Environment perception in robotics

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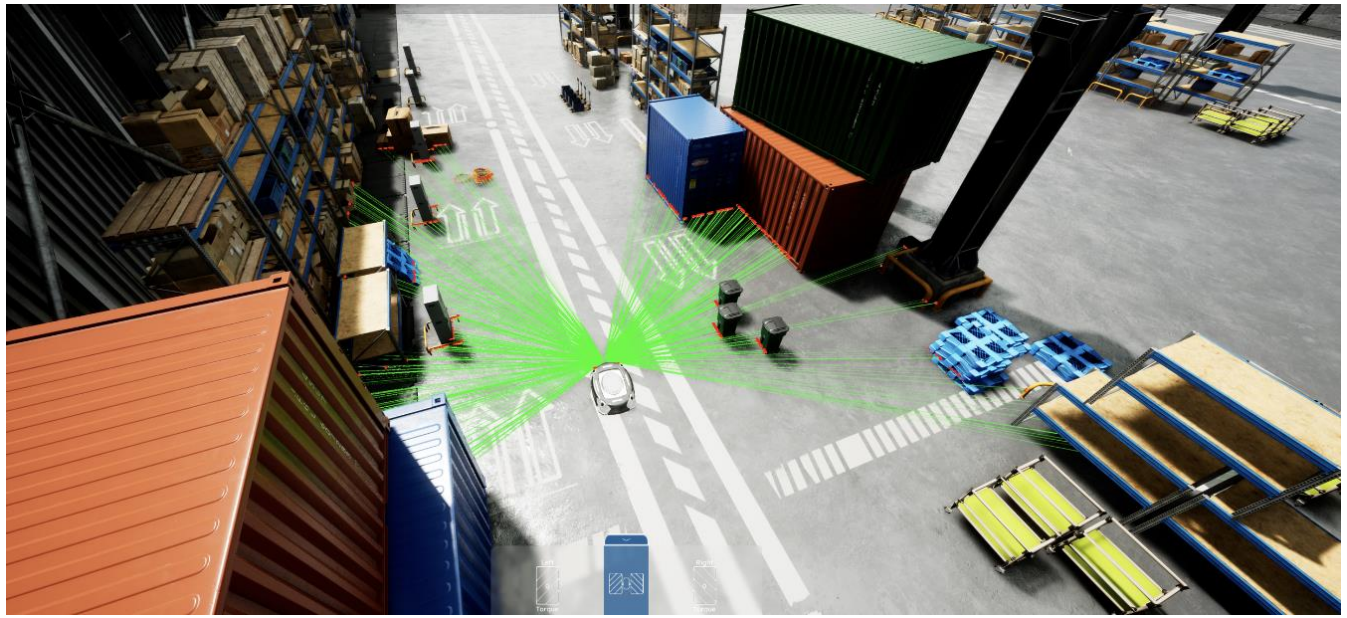
Motivation

Environmental perception has commonly been defined as **awareness of, or feelings about, the environment, and as the act of apprehending the environment by the senses**. A more encompassing definition and theoretical framework was provided by psychologist William Ittelson (1973)[1] who described environmental perception as a multi-dimensional phenomenon, as a transactional process between the person and the environment[2].



Duality Robotics simulated warehouse environment sensing

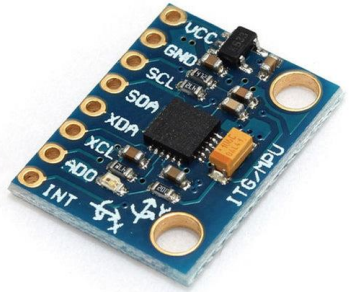
[1] Ittelson, W. H. (1973). Environment and cognition. Seminar Press.
[2] Zube, E.H. (1999). Environmental perception. In: Environmental Geology. Encyclopedia of Earth Science. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4494-1_120

How does a machine ‘understand’ the environment?

Sensors are devices that detect and measure specific physical properties—such as light, pressure, motion, or sound—and convert these measurements into electrical signals. This process enables digital systems, like computers or control units, to interpret, process, and respond to real-world data.

