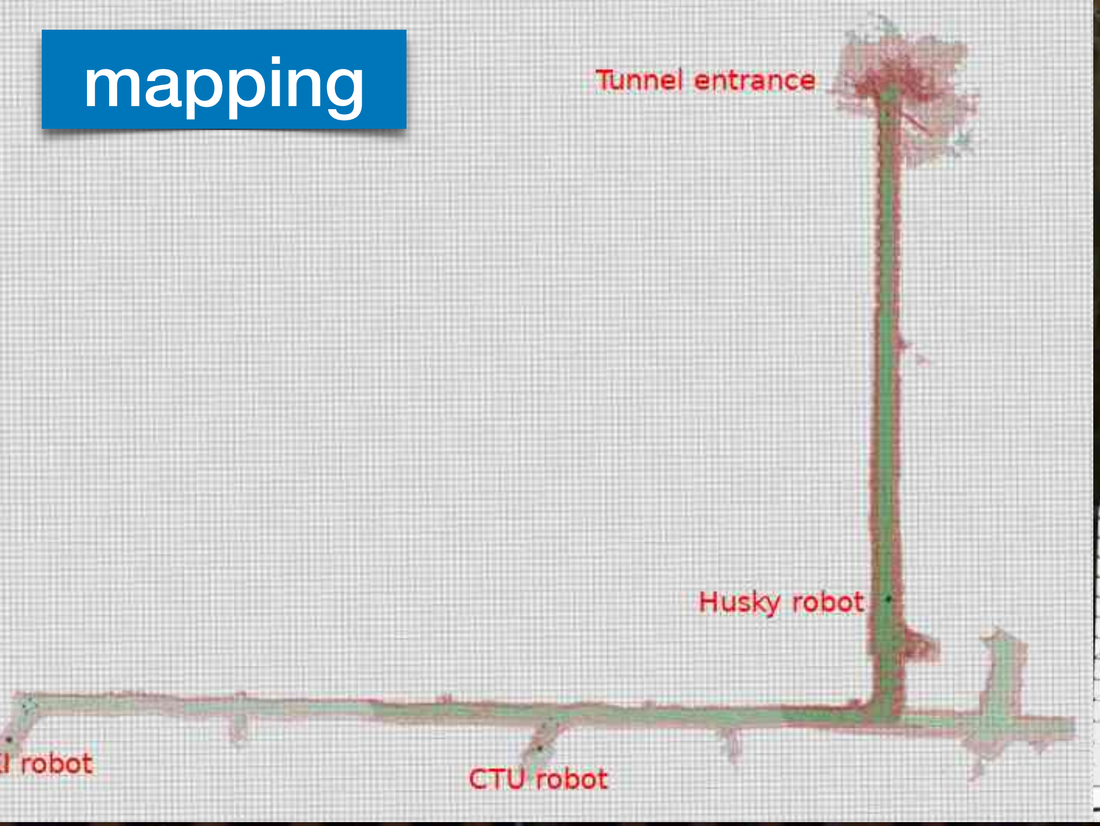
CTU-CRAS-NORLAB

@DARPA Subterranean Challenge
URBAN CIRCUIT

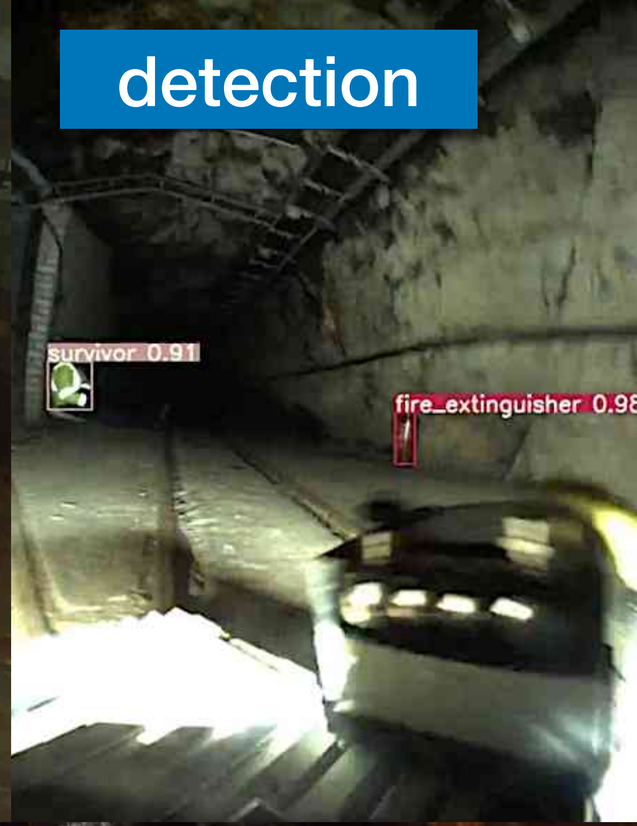
http://robotics.fel.cvut.cz/cras/darpa-subt/


Boston Dynamics
1


97% CUBE
1392.00
CO2 [ppm]
Mission time: 59 s
Prize round
Spot 1
Command: path follow
Status:
True detections: 0
False detections: 2
-36.00
Mid-range RSSI
0.00
Long-range RSSI


mapping
Tunnel entrance
Husky robot
l robot
CTU robot


exploration


detection
survivor 0.91
fire_extinguisher 0.98


high-level control
communication

3D Mapping

3D LiDAR maping, ICP++

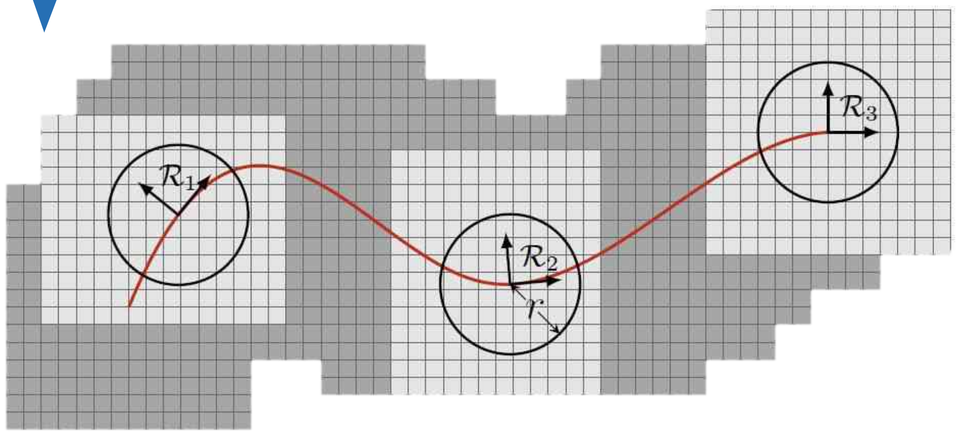
https://norlab.ulaval.ca

- Characteristics:
  - Lidar-based, using LSLIDAR C16 and OS0-128 sensors
  - Incremental mapping without global optimization
    - Design choice to keep it lightweight
    - The environment allowed it.
  - Available https://github.com/norlab-ulaval/norlab_icp_mapper_ros
  - Based on the PointMatcher libr
    - https://github.com/ethz

