Playing Marco Polo with a Robot Dog:

Sound Source Tracking as a Heuristic for Frontier Exploration in Search and Rescue

Francesco Marrato (15fram@queensu.ca) and Joshua Marshall (joshua.marshall@queensu.ca)

Introduction

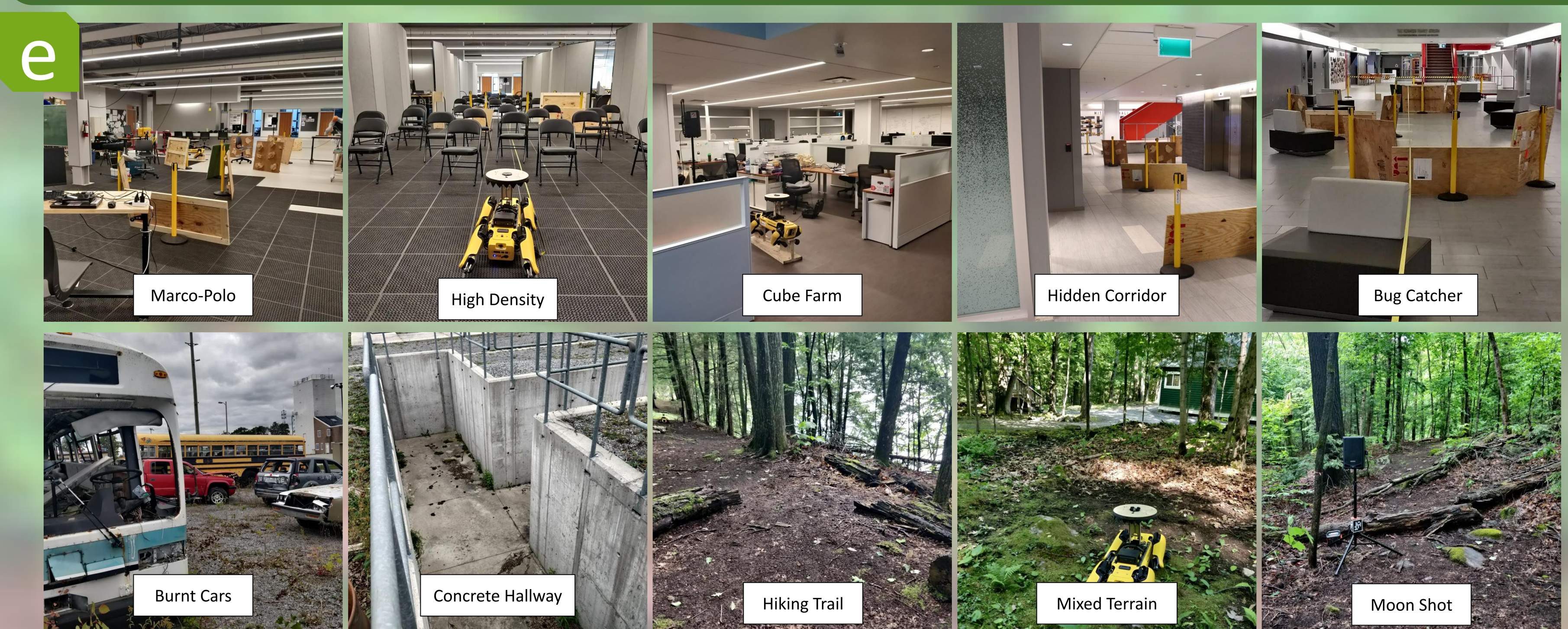
Current disaster robots are teleoperated, with operators handling both the maneuvering of the robot and the demanding task of searching for disaster victims. Perceiving the robot's surroundings through video feeds has caused high failure rates in the field [1].

By introducing autonomous search systems that use nonvisual sensing, we can increase the exploration capabilities of modern search and rescue robots.