Infrared Proximity Sensor - Sharp GP2Y0A21YK

HY-SRF05 Ultrasonic Distance Sensor Module



MPU6050 6DOF IMU Module (accelerometer + gyro)

Basler Dart MIPI IMX8 Camera

What kind of sensor exists?

- **Vision Sensors (camera)**
- **Proximity Sensors (infrared, ultrasound)**
- **Temperature Sensors (thermometer)**
- **Pressure Sensors**
- **Motion and Orientation Sensors (accelerometer or gyroscope)**
- **Sound Sensors (microphone)**
- **Gas and Chemical Sensors (carbon monoxide sensor)**
- **Magnetic Sensors (magnetometer)**
- **Touch Sensors (capacitive or resistance)**
- **…**

What kind of sensors should I use?

Sensor Selection Checklist (proposed):

1.Task

Clearly define the task or purpose of measurement.

2.Physical Property to Measure

Specify the physical property you want to measure (e.g., temperature, pressure, distance).

3.Budget

Set a budget range for the system or sensor.

4.Choice/Opinion/Recommendation

List the preferred sensor choices or recommendations based on requirements.

5.System Size

Determine the allowable size or constraints for the system.

6.Working Distance

Define the required working distance for accurate measurement.

7.Working Environment Conditions

Specify environmental conditions (e.g., temperature range, humidity, presence of dust or moisture) that may affect performance.

Can the system perform the task without sensing?

It can, but the error might occur …

(We can only provide feedback to the system once we have detected the presence of the specific parameter)

Does incorporating sensing make the system more intelligent?

Camera data understanding (processing) with computer vision

- Visual data understanding can give a broad spectrum of details about objects in the environment
- By employing an artificial intelligence processing pipeline, it is possible to determine object/and their properties in the scene.

Caputo, S., Castellano, G., Greco, F., Mencar, C., Petti, N., Vessio, G. (2022). Human Detection in Drone Images Using YOLO for Search-and-Rescue Operations. In: Bandini, S., Gasparini, F., Mascardi, V., Palmonari, M., Vizzari, G. (eds) AIxIA 2021 – Advances in Artificial Intelligence. AIxIA 2021. Lecture Notes in Computer Science(), vol 13196. Springer, Cham. https://doi.org/10.1007/978-3-031-08421-8_22

C. Xie, Y. Xiang, A. Mousavian and D. Fox, "Unseen Object Instance Segmentation for Robotic Environments," in *IEEE Transactions on Robotics*, vol. 37, no. 5, pp. 1343-1359, Oct. 2021, doi: 10.1109/TRO.2021.3060341

Camera (visible) data drawbacks… (1)

- Environmental conditions, such as fog, dust, partial occlusion, and low or poor light reduce visibility

https://abc13.com/fog-houston-weather-dense-advisory/4998671/ Dense fog on the street

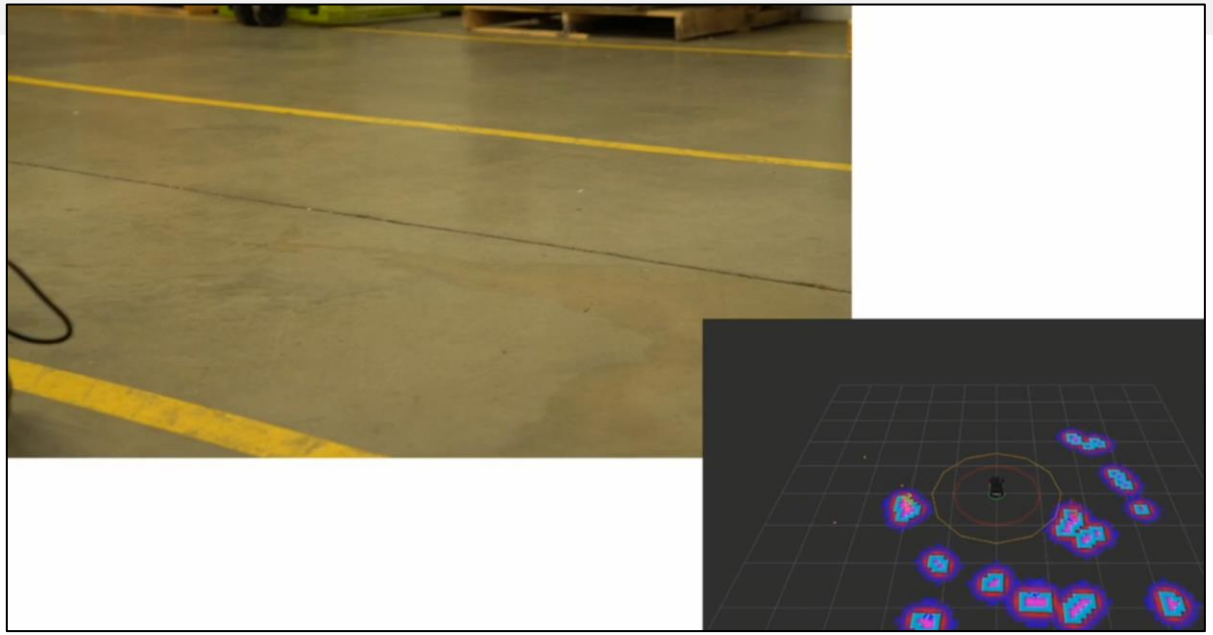
https://pxhere.com/en/photo/93278 Electric line in a fog