UGV mapping - SubT-specific modifications

https://norlab.ulaval.ca

- Specific properties for SubT:
  - The spatial drift improved by constraining the ICP algorithm by the gravity vector information
  - Computational complexity bounded by splitting the global map into large voxels
    - Possible to offload them to a hard drive
  - Initial alignment based on total-station measurements

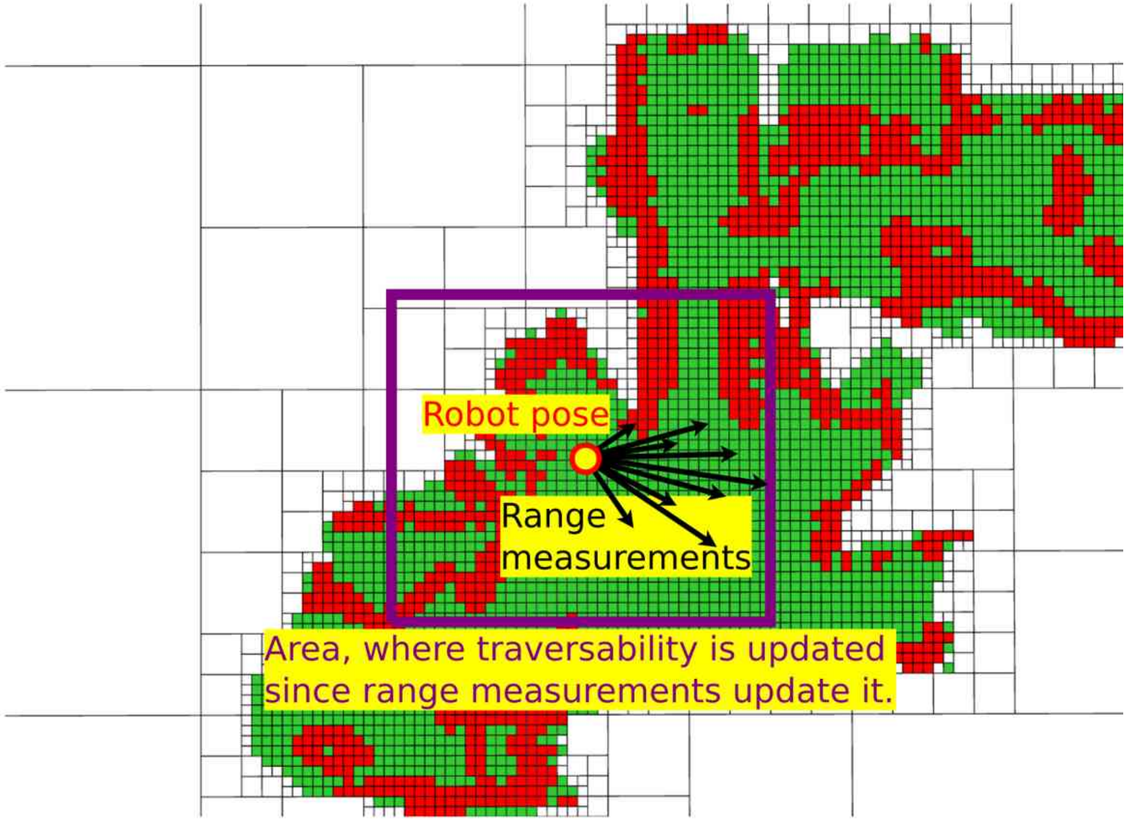


Exploration, autonomy
Where to go next?

Denser maps, elevation, traversability, …

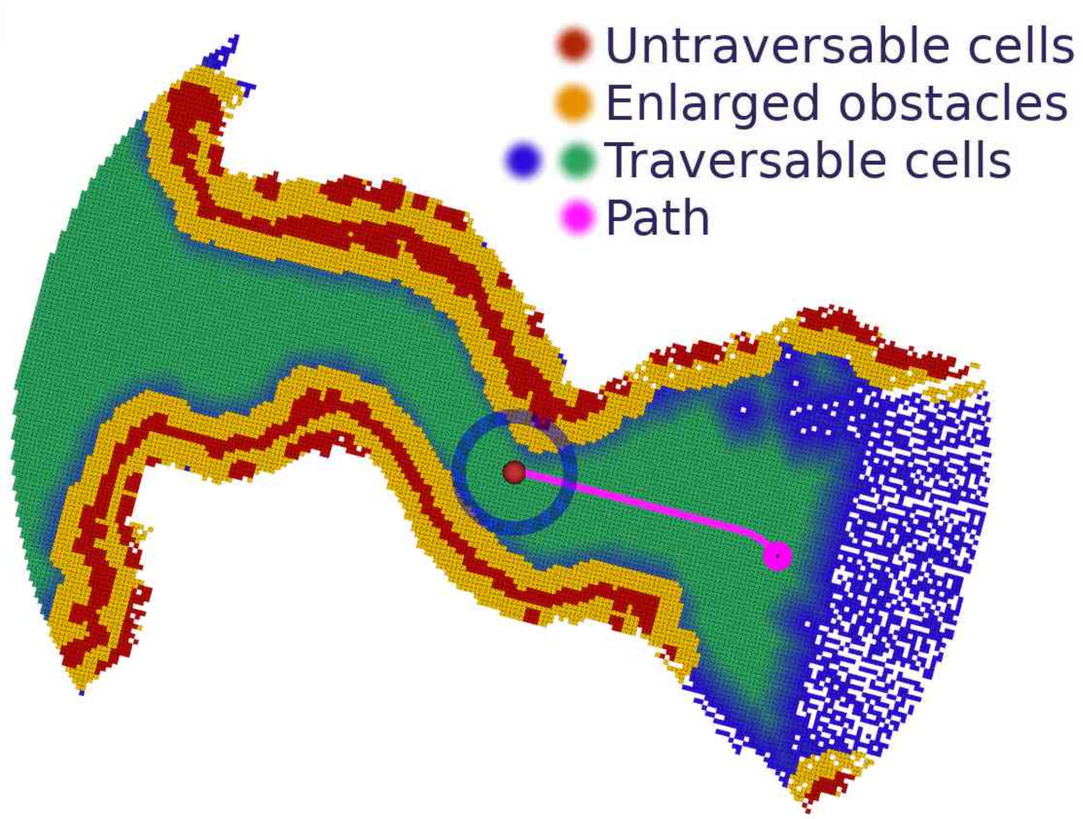
https://comrob.fel.cvut.cz

- Elevation mapping
  - Quadtree representation with local area update.



Bayer J., Faigl J.: *Speeded Up Elevation Map for Exploration of Large-Scale Subterranean Environments*, MESAS, 2019, 190–202.

