Introduction to Search and Rescue Robotics

Prof. Mirko Kovač

Laboratory of Sustainability Robotics

EPFL, Switzerland

Source: [1] https://www.mdpi.com/2076-3417/13/3/1800?type=check_update&version=2

Learning goals

- Understand the challenges of search and rescue.
- Learn how different robots can assist across different disasters.
- Learn how robots can use novel sensors and algorithms for search and rescue.

What is Search and Rescue (SAR) Robotics?

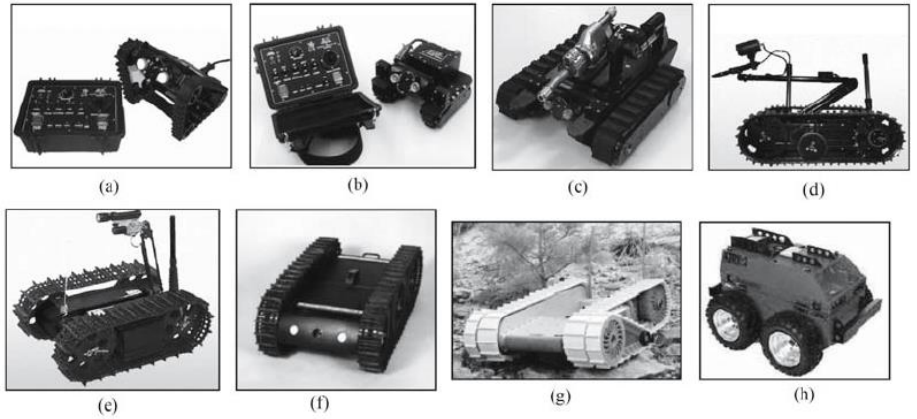
- Robotics applied in disaster scenarios: earthquakes, tsunami, floods, industrial accidents
- Robots help locate and assist victims
- Enhance safety and efficiency for human rescuers

Source: [1] URL: https://www.swissinfo.ch/eng/sci-tech/dronefrontier_how-drones-are-transforming-humanitarian-aid/44141254; [2] URL: https://www.indiatoday.in/world/story/nepal-earthquake-drones-sensors-nasa-team-rubicon-halodrop-252008-2015-05-08

Historical Context & Motivation

- First notable deployments: 9/11 World Trade Center rescue efforts
- Fukushima Daiichi nuclear accident response
- Motivation: Robots go where humans can't safely venture; speed up victim identification, cleaning up, and situational assessment

Robots deployed for September 11 attacks



Robots deployed in Fukushima

Radioactive Resistant Robot

Cleaning Robot

Source: [911.1] URL: https://www.nsf.gov/news/mmg/mmg_disp.jsp?med_id=77486&from=; [911.2] URL: https://www.researchgate.net/figure/Search-and-rescue-robots-used-in-World-Trade-Centers-rescue-operation-a-Micro-VGTV_fig11_239417125; [fuk1] URL: https://www.science.org/content/article/how-robots-are-becoming-critical-players-nuclear-disaster-cleanup; [fuk2] URL: https://www.theguardian.com/environment/2024/nov/02/robot-retrieves-radioactive-fuel-sample-from-fukushima-nuclear-reactor

Spotlight: Center for Robot-Assisted Search and Rescue

https://www.youtube.com/watch?v=1ccZ6gGDeSs

Search Phase

- Rapidly cover large areas to find survivors
- Use of aerial drones to scan debris fields
- Thermal cameras to detect human body heat

Source: [1] URL: https://www.istockphoto.com/photo/severely-damaged-by-hurricane-ian-houses-in-florida-mobile-home-residential-area-gm1431442539-474039036; [2] URL: https://www.somersetlive.co.uk/news/somerset-news/incredible-photo-drone-finds-missing-6180615; [3] URL: https://dronelife.com/2018/09/14/another-life-saved-by-a-drone-with-thermal-imaging/

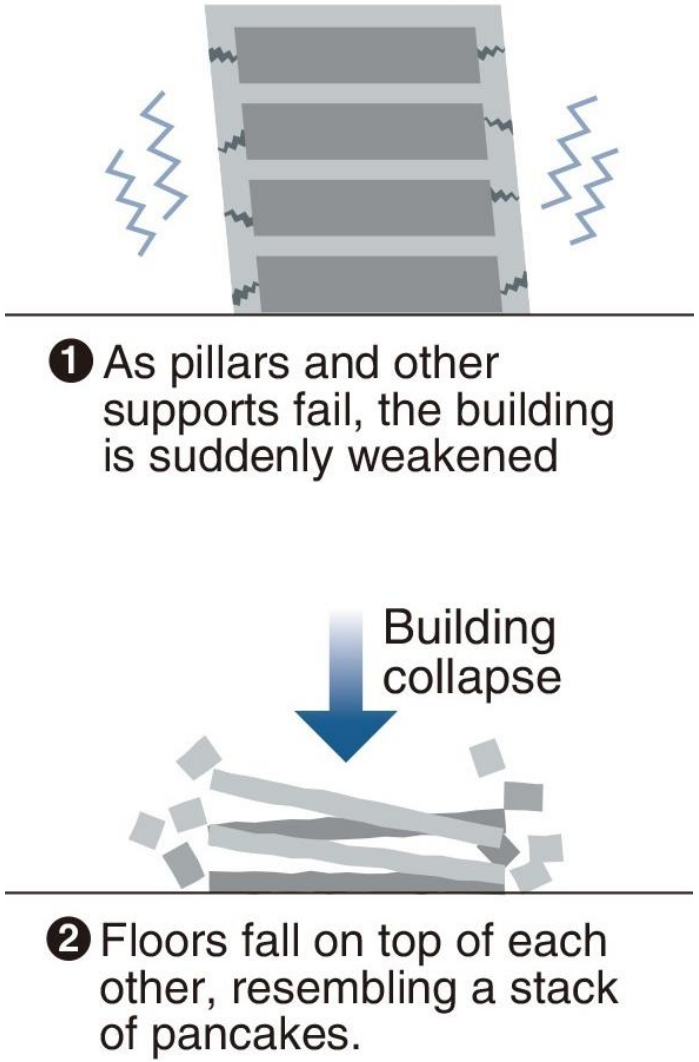
Rescue Phase

- Deliver medical supplies, water, or communication devices to trapped victims
- Provide situational awareness to guide human rescue teams safely

Source: [1] URL: https://www.zdnet.com/article/disaster-robots-slow-to-gain-acceptance-from-responders/; [2] URL: https://www.internationalsos.it/blog/drones-deploying-medical-supplies-and-care

Extreme “pancake” buildings

- “Multi-story building collapses are rare, but increasingly so, due to, well, military.”
  - Prof. Robin Murphy



https://japannews.yomiuri.co.jp/world/wider-world/20230216-91447/
https://edition.cnn.com/2021/06/25/us/pancake-collapse-explainer-trnd