Camera (visible) data drawbacks… (2)

Environment (visual context) can be extremely complex to understand from a visual perspective only. Higher-level understanding requires huge processing resources (or it is time-consuming on constrained computational resource hardware).

Taking advantage of radar (distance) data (1)

Obstacle avoidance or environmental scenery interpretation with distance evaluation of the object can be done with radars mounted on the machine.



AWR1843 TI radar for obstacle avoidance https://www.ti.com/video/series/mmwave-training-series.html

Taking advantage of radar (distance) data (2)

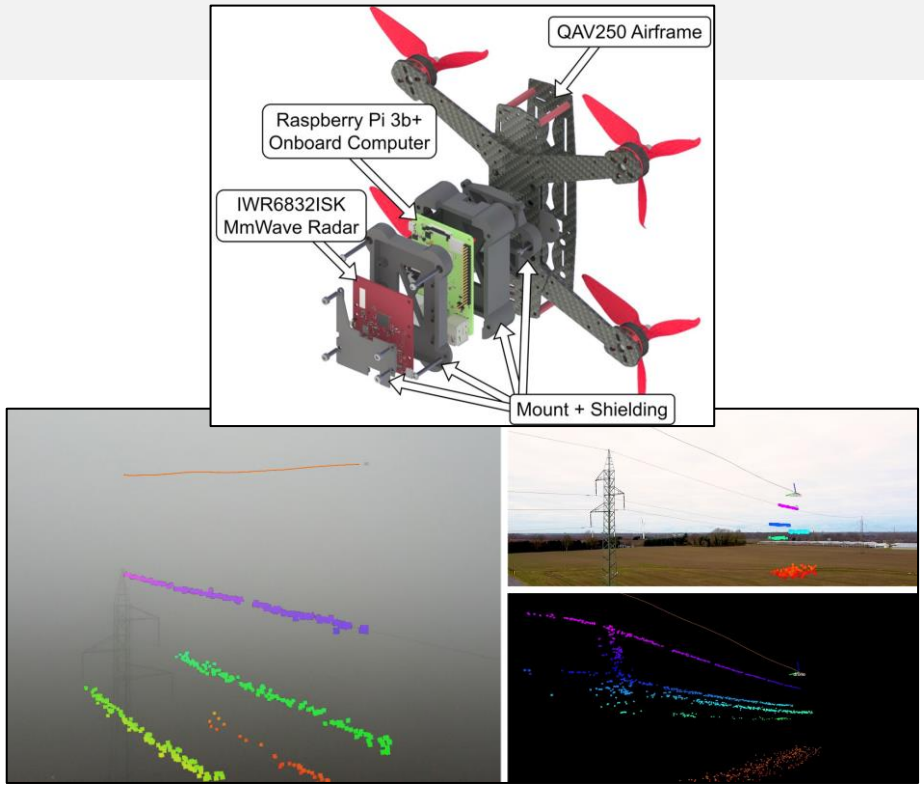
Radars have been used in autonomous vehicles for some time and there is adoption by known car brands.