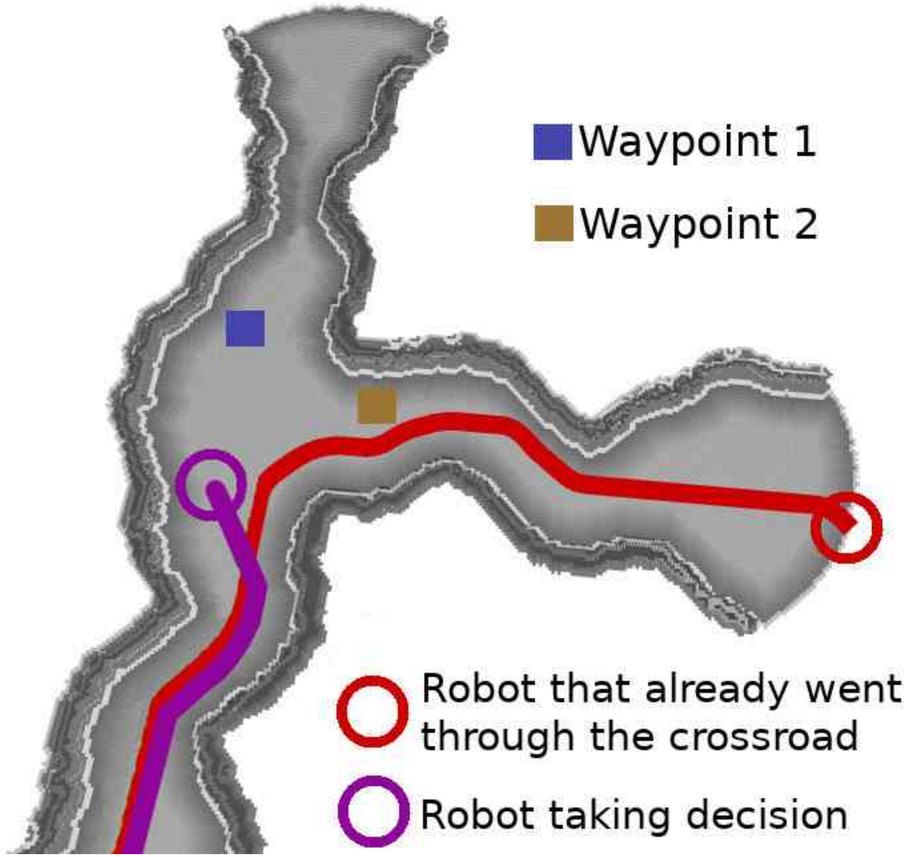
- Traversability estimation



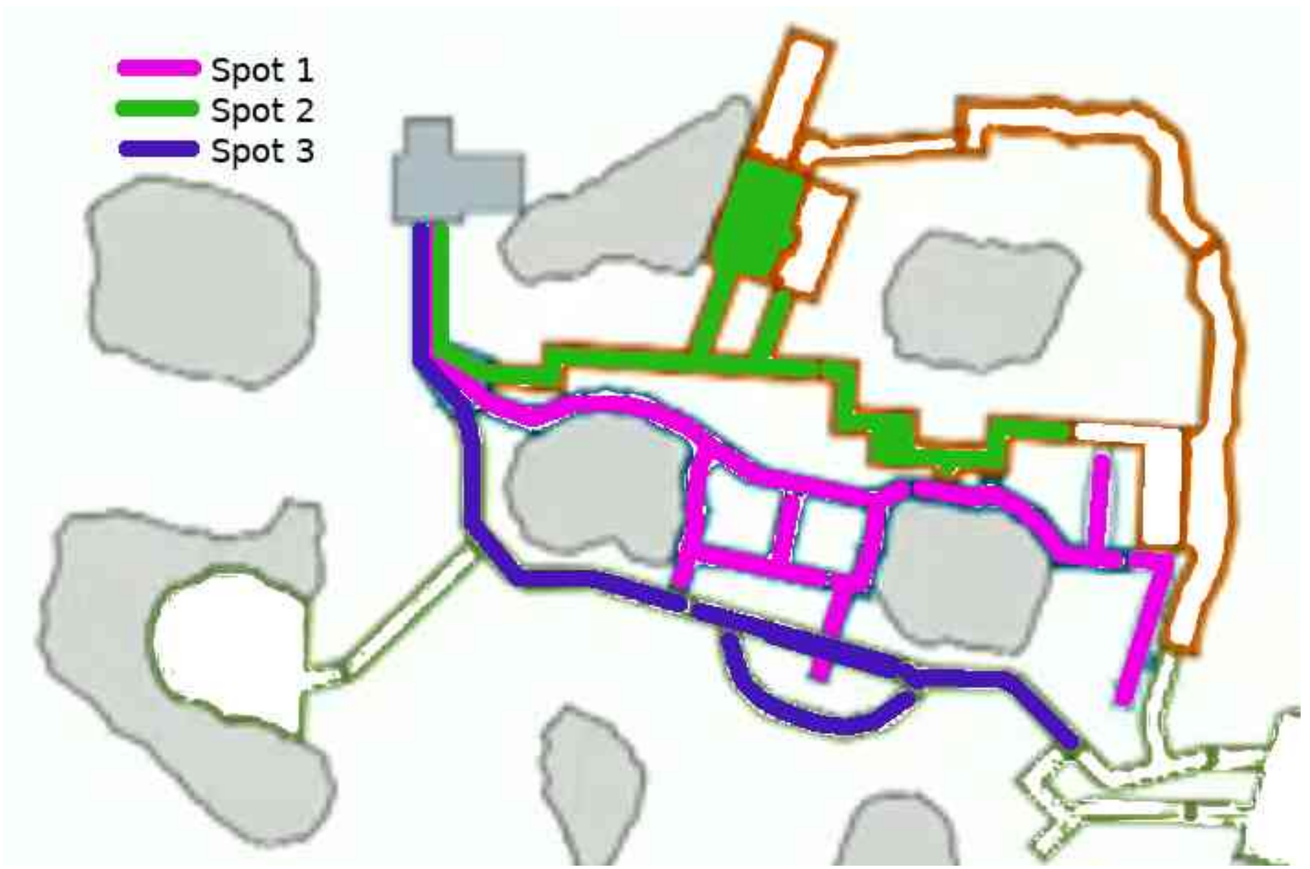
Bayer J., Faigl J.: *On Autonomous Spatial Exploration with Small Hexapod Walking Robot using Tracking Camera Intel RealSense T265*, ECMR, 2019, 1–6.

Multi-robot coordination

- Decision at a crossroad.



