Introduction to Cognitive Robotics

Module 3: Mobile Robots

Lecture 1: Types of mobile robots; locomotion vs. navigation; challenges of navigation: localization; search, path planning, coverage, SLAM

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www.vernon.eu

Types of Mobile Robots

Wheeled

transport robot

Picker Robots

Picker Robots are mobile machines designed to autonomously retrieve and carry products in a warehouse. The robots are directed through AI-powered software that identifies the most efficient paths for them to pick, replenish, return, and count goods.

CREATOR
inVia Robotics

COUNTRY
United States 🇺🇸

YEAR
2015

TYPE
Industrial

Source: https://robots.ieee.org/robots/invia/


Video

Types of Mobile Robots

Wheeled transport robot

Freight

Freight is an autonomous mobile base for use in warehouses to transport materials from point A to point B. The robot platforms come in three zippy flavors – 100, 500 and 1500, all of which represent the payload it can handle in kilograms.

CREATOR
Fetch Robotics

COUNTRY
United States

YEAR
2014

TYPE
Industrial

Source: https://robots.ieee.org/robots/freight/

Types of Mobile Robots

Wheeled

telepresence robot

Beam

Beam is a telepresence robotic system that can "teleport" you to a remote location, allowing you to move around and interact with people. It is easy to drive and has a large display to improve face-to-face, or screen-to-face, communication.

CREATOR
Suitable Technologies

COUNTRY
United States

YEAR
2011

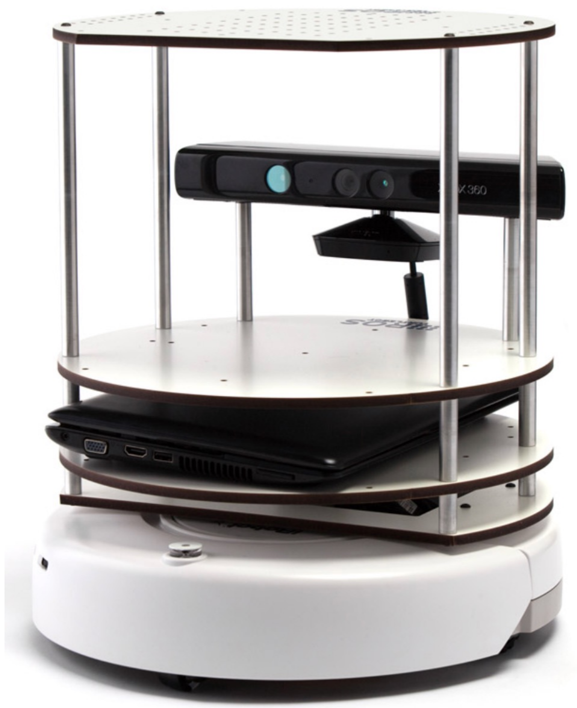
TYPE
Telepresence, Consumer

Source: https://robots.ieee.org/robots/beam/

Types of Mobile Robots

Wheeled

education robot



TurtleBot

TurtleBot is a low-cost personal robot designed for hobbyists and researchers. It's open source, runs the ROS operating system, and combines a netbook with a Kinect 3D sensor and a mobile base.