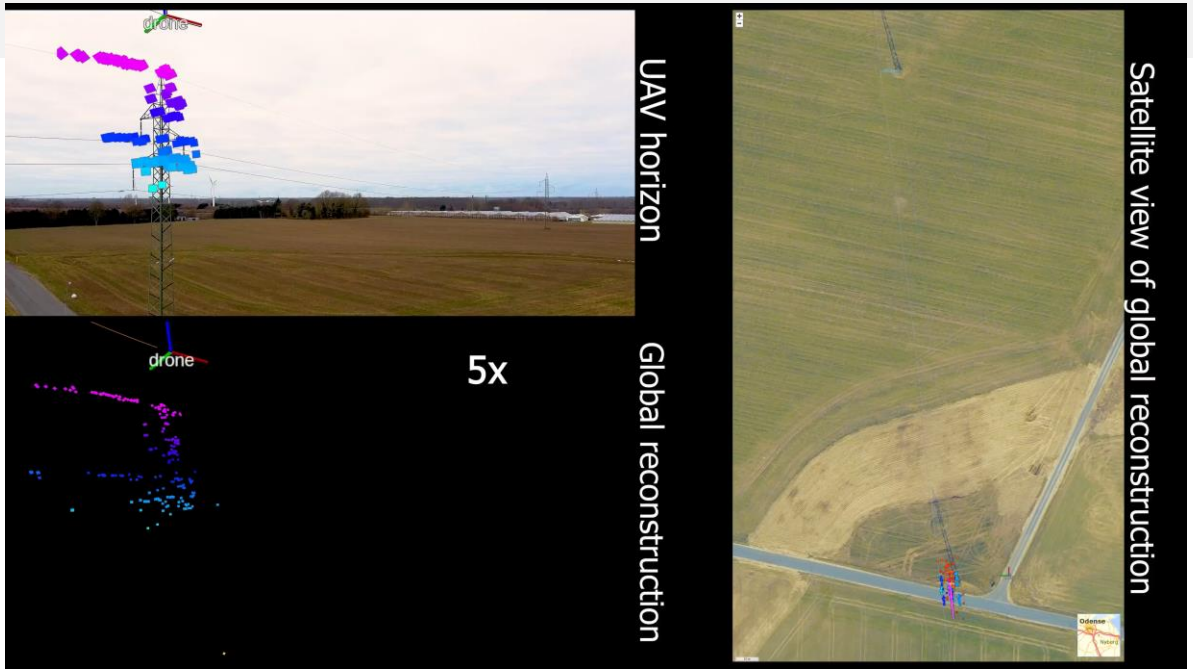
Company	Autonomous Driving System	Sensor Configuration
Tesla	Autopilot	8 cameras, 12 ultrasonic radars, **mmWave radar**
Baidu	Apollo	Lidar, **mmWave radar**, Camera
NIO	Aquila	Lidar, 11 cameras, **5 mmWave radars**, 12 ultrasonic radars
Xpeng	XPILOT	6 cameras, **2 mmWave radars**, 12 ultrasonic radars
Audi	Traffic Jam Pilot	6 cameras, **5 mmWave radars**, 12 ultrasonic radars, Lidar
Mercedes Benz	Drive Pilot	4 panoramic cameras, Lidar, **mmWave radar**

Wei, Z.; Zhang, F.; Chang, S.; Liu, Y.; Wu, H.; Feng, Z. MmWave Radar and Vision Fusion for Object Detection in Autonomous Driving: A Review. Sensors 2022, 22, 2542. https://doi.org/10.3390/s22072542

Taking advantage of radar (distance) data (3)

Recent research proposes radar usage on UAVs as an alternative for LiDAR and/or hybrid approaches with cameras.