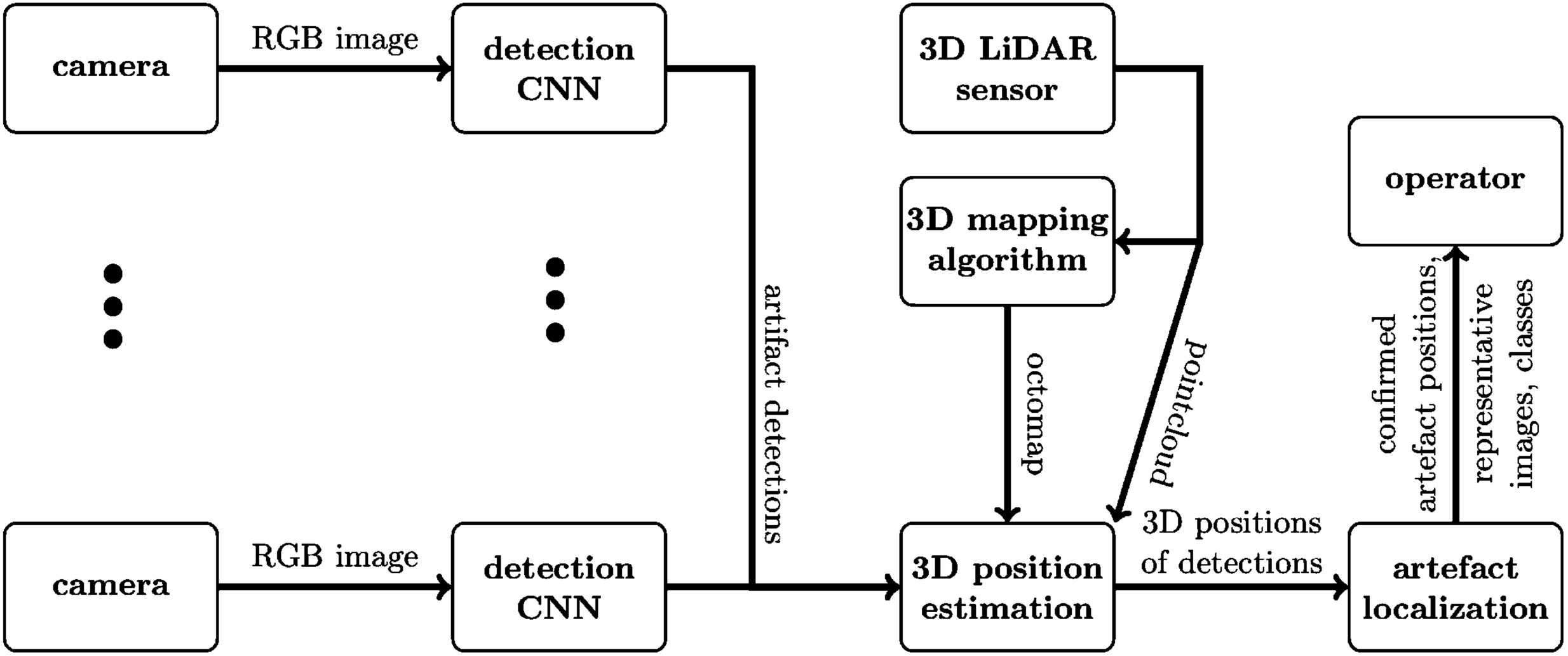
- Deployment during the post event testing



Bayer J., Faigl J.: *Decentralized Task Allocation in Multi-robot Exploration with Position Sharing Only*, DARS-SWARM2021, 2021.

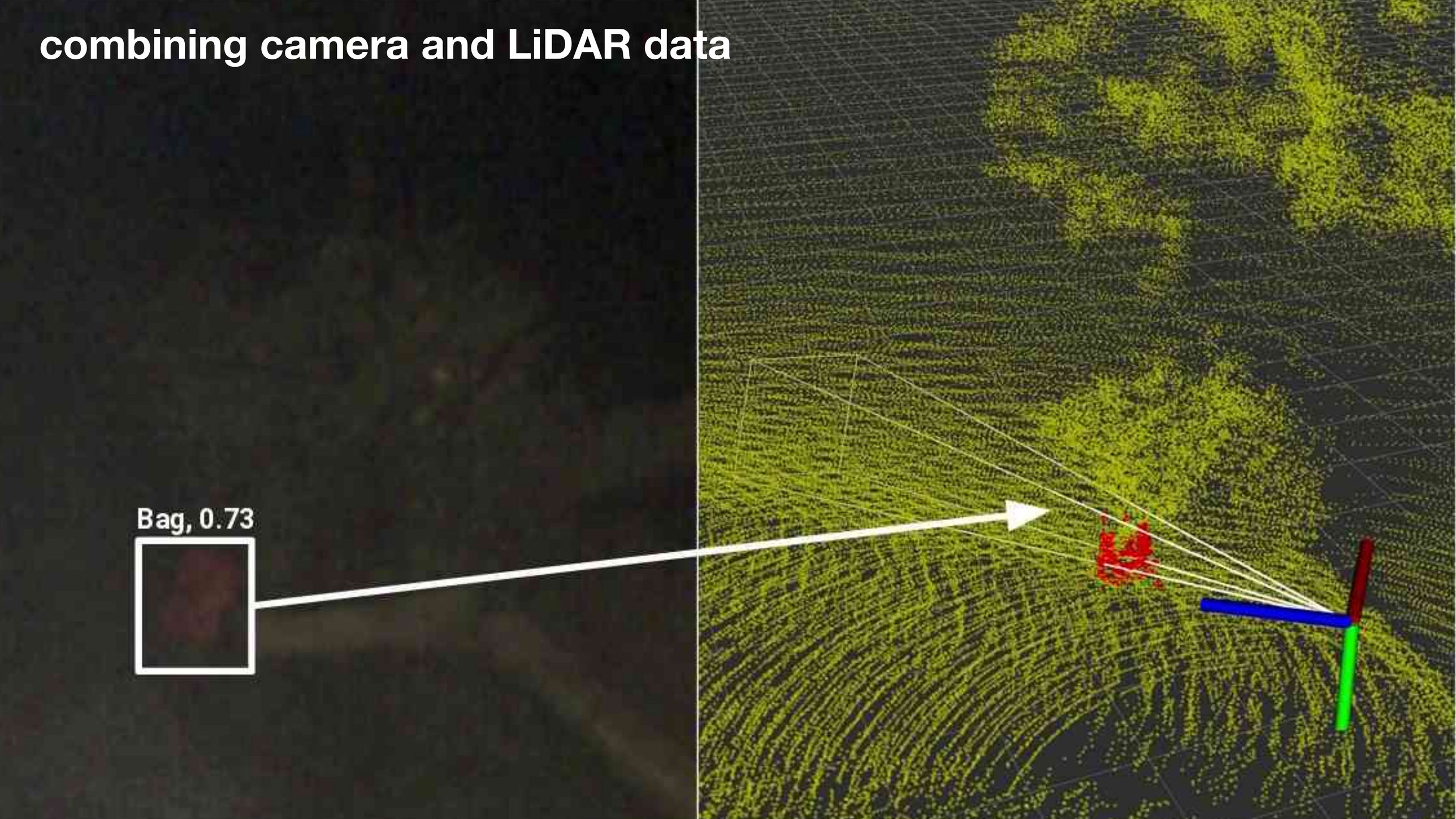
Object detection and 3D localisation

Runs on each robot, multicam setups




fire_extinguisher 0.98
survivo
survivor 0.91
fire_extinguisher 0.98
survivor 0.99