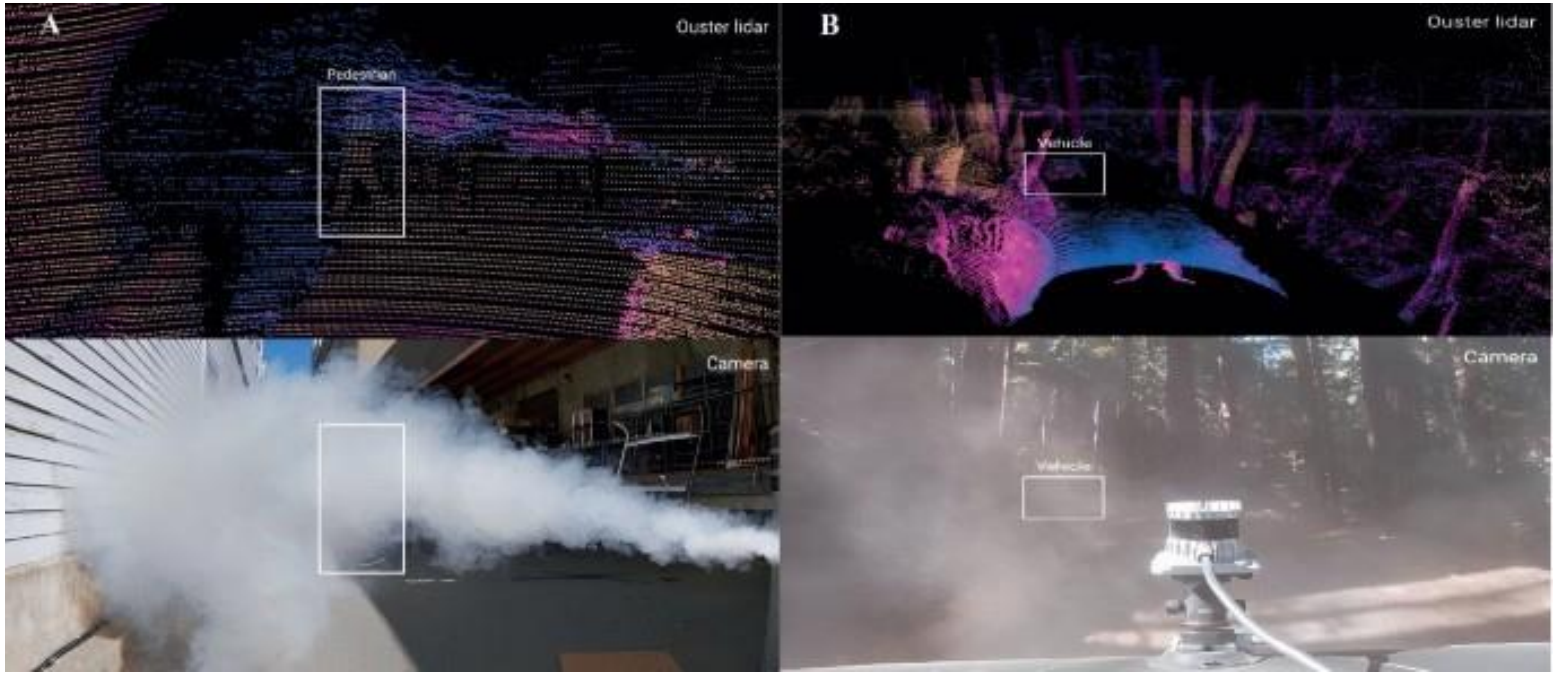
Environmental Challenges

- Unstable rubble, narrow passages, variable lighting
- Weather conditions (rain, wind, dust) affect robot stability and perception
- Risk to make the situation worse!
  - Could collapse the building further

Source: [1] URL: https://www.cbc.ca/news/world/9-11-anniversary-what-was-lost-in-the-damage-1.1123528

Sensory & Perception Challenges

- Smoke, dust, darkness reduce camera effectiveness
- Noisy sensor data in chaotic environments
- Robust perception algorithms needed for reliable victim detection



Source: [1] URL: https://link.springer.com/chapter/10.1007/978-3-031-43763-2_9

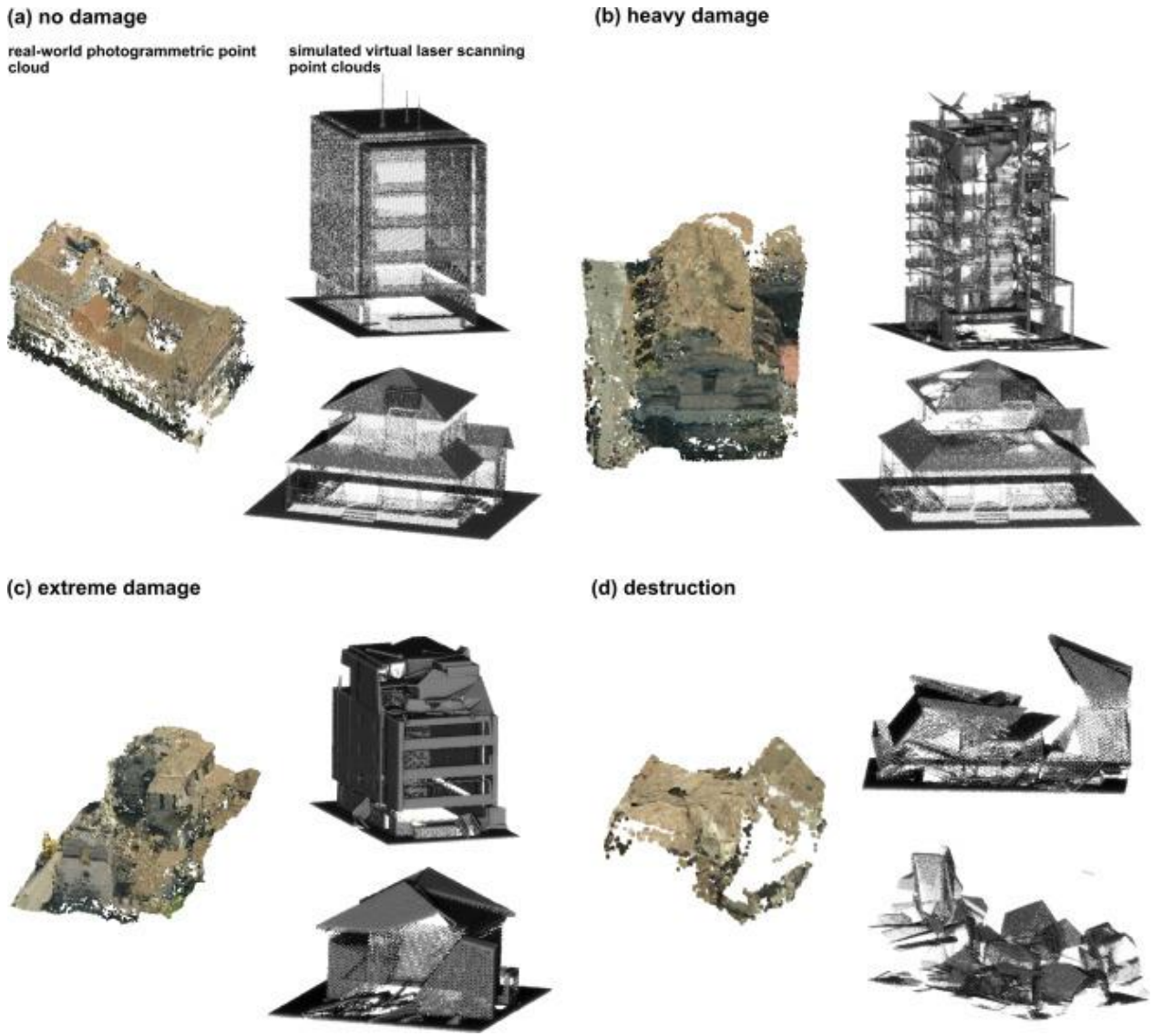
Challenges: Pancake collapse

- Almost no access points
  - No room to navigate inside (voids)
- Have to carry *all* supplies
  - Electricity, material sandwiches
  - “Compressed air surprisingly easy to access”
- Building collapse structural integrity assessment
  - Civil engineers to assess debris removal
  - Any information is useful

https://spectrum.ieee.org/why-robots-cant-help-find-survivors-in-the-florida-building-collapse

Application: Structural Assessment & Mapping

- Robots inspect damaged infrastructure (collapsed buildings, unstable structures)
- Generate maps of interior environments, safe routes, and hazard zones



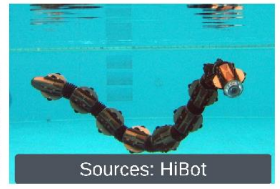
Source: [1] URL: https://www.sciencedirect.com/science/article/pii/S1569843223002303

Application: Earthquake Response

- Example: UAVs mapping collapsed buildings in Haiti or Turkey-Syria earthquake
- Ground robots assessing voids where survivors might be trapped
- Throwback: Patrick Meier guest lecture
  - WeRobotics, Flying Labs

https://americanredcross.github.io/2018/04/09/canaan-drones/;
https://news.sky.com/story/turkey-syria-earthquake-how-technology-can-be-used-to-help-respond-to-natural-disasters-12805170

Search and rescue robots

UAV	• mapping • victim search • target observation • delivery • communication	 Sources: Aerialtronics	 Sources: Prox Dynamics	 Sources: C-ASTRAL	 Sources: Draganfly	 Sources: GRIFF Aviation			
		Altura Zenith	Black Hornet	sUAS	Dragonflyer Commander	GRIFF 135			
USV/ AUV	• on/in water victim search • carry life raft • underwater mapping • collecting samples/ data	 Ref: https://www.intechopen.com/chapters/56139	 Ref: https://www.intechopen.com/chapters/56139	 Ref: https://www.intechopen.com/chapters/56139	 Sources: EMILY robot	 Sources: Aquabotix	 Sources: NTNU		
		U-Ranger USV	Roaz II USV	Unmanned capsule	EMILY	AUV & RoV	Mamba		
UGV	• high mobility • uncertain/ constrained environment • delivery • mapping • victim search	 Sources: Sarcos Robotics	 Sources: Vecna Technologies	 Sources: US Navy	 Sources: Shark Robotics	 Sources: ANYbotics	 Sources: IIT and WALK-MAN project	 Sources: CMU	
		GuardianS	BEAR	SAFFiR	COLOSSUS	ANYmal	WALK-MAN	UncleSam	
UHV/ UApV	• multi-terrain mobility • Inspection • communication and logistics • mapping • victim search	 Sources: Rutgers University	 Sources: Singapore defense	 Sources: EPFL	 Sources: Ben Gurion University	 Sources: HiBot			
		Naviator NV03	Hybrid drone	Salamandra robotica	FSTAR drone	ACM-R5H			