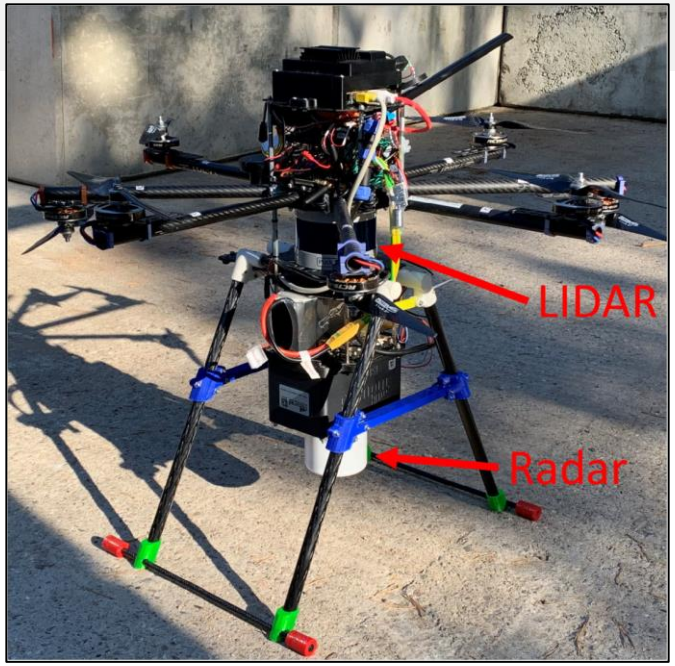


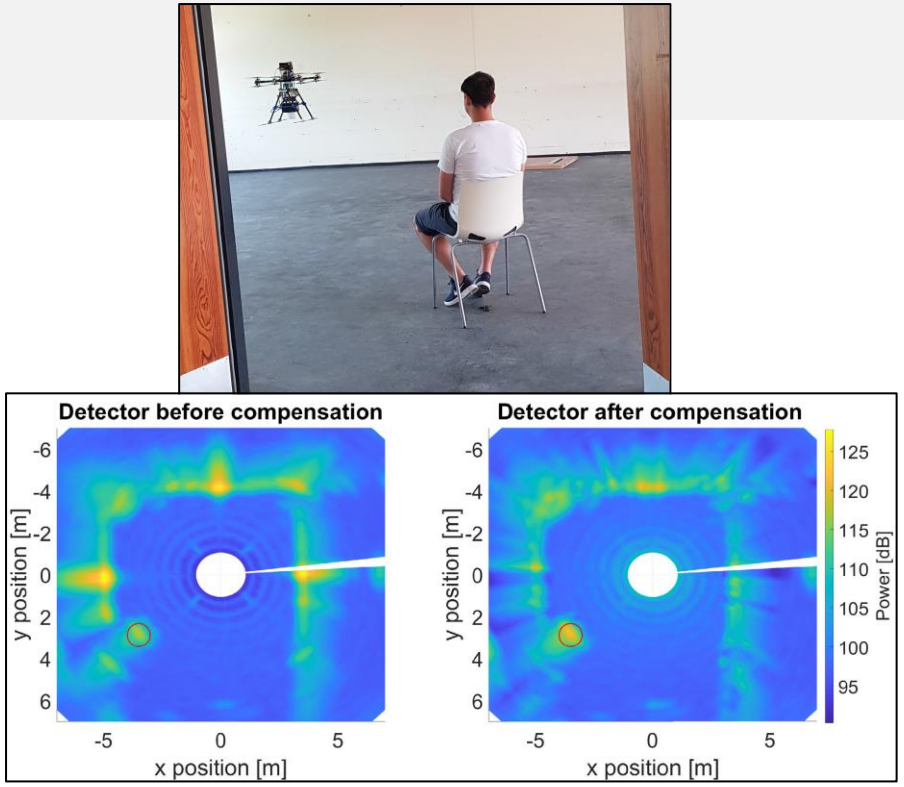


Malle, Nicolaj Haarh and Emad Ebeid,Autonomous Power Line Tracking using mmWave Radar, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2024 (Early Access)

Taking advantage of radar (distance) data (4)

Recent research proposes radar usage on UAVs as an alternative for LiDAR and/or hybrid approaches with cameras.