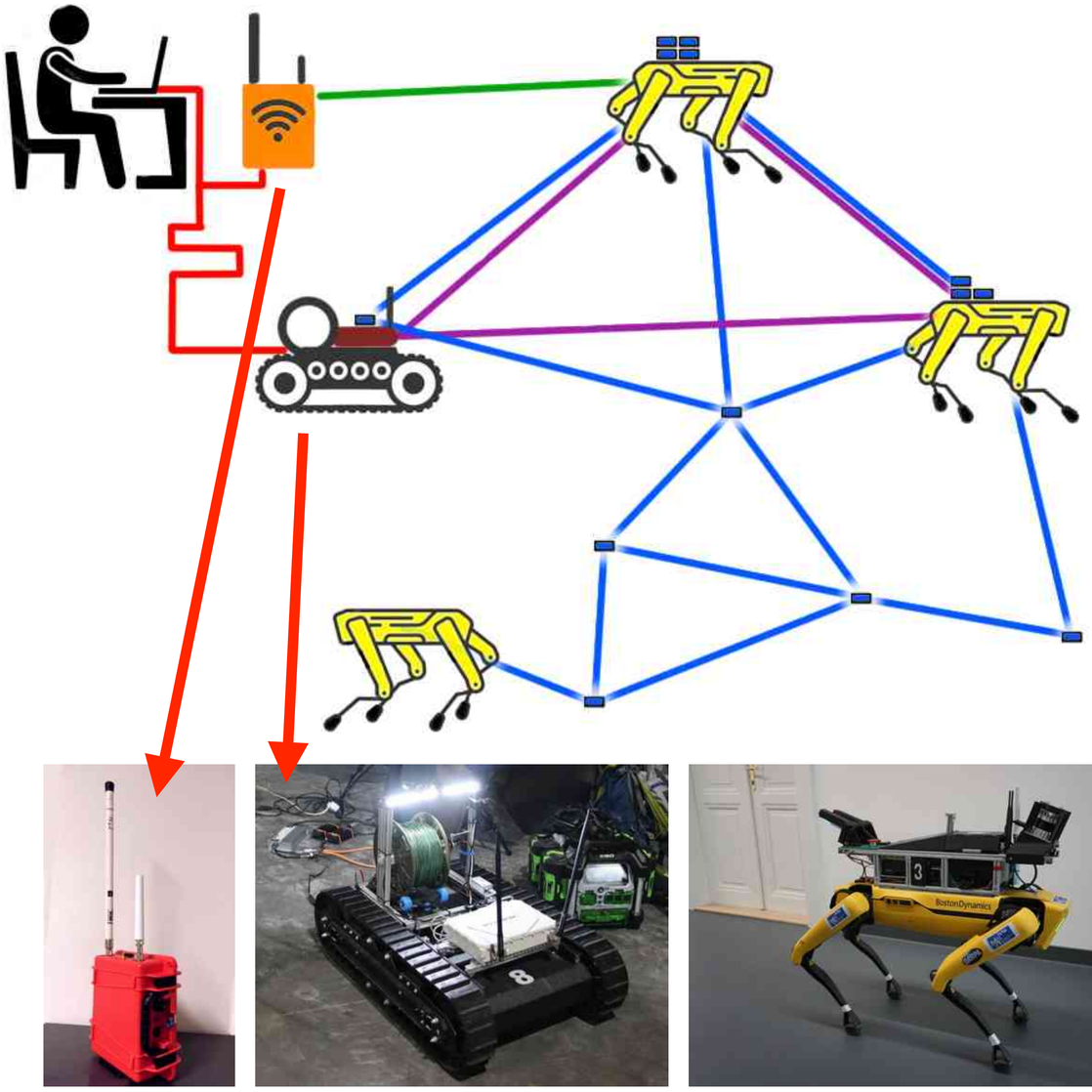
combining camera and LiDAR data



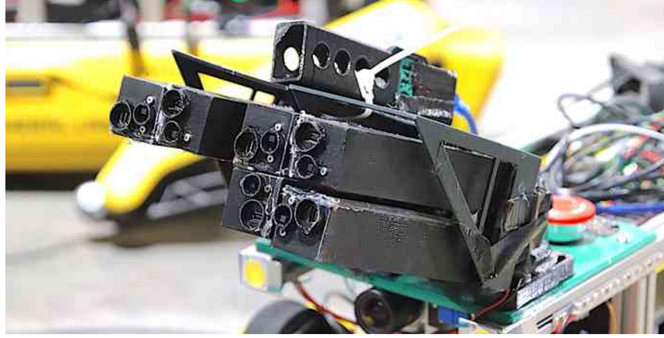
Communication

Wire, WiFi, and beyond …

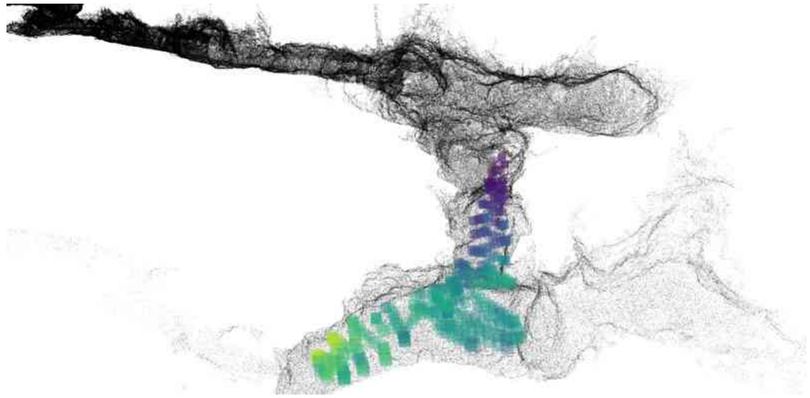
- **Ubiquity AirMAX** (5 GHz)
  - **Bandwidth**: approx. 100 Mbit s^{-1}.
  - **Range**: tens of meters.
  - System start-up and monitoring from staging area.
- **Mobilicom 4G+ Mobile MESH** (2.4 GHz)
  - **Bandwidth**: 8 Mbit s^{-1} for the whole network.
  - **Range**: hundreds of meters on surface.
  - Based on precise time-division multiplexing.
  - Sharing mission data such as maps and images.
- **RFM69HCW-based Breadcrumbs** (915 MHz)
  - **Bandwidth**: 1 kbit s^{-1} per robot.
  - **Range**: hundreds of meters on surface.
  - Based on custom flood-routing protocol that creates ad-hoc mesh.
  - Each robot is equipped with at least one module.
  - Small deployable units (up to 8 units per ugv).
  - Lower-power – last up to 8 h.
  - Telemetry data (robot pose) and control commands.