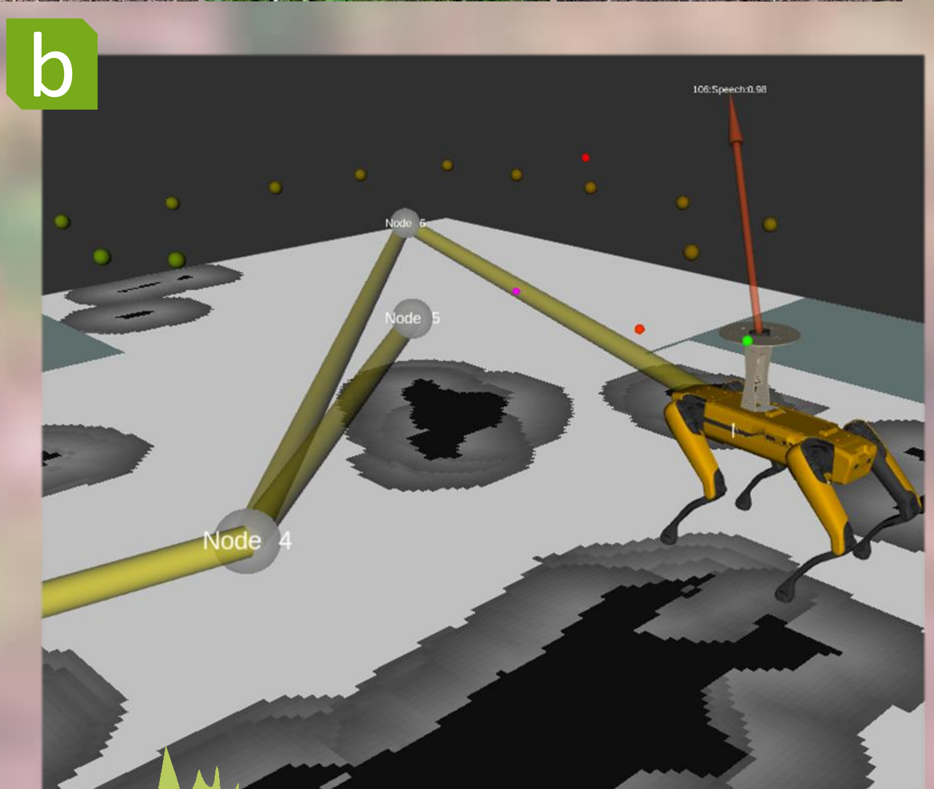
We've developed a robust exploration system that uses sound direction as a heuristic for exploration. Much like human search parties, our quadruped uses human voice as a compass, building a map of its environment as it searches for its source.

Objectives

1. Study whether human voice is a capable heuristic for frontier exploration in search and rescue robotics.
2. Develop a system able to explore previously unmapped environments, navigating mazes of obstacles, and successfully tracking human voices.
3. Demonstrate system robustness at a concept experimentation level through a series of mock disaster scenarios in forest and urban environments.