CREATOR
Willow Garage

COUNTRY
United States

YEAR
2011

TYPE
Consumer, Research, Education

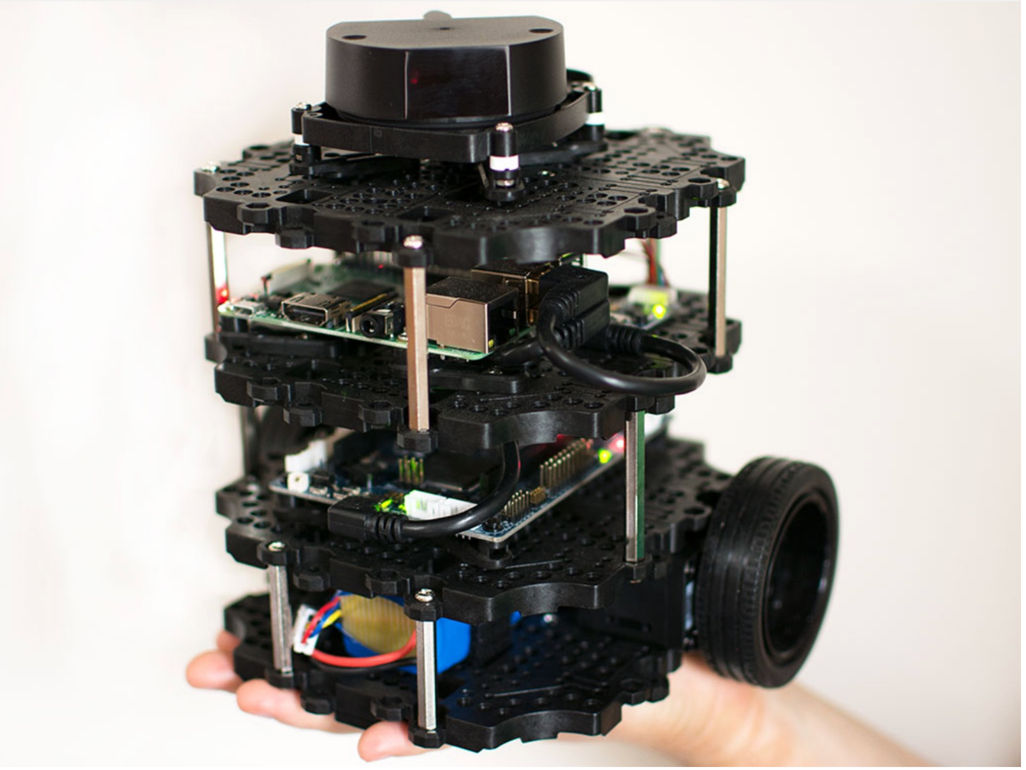
Source: https://robots.ieee.org/robots/turtlebot/

Video

Types of Mobile Robots

Wheeled

education robot



TurtleBot 3

TurtleBot3 is a small programmable mobile robot powered by the Robot Operating System (ROS). It carries lidar and 3D sensors and navigates autonomously using simultaneous localization and mapping (SLAM).

CREATOR
Robotis and OpenRobotics

COUNTRY
South Korea

YEAR
2017

TYPE
Research, Education

Source: https://robots.ieee.org/robots/turtlebot3/

Types of Mobile Robots

Wheeled
humanoid robot

Armar

Armar is a robot created to be a helper in industrial environments. Its humanoid form lets it use human tools like power drills and hammers. Earlier versions were home helpers that could clean tables and load the dishwasher.