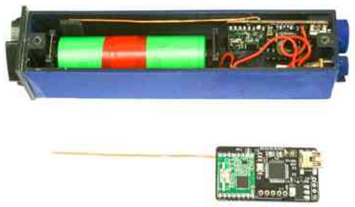


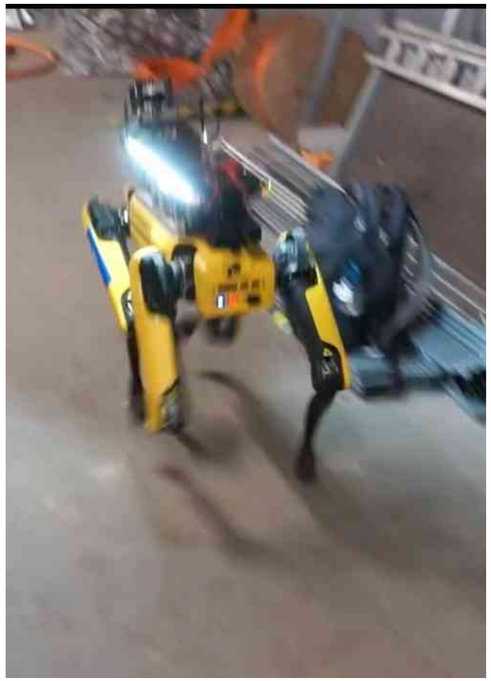
Communication Breadcrumbs



- Low-power 150 mW with approx. 1 kbit s^{-1} per robot.
- Packet-based communication with 64 B packet payload.
- **Flood-network routing** protocol with constrained randomized arbitration of the wireless media access.
  - **Periodic transmission** of robot status and commands.
  - Network scales to hundreds of modules.
  - Throughput given by the network topology.
- 280 m long part of the Bull rock cave has been covered with six modules.