Source: [1] URL: https://www.mdpi.com/2076-3417/13/3/1800?type=check_update&version=2

Key Takeaways

- Robots extend human capabilities in dangerous, hard-to-reach areas
- Variety of robot types, from aerial drones to ground crawlers
- Key challenges: environmental harshness, perception complexity, limited autonomy

Source: [1] URL: https://www.nist.gov/news-events/news/2007/06/rescue-robot-tests-offer-responders-high-tech-help

Limitations: Energy & Endurance

- Battery life restricts mission duration
- Need for efficient power management, swappable batteries, tethered power sources or other power sources (e.g. gas)
  - Electricity not always available on disaster sites!
- Rugged, reliable hardware that can withstand harsh conditions

Source: [1] URL: https://microavia.com/news/drone-in-a-box_systems_with_automatic_battery_swapping; [2] URL: https://www.mistralsolutions.com/homeland-security/products/mistral-kite-tethered-drone-system/; [3] URL: https://www.xer-tech.com/

Platforms

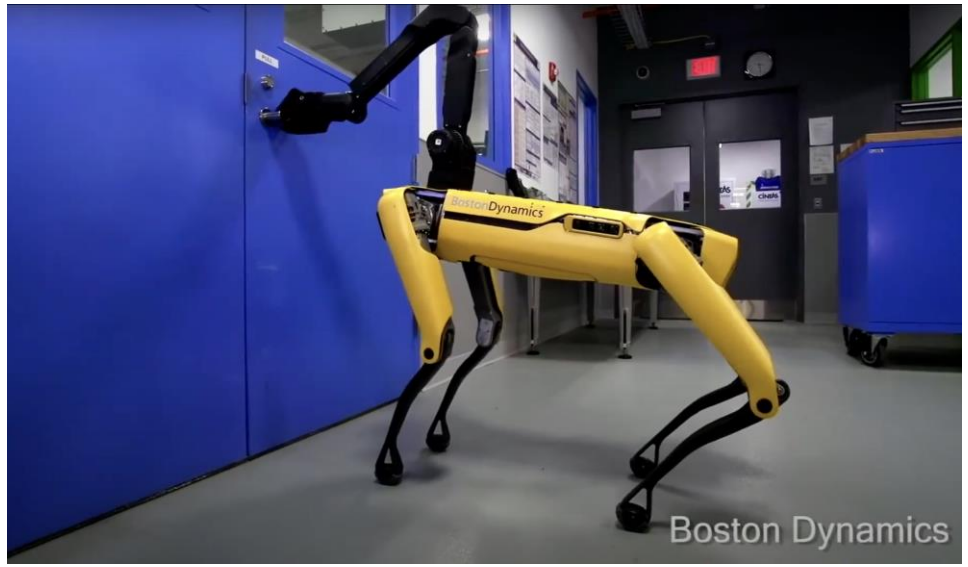
Ground Platforms

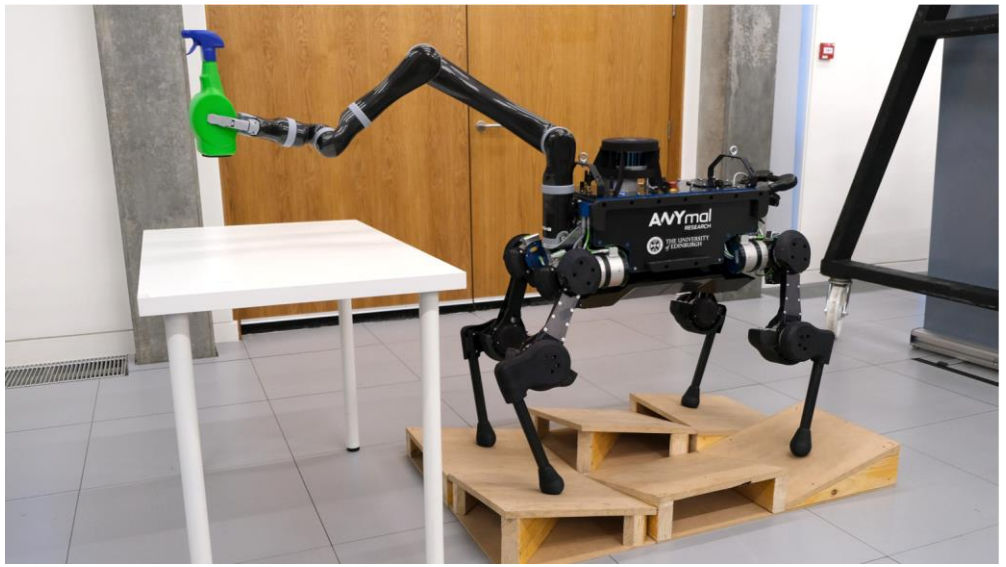
- Tracked/wheeled UGVs for rubble traversal
- Snake-like robots for confined spaces (pipes, collapsed floors)
- Strengths: Stability, continuous operation; Challenges: mobility in extreme rubble

Source: [1] URL: https://www.flir.co.uk/products/packbot/?vertical=ugs&segment=uis; [2] URL: https://www.nist.gov/news-events/news/2007/06/rescue-robot-tests-offer-responders-high-tech-help; [3] URL: https://economictimes.indiatimes.com/magazines/panache/new-robot-snake-to-aid-rescue-missions/articleshow/45098487.cms?from=mdr

Legged robots

- Legged robots navigate **rough terrains** like rubble, making them ideal for search and rescue in disaster areas.
- They balance and adapt where other robots fail:
  - They can be equipped with **manipulators** for lifting obstacles and detrities.

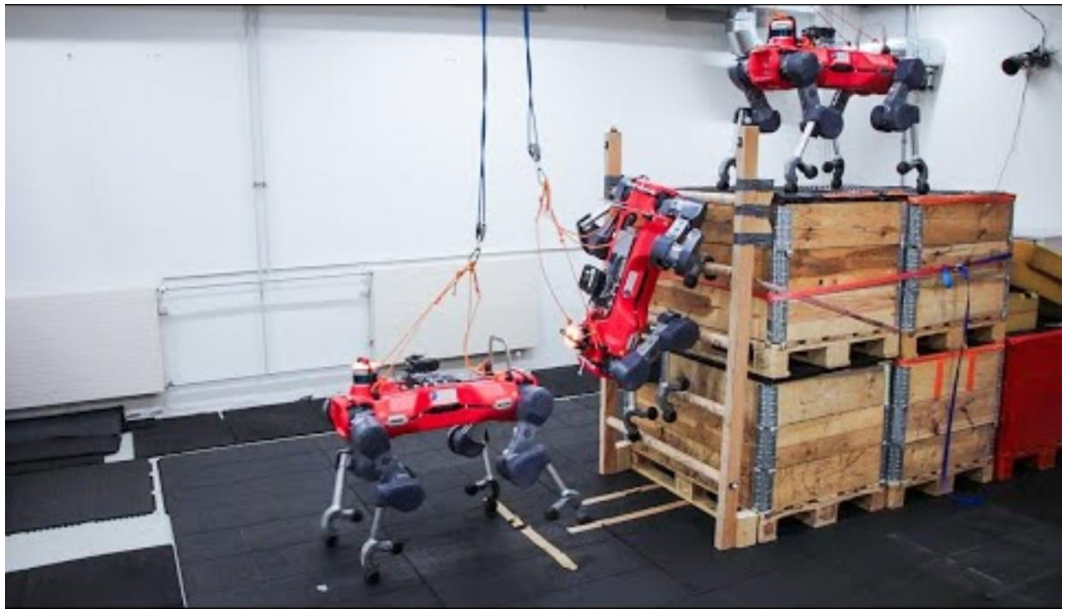




Source: Ferrolho et al., Optimizing dynamic trajectories for robustness to disturbances using polytopic projections, IEEE IROS 2020