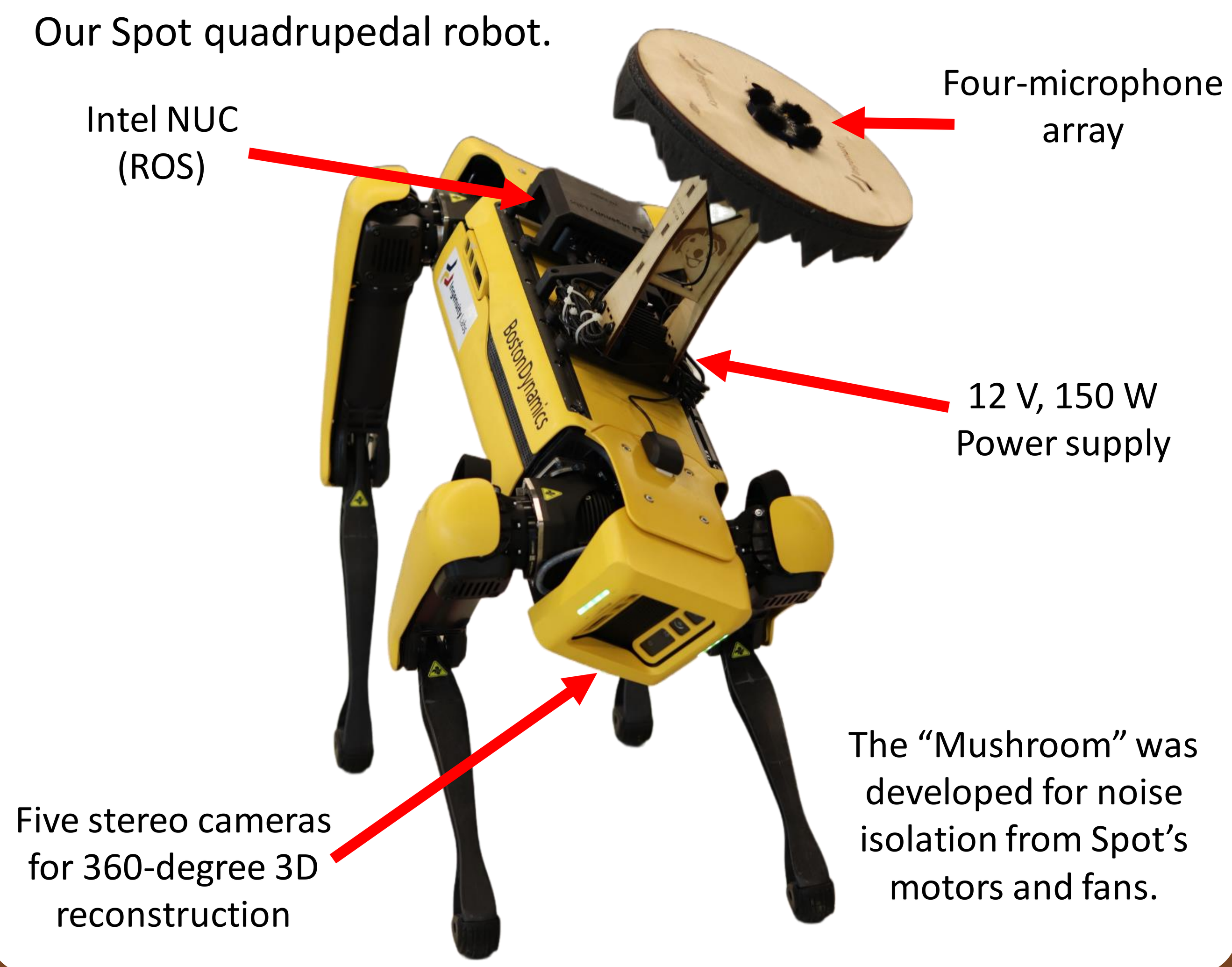


Spot uses a 2D occupancy grid and a graph of 'safe' nodes to navigate through the known environment.