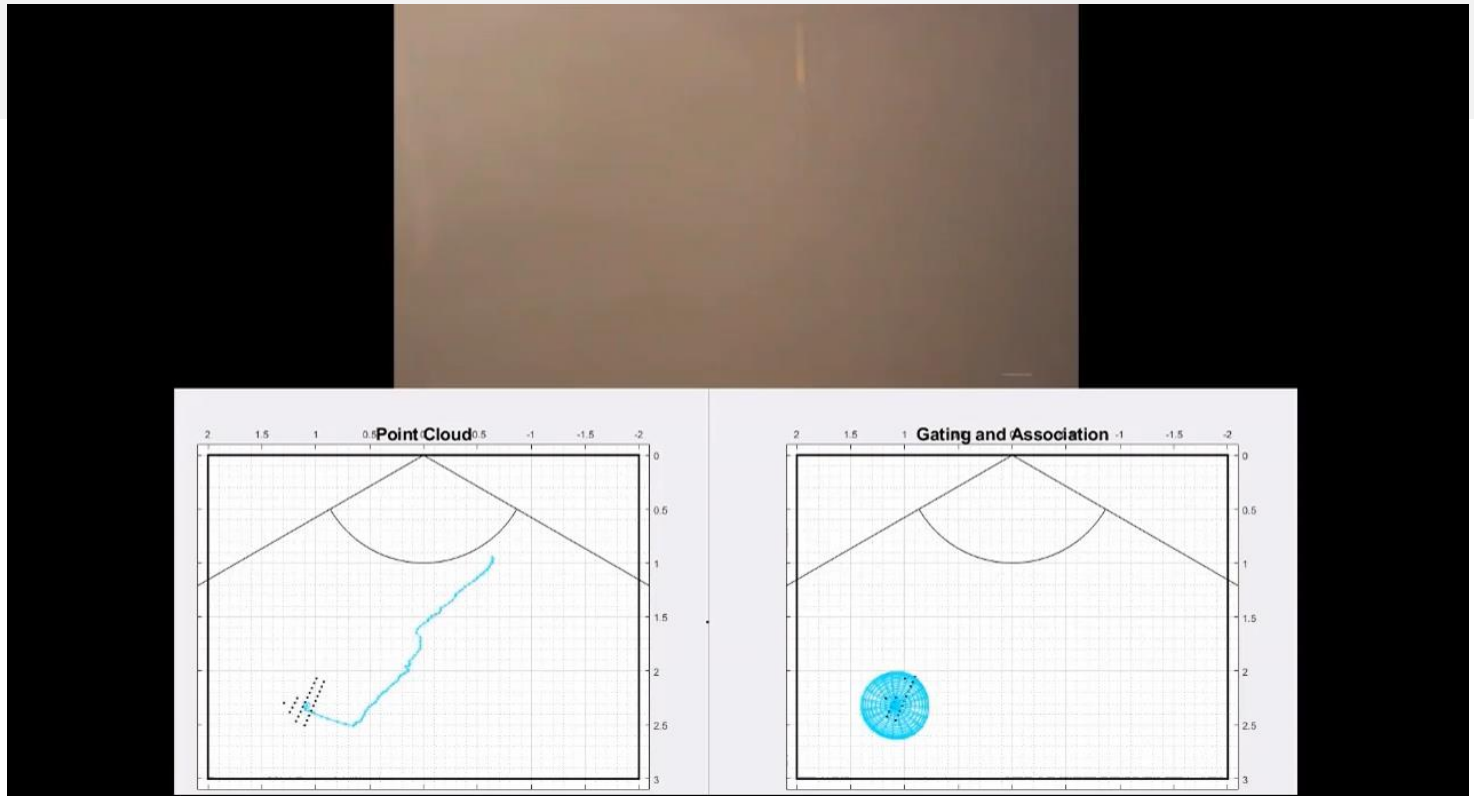




P. Stockel, P. Wallrath, R. Herschel and N. Pohl, "Detection and Monitoring of People in Collapsed Buildings Using a Rotating Radar on a UAV," in IEEE Transactions on Radar Systems, vol. 2, pp. 13-23, 2024, doi: 10.1109/TRS.2023.3342368

Taking advantage of radar (distance) data (5)

Radars have an advantage compared to visible light sensors in harsh environments, such as fog, dust, etc.



TI IWR1443 radar human detection in foggy environment https://www.ti.com/video/5770000765001

Thank you for your attention!
Questions?

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