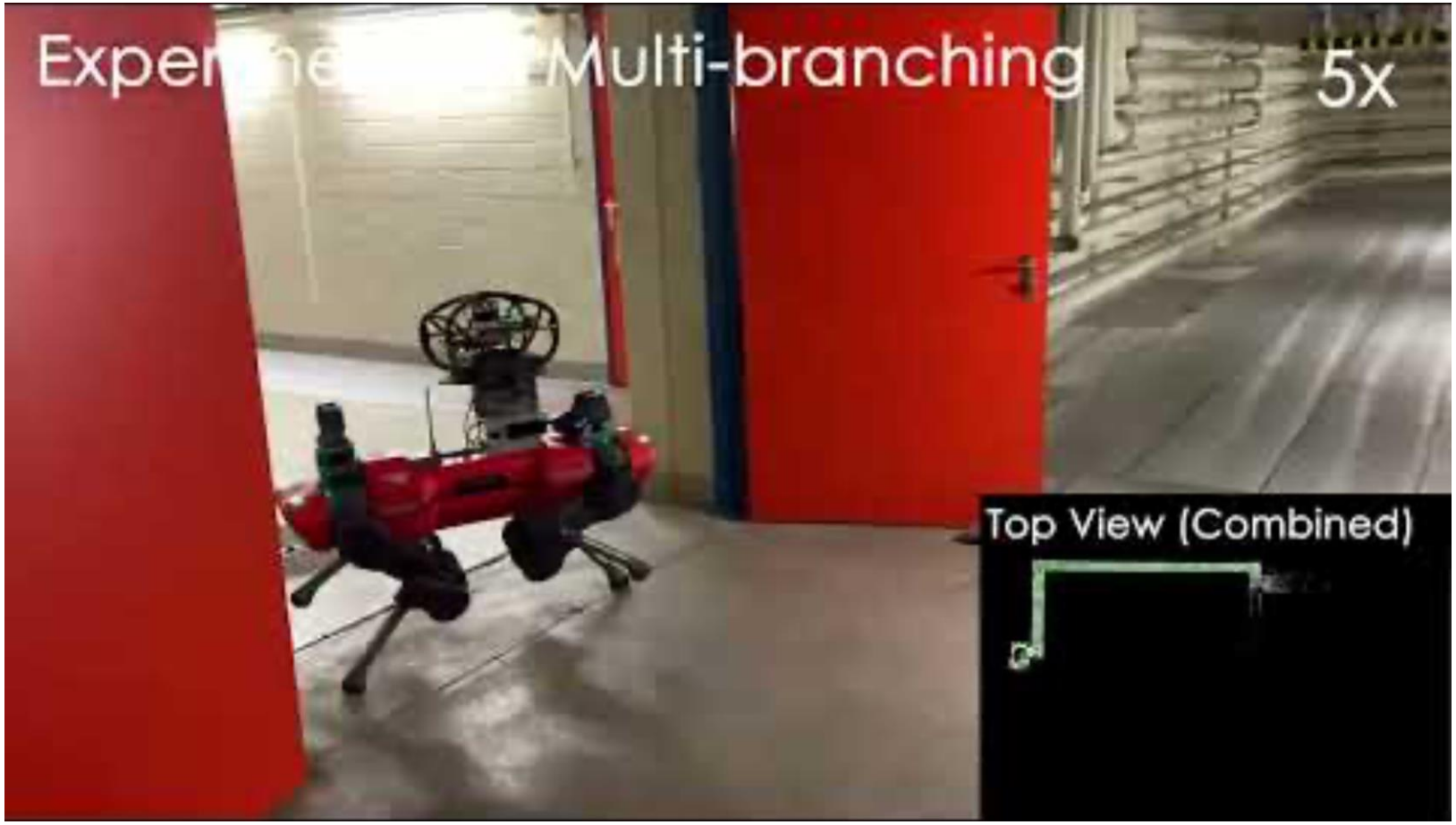
Legged robots

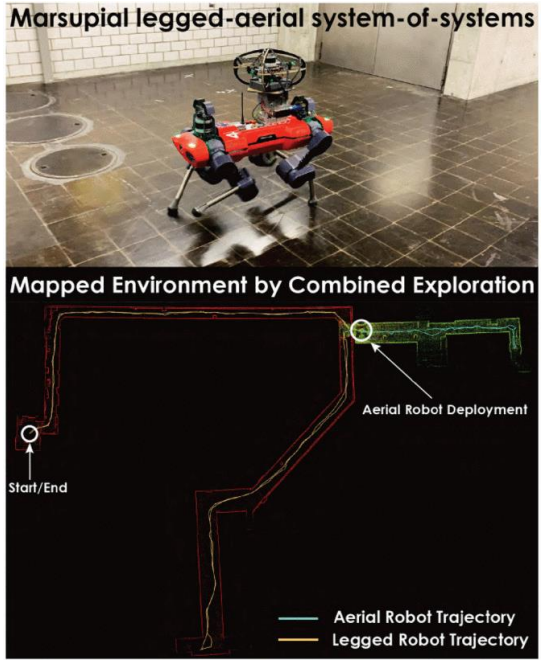
- They are equipped with wheels or ladder-climbing features to navigate diverse terrains and improve locomotion efficiency.



Source: Vogel et al., Robust Ladder Climbing with a Quadrupedal Robot, 2024; Unitree

Combined legged-flying robots





https://www.youtube.com/watch?v=EqCz_WZBJlM

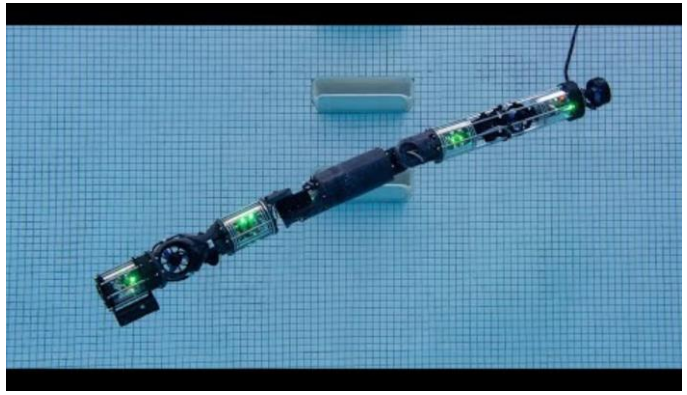
Snake robots

- Traverse environments that are inaccessible to wheeled or legged robots
  - Locations with rubbles
  - Narrow gaps and pipes
- Versatile locomotion
  - Swim
  - Slither
  - Side-wind
  - Climb
  - Inch

https://www.youtube.com/watch?v=8VLjDjXzTiU
https://www.youtube.com/watch?v=8jvwrvbYAiY
https://www.youtube.com/watch?v=tGJvrKFQcpM