CREATOR
Karlsruhe Institute of Technology

COUNTRY
Germany

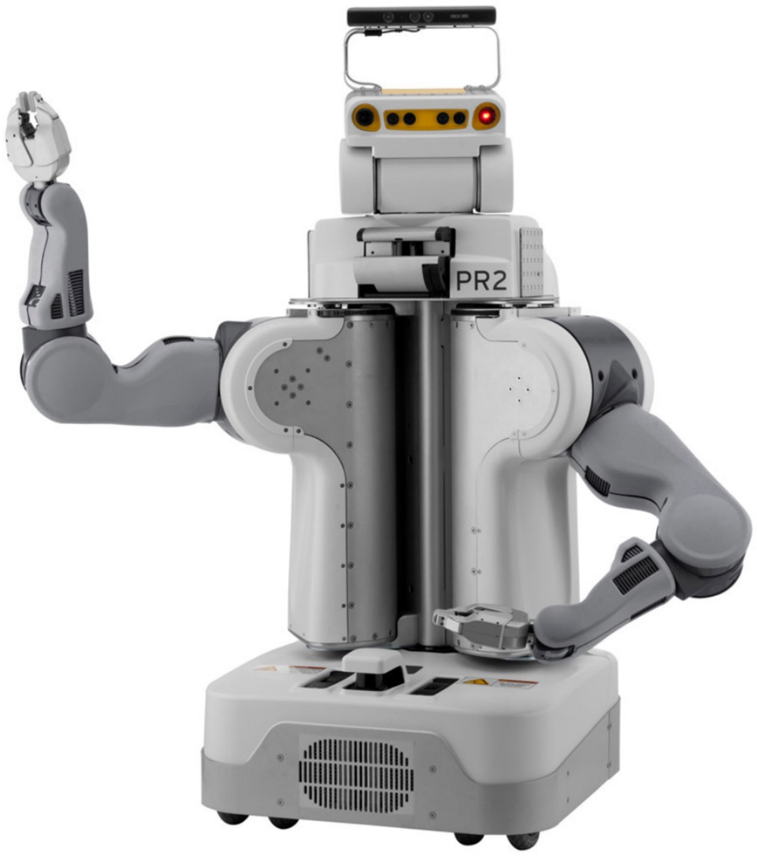
YEAR
2017

TYPE
Humanoids, Research

Source: https://robots.ieee.org/robots/armar/

Types of Mobile Robots

Wheeled humanoid robot



PR2

The PR2 is one of the most advanced research robots ever built. Its powerful hardware and software systems let it do things like clean up tables, fold towels, and fetch you drinks from the fridge.

CREATOR
Willow Garage

COUNTRY
United States

YEAR
2010

TYPE
Research, Humanoids

Source: https://robots.ieee.org/robots/pr2/

Types of Mobile Robots

Wheeled
humanoid robot

Pepper

Pepper is a friendly humanoid designed to be a companion in the home and help customers at retail stores. It talks, gesticulates, and seems determined to make everyone smile.

CREATOR
SoftBank Robotics
(originally created by Aldebaran Robotics, acquired by SoftBank in 2015)

COUNTRY
Japan

YEAR
2014

TYPE
Humanoids, Consumer, Entertainment

Source: https://robots.ieee.org/robots/pepper/

Types of Mobile Robots

Legged humanoid robot

Nao

Nao is a small humanoid robot designed to interact with people. It's packed with sensors (and character) and it can walk, dance, speak, and recognize faces and objects. Now in its sixth generation, it is used in research, education, and healthcare all over the world.

CREATOR
SoftBank Robotics
(originally created by Aldebaran Robotics, acquired by SoftBank in 2015)

COUNTRY
France 🇫🇷

YEAR
2008

TYPE
Humanoids, Research, Education

Source: https://robots.ieee.org/robots/nao/

Types of Mobile Robots

Legged
humanoid robot

HRP-4

HRP-4 is one of the world's most advanced humanoids, the culmination of a decade of R&D. It's designed to collaborate with humans and can perform remarkably natural, human-like movements.

CREATOR
Kawada Industries and AIST

COUNTRY
Japan 🇯🇵

YEAR
2010

TYPE
Humanoids, Research

Source: https://robots.ieee.org/robots/hrp4/

Types of Mobile Robots

Legged
humanoid robot

Atlas

Atlas is the most agile humanoid in existence. It uses whole-body skills to move quickly and balance dynamically. It can lift and carry objects like boxes and crates, but its favorite tricks are running, jumping, and doing backflips.