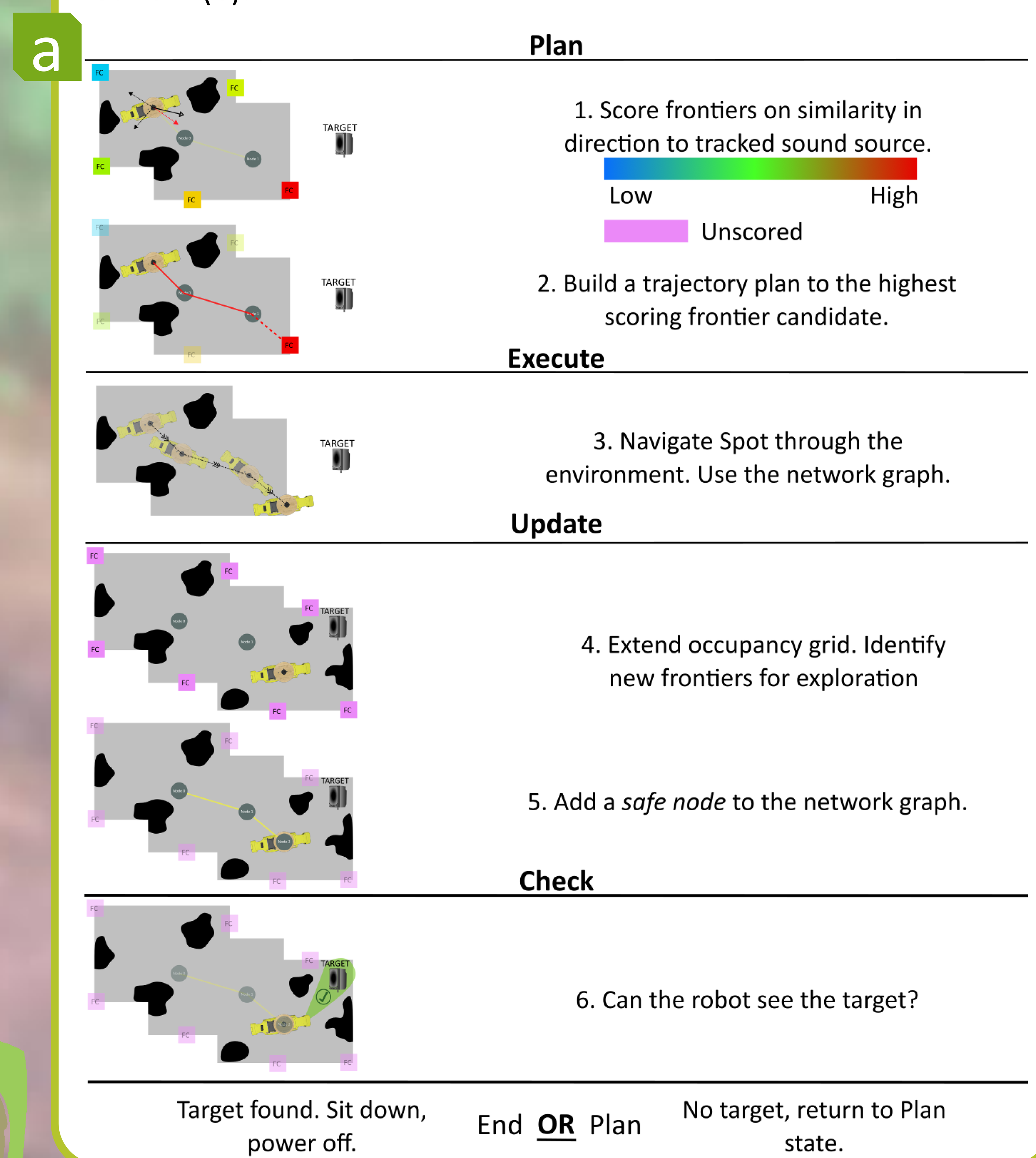
Hardware and Robotic Ears

Our Spot quadrupedal robot.