Howie Choset SNAKE ROBOT CMU

Same Robot Perching

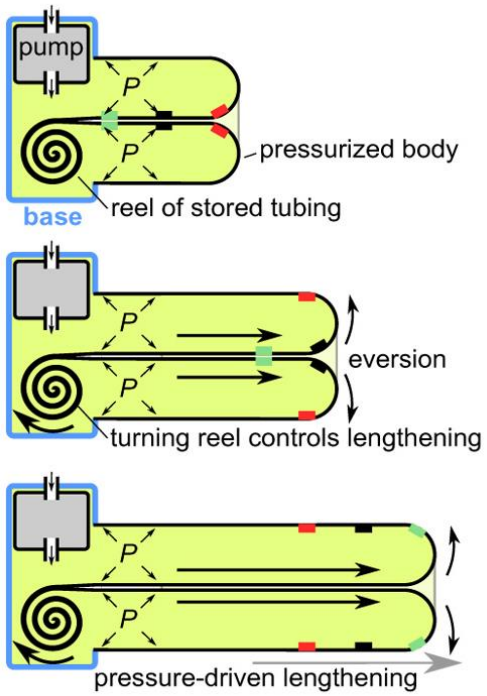


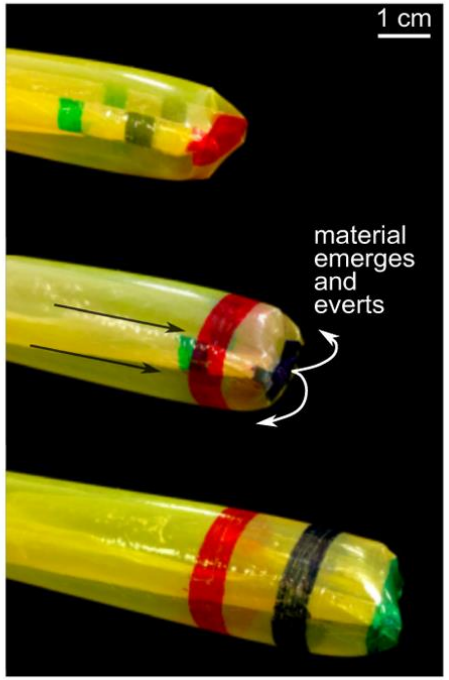
Same Robot Swimming

Snake robots

https://www.youtube.com/watch?v=ifCIDT4X9AM

Throwback Week 9: Search and Rescue robotics





ENV-530 Sustainability Robotics

Search and Rescue robotics

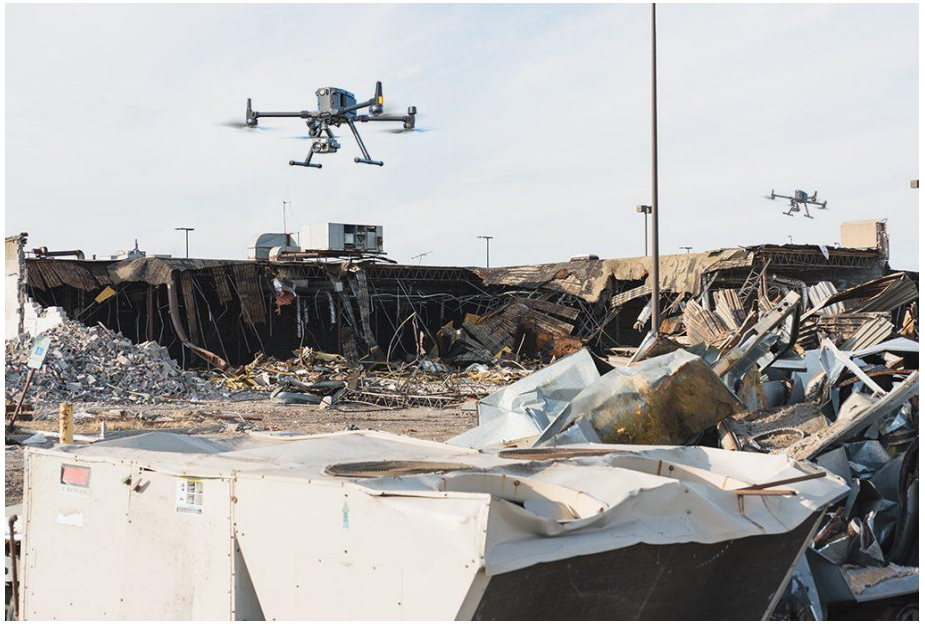
MIT Sprout

ETHz Roboa (start-up)

https://www.youtube.com/watch?v=ULm-Xc9jbyY
https://www.youtube.com/watch?v=DaMCTH4qZTE

Aerial Platforms (UAVs)

- Multirotor drones with cameras and thermal sensors
- Rapid area coverage, overhead mapping
- Challenges: Limited flight time, wind sensitivity



Source: [1] URL: https://www.flytbase.com/blog/drone-disaster-relief

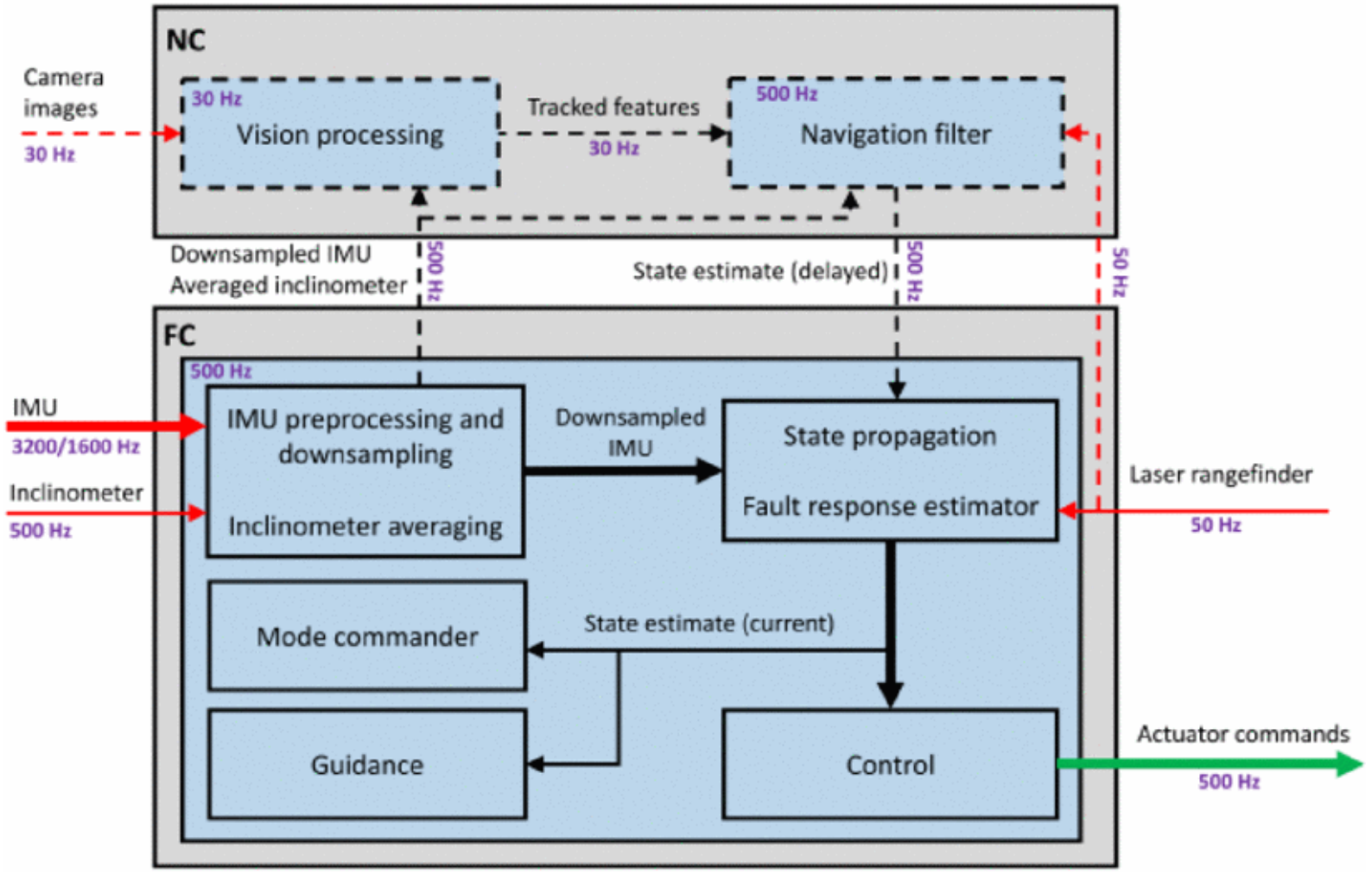
Acoustic localisation

https://www.youtube.com/watch?v=Y6Qt2X7UBIk

Drone swarms

https://www.youtube.com/watch?v=bxIc969qtYo

Drone control diagram



Flight Control System for NASA's Mars Helicopter

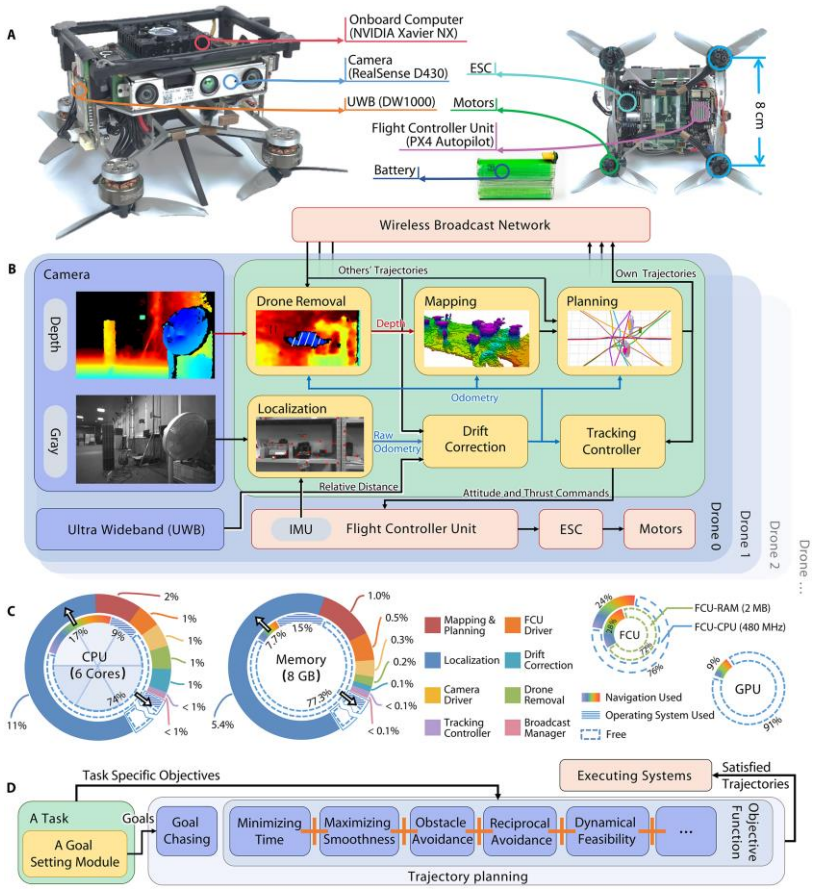
NASA Ingenuity Helicopter

https://arc.aiaa.org/doi/abs/10.2514/6.2019-1289
https://science.nasa.gov/mission/mars-2020-perseverance/ingenuity-mars-helicopter/