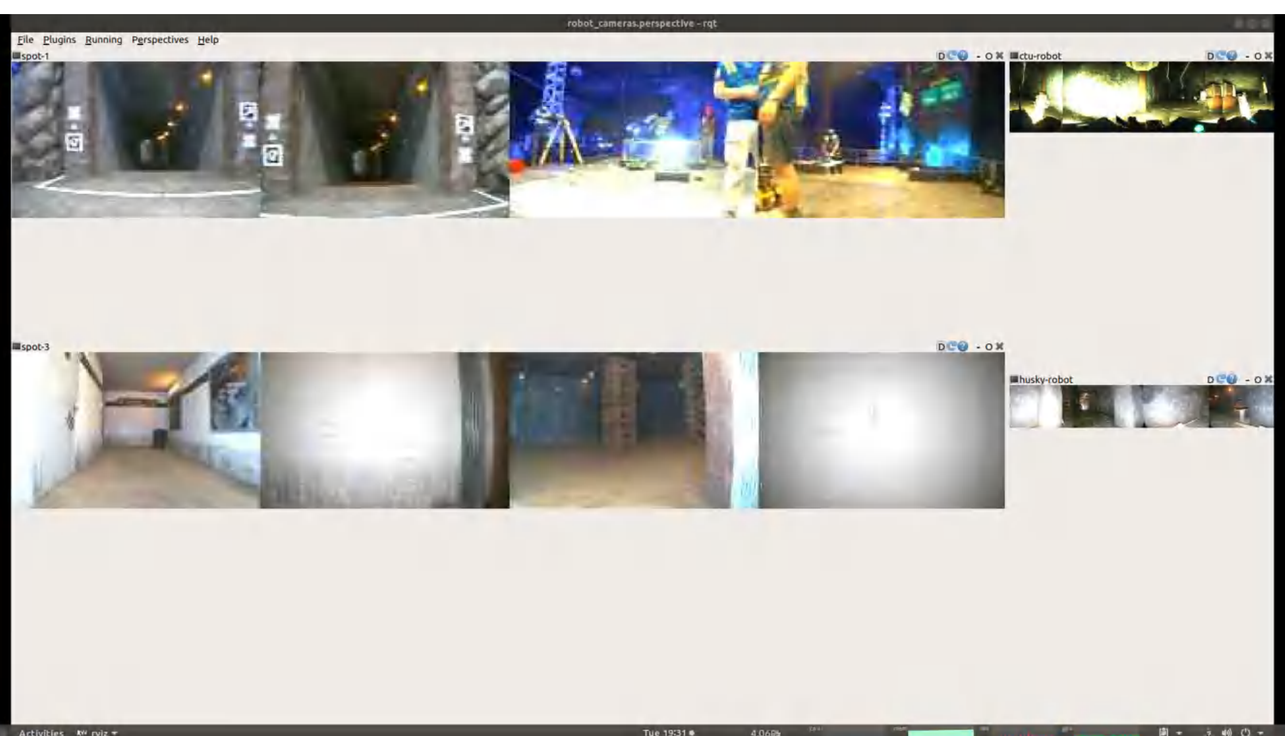


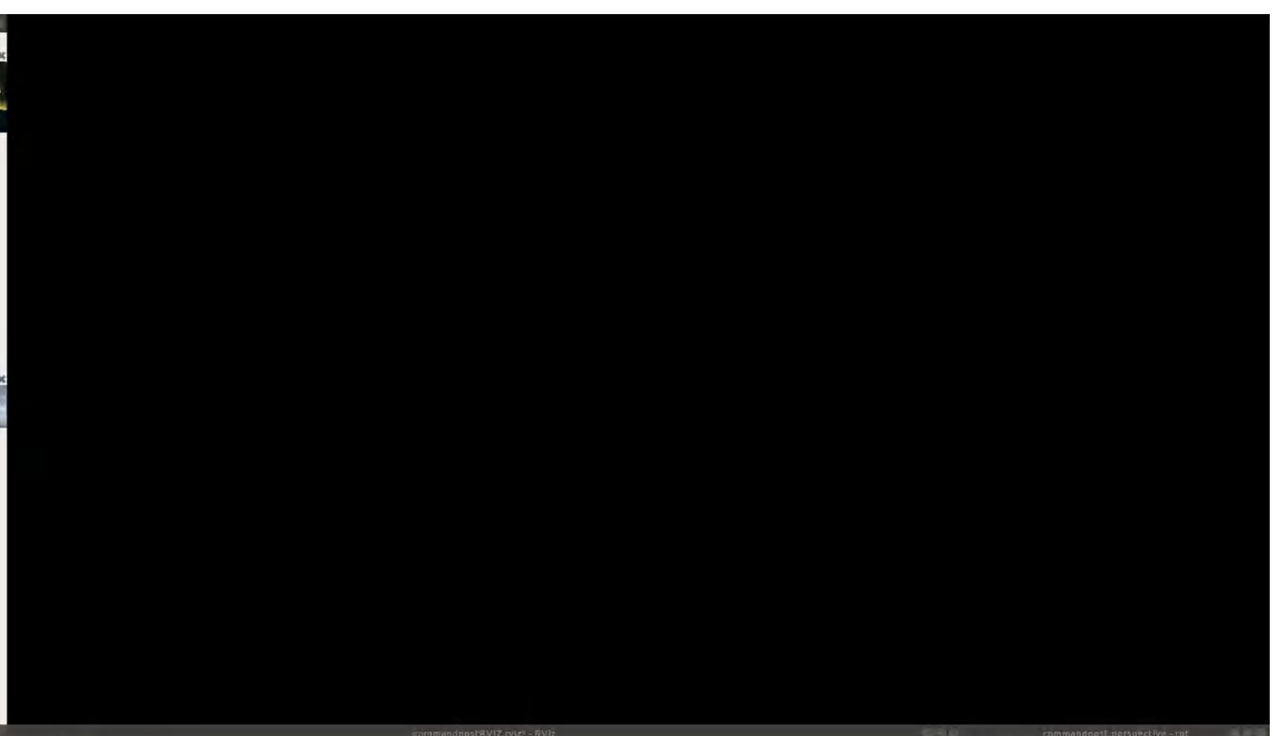


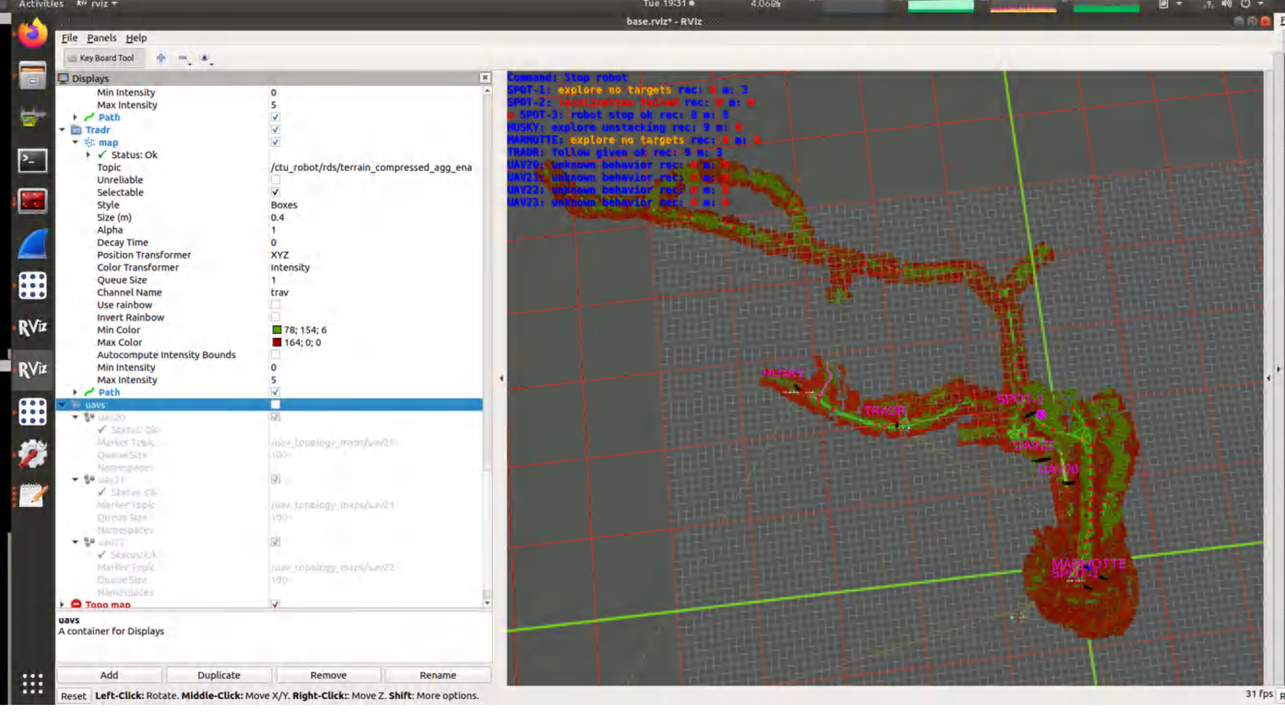


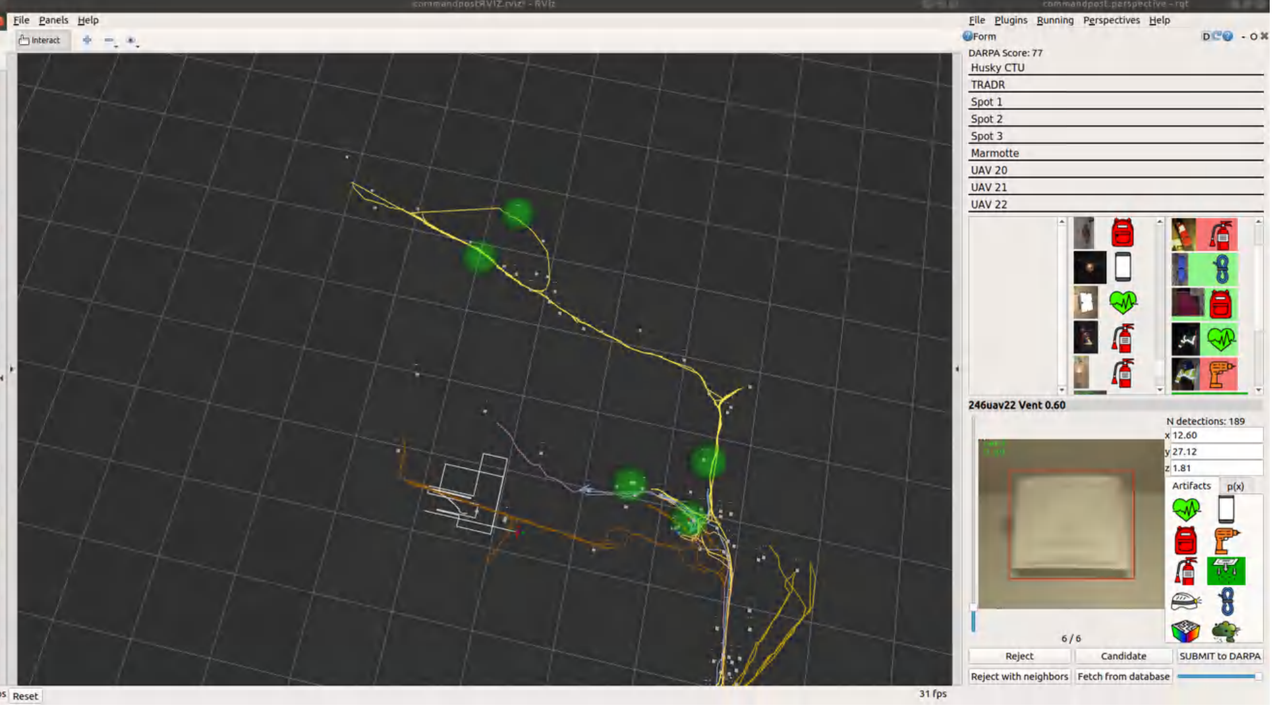
- In SubT Finals environment, all robots have been reachable within the explored area.