Autonomous Exploration

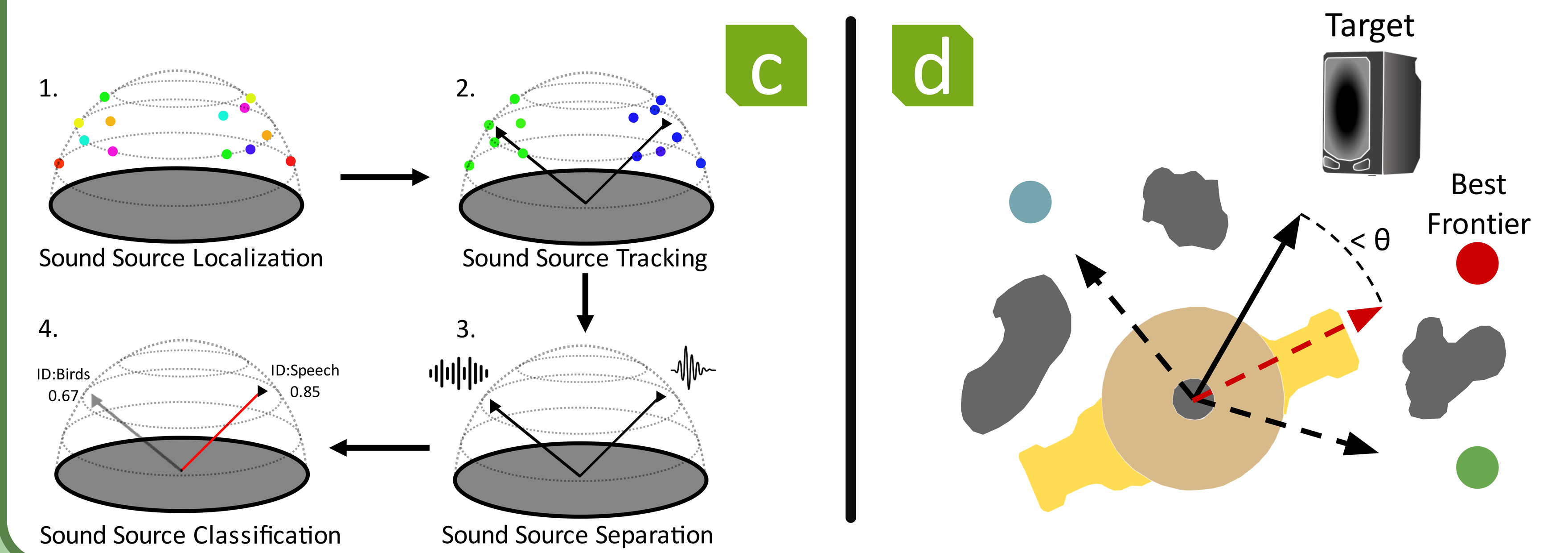
Spot uses a state machine for its decision-making processes (a). After each successful exploration step, its current position is considered 'safe', and a new node is added to the 'safe' node network (b).



Sound Source Tracking as a Heuristic for Frontiering

A four-stage process turns raw audio into a unit vector pointing in the estimated direction of human voices (c). The Open embedded Audition System [2] tracks sound sources while a YAMnet model classifies them [3].

Spot explores the frontier with the smallest difference in heading compared to the tracked sound with the highest confidence of being a human voice (d).



Field Trials and Results

Field trials were performed in 10 diverse scenarios, including urban and forest-based mock disasters (e). The system proved to generalize well, achieving an overall Success Rate (SR) of 69% with a Success weighted by Path Length (SPL) score of 0.42.

Two methods of sound source tracking were tested. Continuous, where the microphone would be left on, and discrete, where the microphone would be turned on only when the robot was stationary. Continuous listening had 14 % higher success rate. Halting the robot for reduced noise during measurements did not improve its ability to achieve the target.

Problem	Continuous SR	Discrete SR	Continuous SPL	Discrete SPL
Marco-Polo	86%	75%	0.70	0.60
High Density	67%	50%	0.33	0.31
Cube Farm	43%	75%	0.25	0.18
Hidden Corridor	100%	50%	0.52	0.34
Bug Catcher	100%	75%	0.40	0.52
Burnt Cars	100%	67%	0.56	0.57
Comparative 6 Average	78%	64%	0.47	0.41
Concrete Hallway	33%	N/A	0.23	N/A
Hiking Traik	N/A	100%	N/A	0.31
Mixed Terrain	N/A	100%	N/A	0.85
Moon Shot	0%	N/A	0.00	N/A
Complete Average	69%		0.42	

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References:
[1] R. R. Murphy et al., 'Search and Rescue Robotics', in Springer Handbook of Robotics, B. Siciliano and O. Khatib, Eds. Berlin, Heidelberg: Springer, 2008, pp. 1151–1173.
[2] F. Grondin et al., 'ODAS: Open embeddeD Audition System', no. arXiv:2103.03954. arXiv, 11-May-2022.
[3] C. Malmberg, 'Real-time Audio Classification onan Edge Device : Using YAMNet and TensorFlow Lite', Dissertation, 2021.