Robust autonomy – Shared SLAM

https://www.youtube.com/watch?v=FoJfXCfaYDw

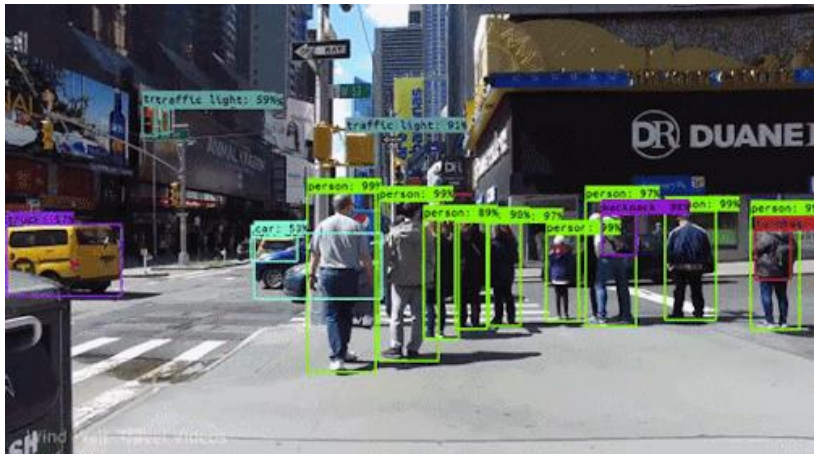
Drone swarms – Shared Formation



https://www.youtube.com/watch?v=L0fJ0EHHfOA

Human Detection and Recognition

- Thermal signatures to spot warm bodies in rubble
- Audio sensors to detect cries for help
- Machine learning models to distinguish human forms from debris



Source: [1] URL: https://www.mdpi.com/1424-8220/23/22/9216; [2] URL: https://www.allsafeindustries.com/hardline-rescue-probe.aspx; [3] URL: https://towardsdatascience.com/everything-you-ever-wanted-to-know-about-computer-vision-heres-a-look-why-it-s-so-awesome-e8a58dfb641e

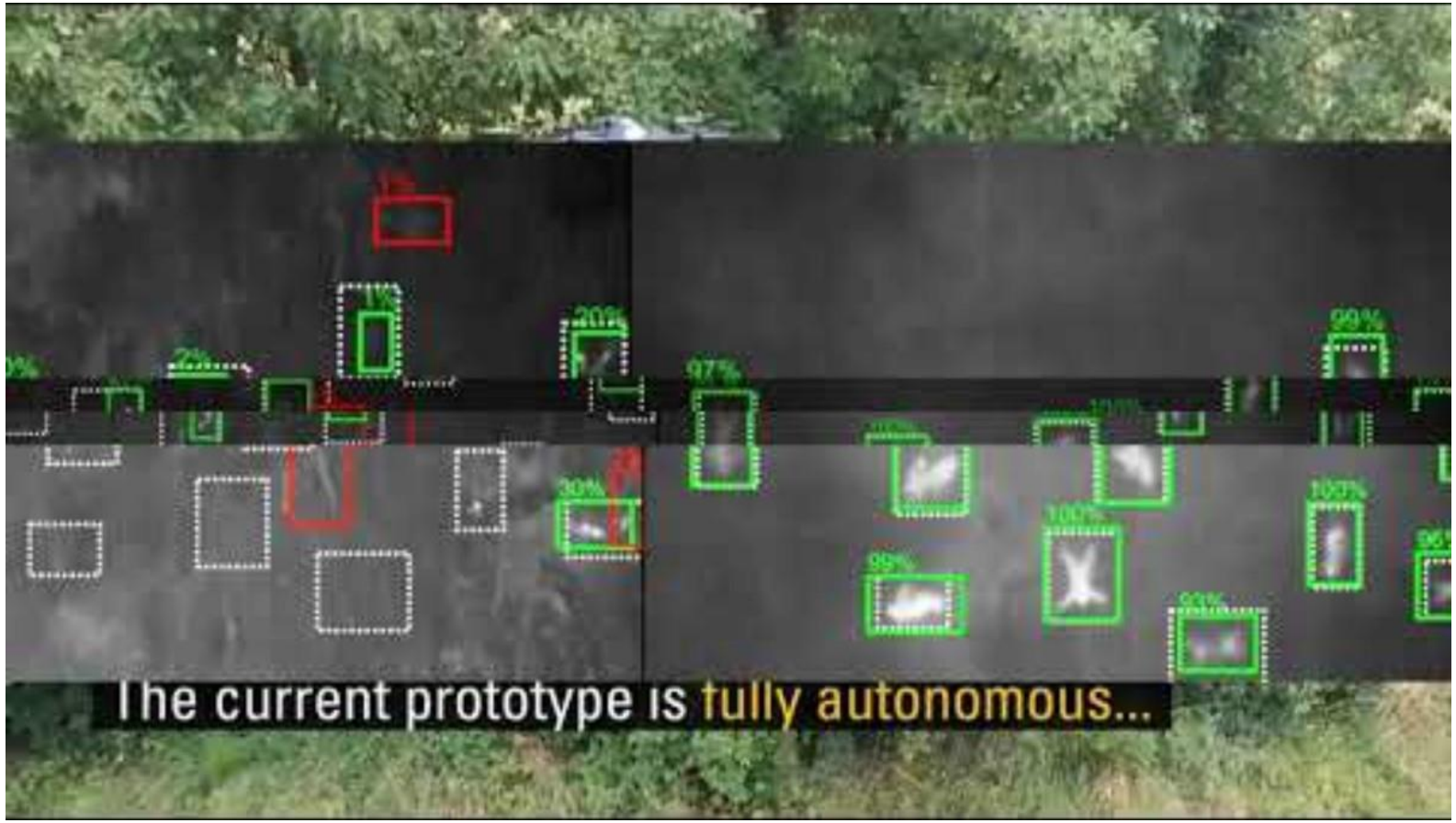
Vision through smoke – Radio signals

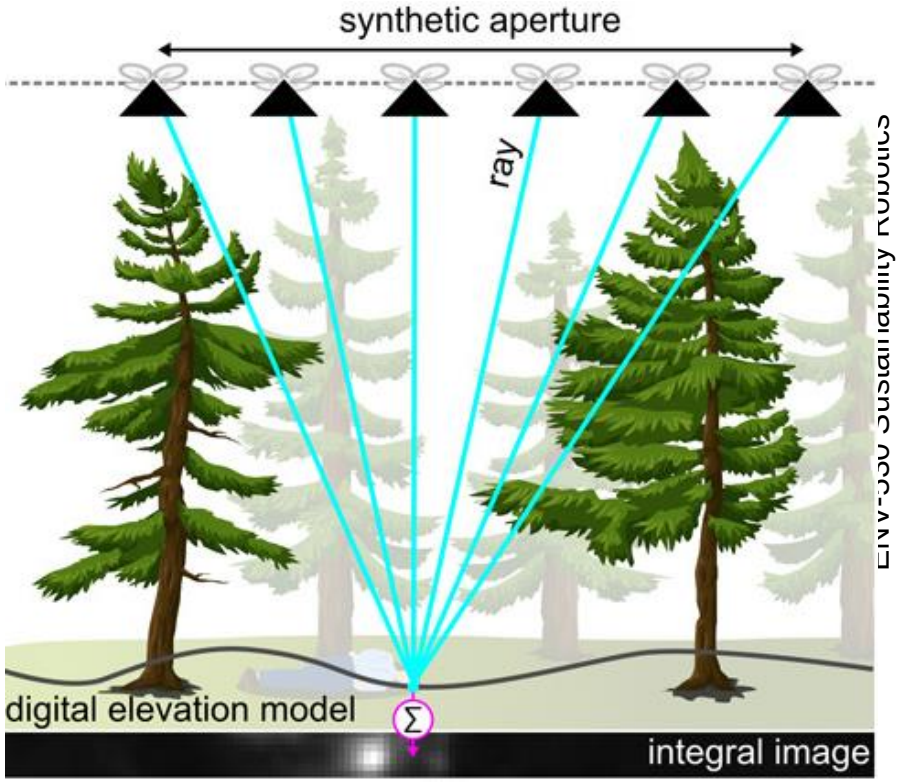
https://www.youtube.com/watch?v=dKyQ1XuPorU