Operator console

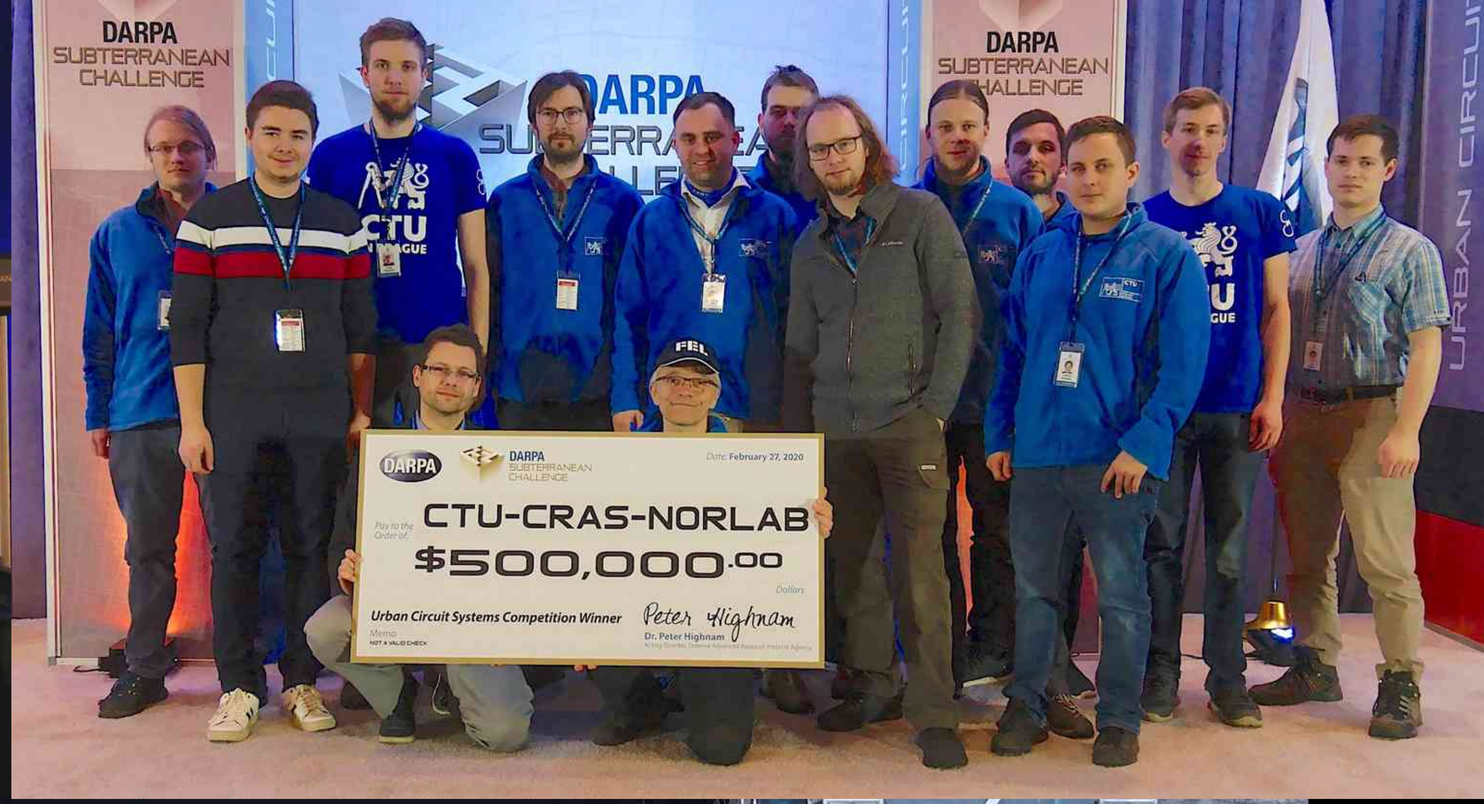

robot_cameras_perspective - rqt
File Plugins Running Perspectives Help
spot-1
ctu-robot
spot-3
husky-robot




Activities
rviz
Tue 19:31
base.rviz* - RViz
File Panels Help
Displays
Min Intensity 0
Max Intensity 5
Path
Tradr
map
Status: Ok
Topic /ctu_robot/rds/terrain_compressed_agg_ena
Unreliable
Selectable
Style Boxes
Size (m) 0.4
Alpha 1
Decay Time 0
Position Transformer XYZ
Color Transformer Intensity
Queue Size 1
Channel Name trav
Use rainbow
Invert Rainbow
Min Color 78; 154; 6
Max Color 164; 0; 0
Autocompute Intensity Bounds
Min Intensity 0
Max Intensity 5
Path
uavs
Topo map
uavs
A container for Displays
Add Duplicate Remove Rename
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Move Z. Shift: More options.
31 fps
HUSKY
TRADR
SPOT-3
UAV22
UAV20
MARMOTTE
SPOT-2


File Panels Help
Interact
File Plugins Running Perspectives Help
Form
DARPA Score: 77
Husky CTU
TRADR
Spot 1
Spot 2
Spot 3
Marmotte
UAV 20
UAV 21
UAV 22
246uav22 Vent 0.60
N detections: 189
x 12.60
y 27.12
z 1.81
Artifacts
p(x)
6 / 6
Reject
Candidate
SUBMIT to DARPA
Reject with neighbors
Fetch from database
Reset
31 fps


DARPA
DARPA SUBTERRANEAN CHALLENGE
Date: August 22, 2019
Pay to the Order of:
CTU-CRAS
$200,000.00
Dollars
Tunnel Circuit Systems Track Winner
Steven Walker
Dr. Steven Walker
Memo
NOT A VALID CHECK


DARPA
SUBTERRANEAN CHALLENGE
DARPA
SUBTERRANEAN CHALLENGE
DARPA
DARPA SUBTERRANEAN CHALLENGE
Date: February 27, 2020
Pay to the Order of:
CTU-CRAS-NORLAB
$500,000.00
Dollars
Urban Circuit Systems Competition Winner
Peter Highnam
Dr. Peter Highnam
Memo
NOT A VALID CHECK


DARPA
CTU-CRAS-NORLAB
$500,000.00
VIRTUAL COMPETITION WINNER


CTU
IN PRAGUE
FINALS
CTU-CRAS-NORLAB
BostonDynamics
GENERAL LASER
6
9
7
2
5


TOM TAILOR
VANS

Mobile robots on the verge

- Ground mobile robots have entered the market
- Mostly semi-automatic - teach and repeat
- (few) Companies selling robots and robots as service