Vision through smoke – Short Wave Infra-red

https://www.youtube.com/watch?v=iewXGB4F9SE

Vision through forest – Sensor fusion

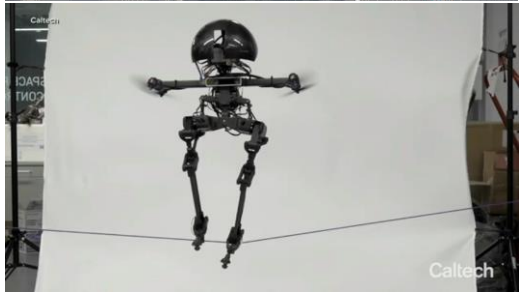




https://www.youtube.com/watch?v=X5lHDFuEd_I

Hybrid & Emerging Platforms

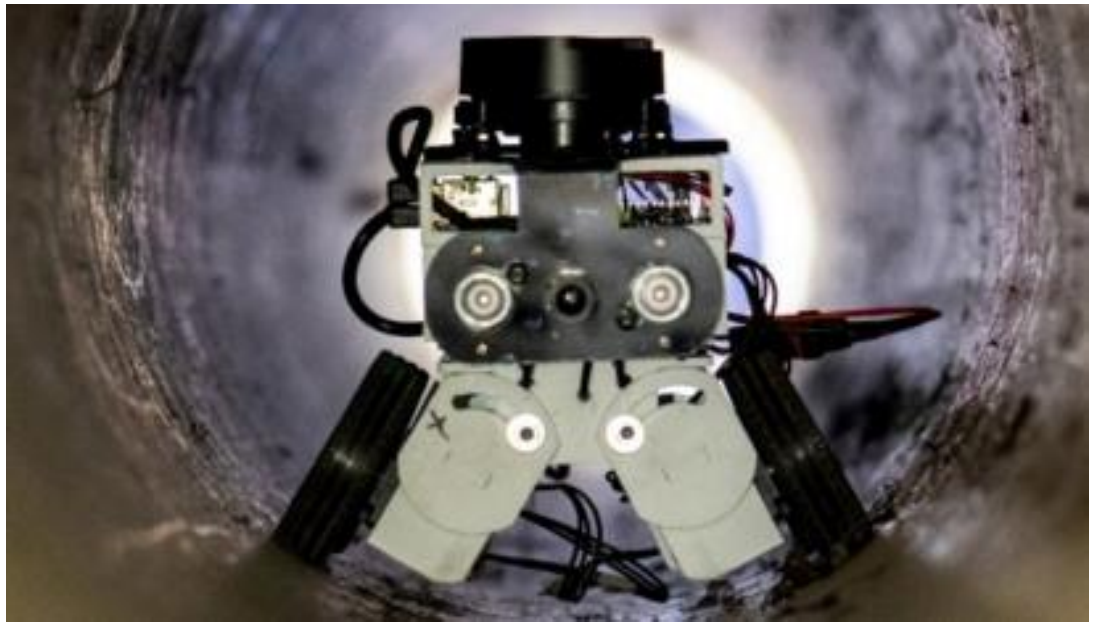
- Legged robots (e.g., Boston Dynamics Spot) for rough terrain
- Transformable robots (flying + driving modes)
- Swarm robotics concepts for distributed search tasks



Source: [1] URL: https://bostondynamics.com/blog/starting-on-the-right-foot-with-reinforcement-learning/; [2] URL: https://indrorobotics.ca/good-dogs-a-look-at-the-newest-unitree-quadrupeds/; [3] URL: https://www.iotworldtoday.com/robotics/two-legged-robot-tackles-forest-terrain; [4] URL: https://www.caltech.edu/about/news/new-bioinspired-robot-flies-rolls-walks-and-more; [5] URL: https://abc7news.com/caltech-robot-video-human-robots-invention/11094635/

Industrial Accidents

- Robots deployed to hazardous chemical leaks or mine collapses
- Reducing risk to human responders in toxic environments



Source: [1] URL: https://www.hazardexonthenet.net/article/191046/Underground-autonomous--Ratty-the-Robot--makes-pipe-inspections-safer.aspx

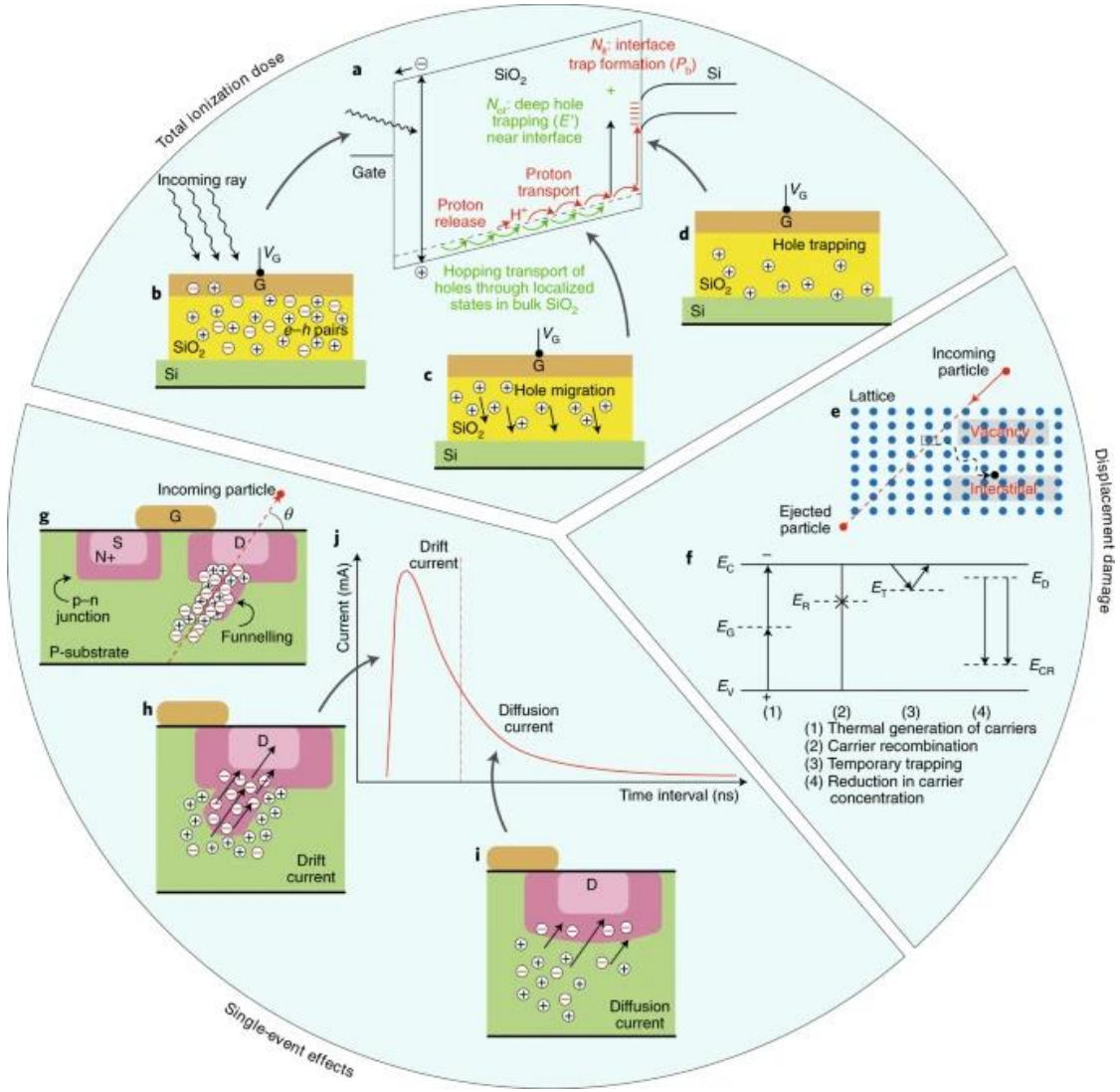
Robotic Arm for Nuclear Accidents

https://www.youtube.com/watch?v=jXgqlU-Xkg0

Fukishima robotics

- Planning: "Teach and repeat" + teleoperated at end-effector (haptic feedback system similar to medical robots)
- Fully autonomous planning very difficult due to high number of degrees of freedom (TEPCO has 18 DoFs)
- Collision avoidance while navigating through small openings is very challenging
- Radiation presents challenges:
  - Actuators and sensors fail under high radiation dosages
  - Robot components can become contaminated

Radiation effects on electronics



https://www.nature.com/articles/s41928-021-00562-4

Nuclear decomissioning

- Dounreay nuclear decommissioning site
- 140 m duct with potential nuclear material
  - Normally requires human inspection
- Robot leads to savings of £3-£4million

https://uomrobotics.com/robots/lyra.html

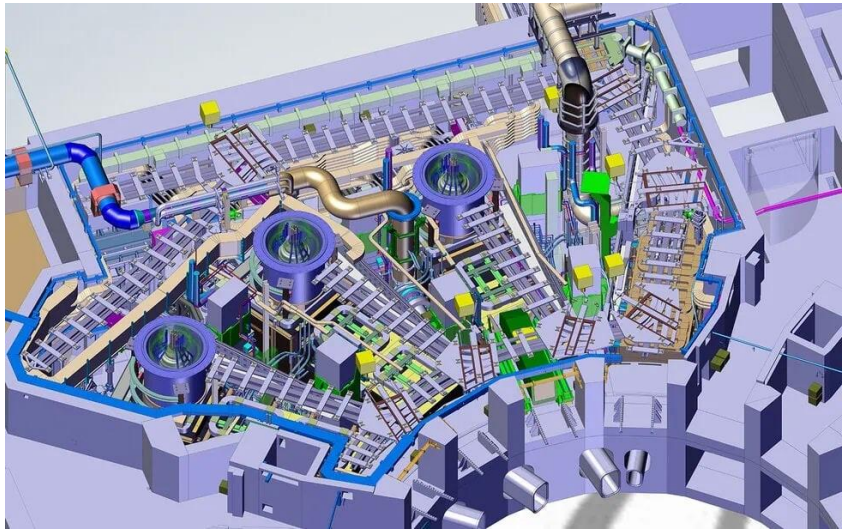
Rescue Robot Testbed

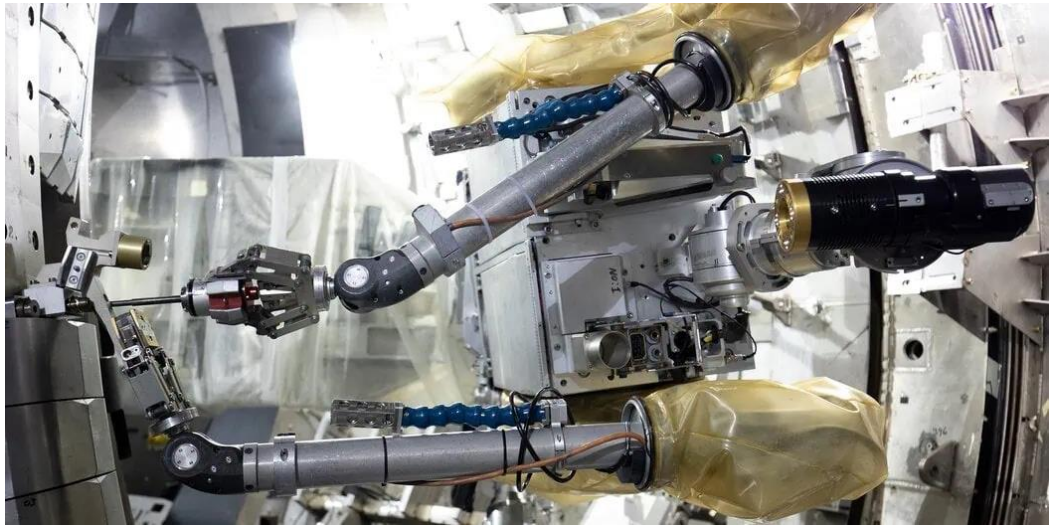
IUB Rescue Arena now the **SSRR Test Arenas**
Jacobs University Bremen in Bremen, Germany

Rescue Robot Testbed - ARCHE

https://www.youtube.com/watch?v=dwewJ8FlLcI

Rescue Robot Testbed



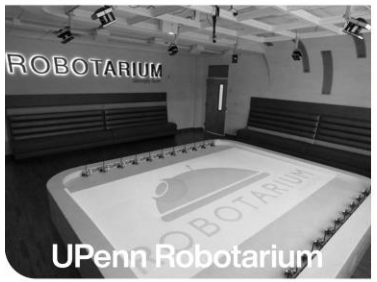


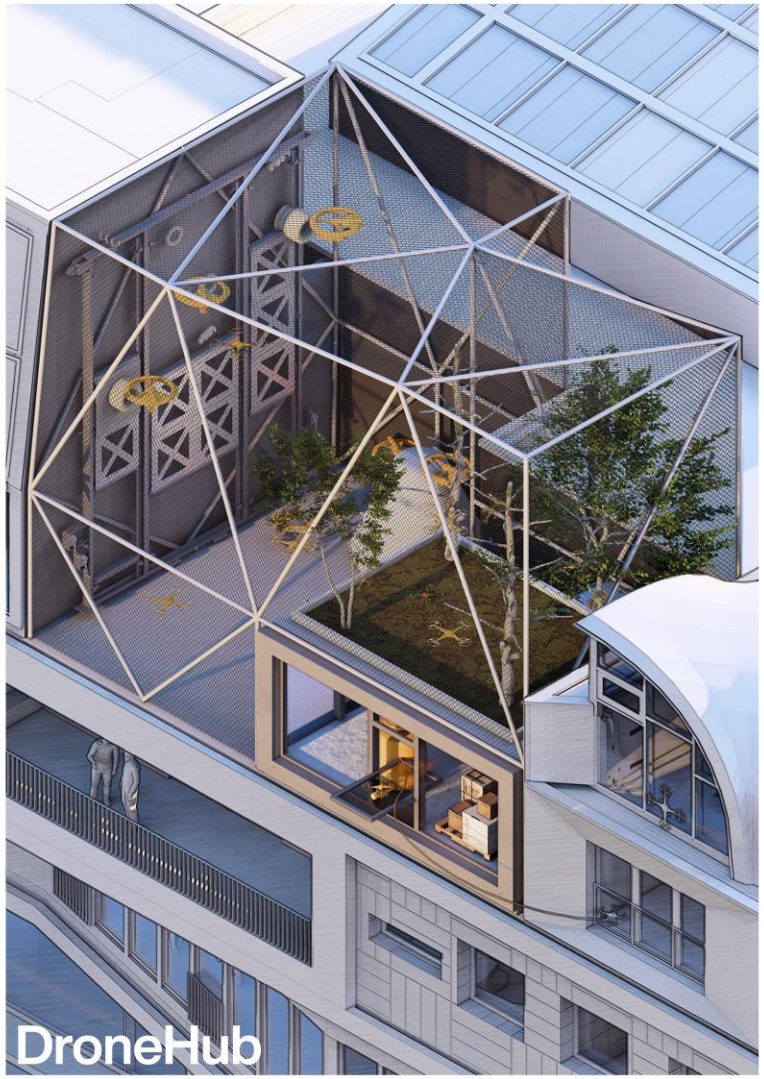
ITER Robotics Test Facility

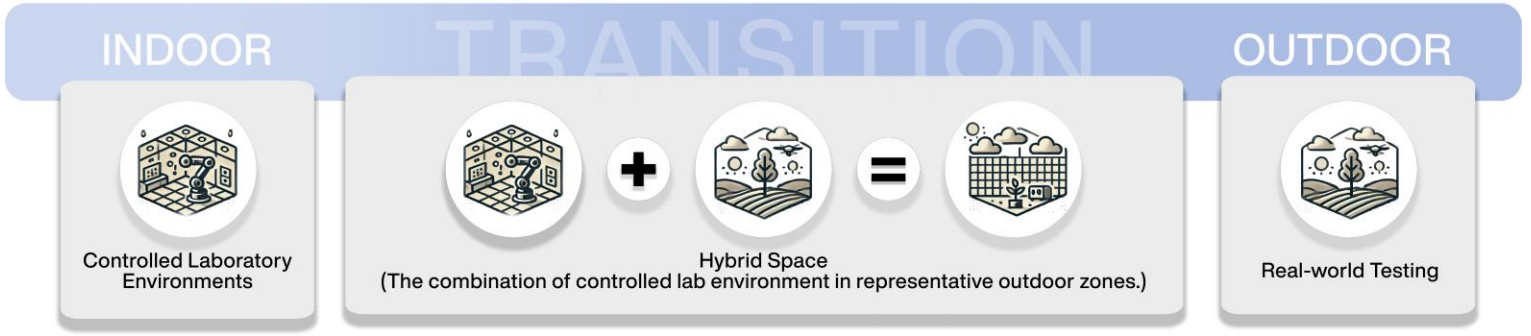
RACE (Remote Applications in Challenging Environments), UKAEA

Testbeds

Testbeds in Switzerland







Firefighting robots

Shark Robotics - Colossus

https://www.youtube.com/watch?v=9v7wm7wm3LQ
https://www.youtube.com/watch?v=6G-79XpzgNc
https://www.youtube.com/watch?v=ycoEAcDbpiw

Firefighting aerial robots

H200 SpiderUAV Firefighter

https://www.youtube.com/watch?v=ziYOeLNv5DA
https://www.youtube.com/watch?v=Uvm4I_6g-GM

Ethical, Legal, and Social Considerations

- Privacy issues: victim images and data handling
- Accountability if robot actions cause harm
- Regulatory frameworks for deploying robots in disaster zones

Learning goals

- Understand the challenges of search and rescue.
- Learn how different robots can assist across different disasters.
- Learn how robots can use novel sensors and algorithms for search and rescue.

Further reading

Books:
Murphy Robin, Tadokoro Satoschi et al. Search and Rescue Robotics. Springer [2008] URL: https://link.springer.com/referenceworkentry/10.1007/978-3-540-30301-5_51

Academic journals:
“IEEE Robotics & Automation Letters,” “Journal of Field Robotics”

Competitions:
DARPA Subterranean Challenge

Online resources:
IEEE Robotics & Automation Society, RoboHub articles