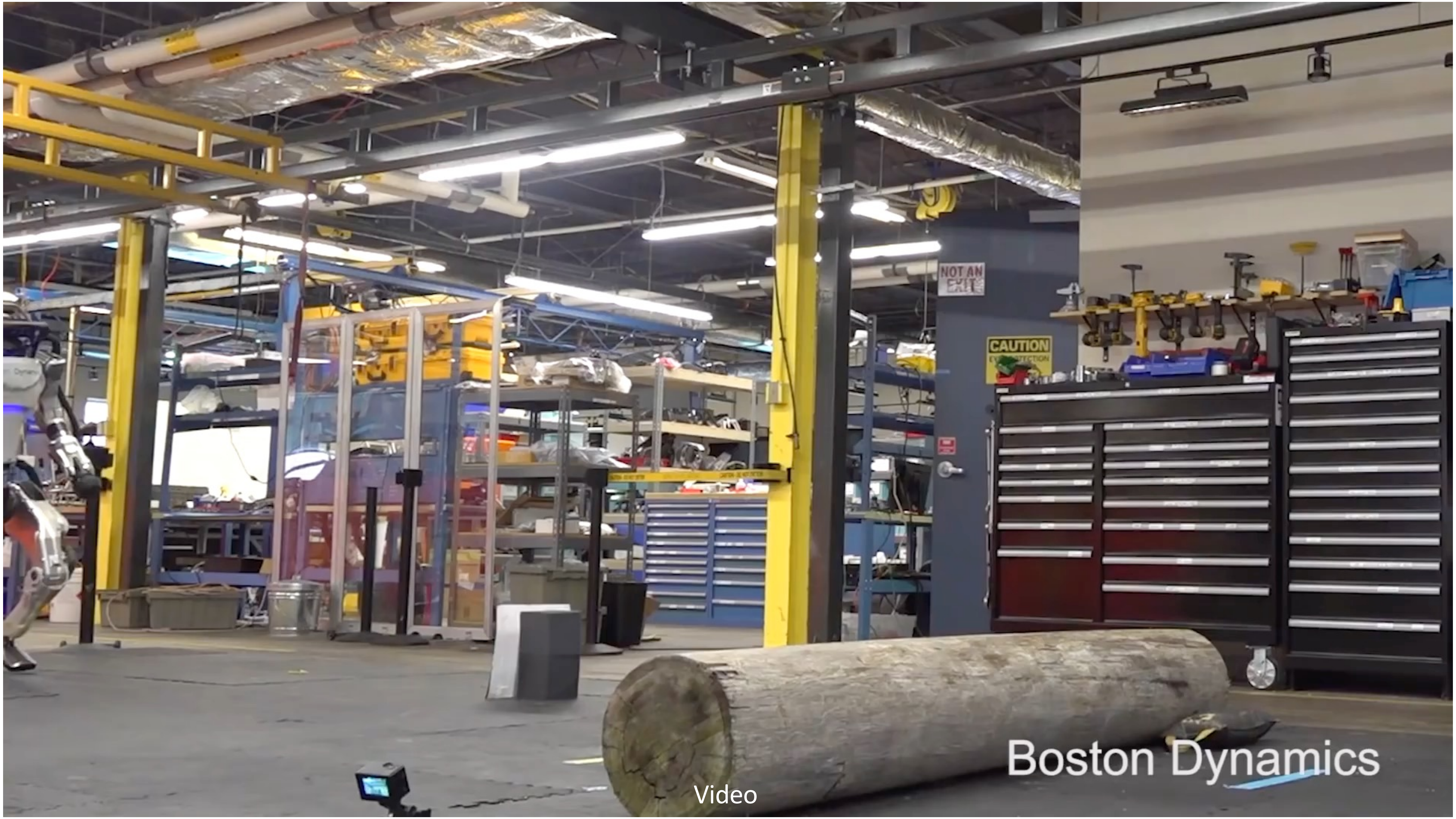
CREATOR
Boston Dynamics

COUNTRY
United States

YEAR
2016

TYPE
Humanoids, Industrial

Source: https://robots.ieee.org/robots/atlas2016/



Video

Types of Mobile Robots

Legged
humanoid robot

iCub

iCub is a child-size humanoid robot capable of crawling, grasping objects, and interacting with people. It's designed as an open source platform for research in robotics, AI, and cognitive science.

CREATOR
RoboCub Consortium and IIT

COUNTRY
Italy

YEAR
2004

TYPE
Humanoids, Research

Source: https://robots.ieee.org/robots/icub/

Types of Mobile Robots

Legged

inspection robot

ANYmal

ANYmal is a rugged, autonomous four-legged robot designed for inspection and manipulation tasks. It uses sensors to scan the terrain and avoid obstacles, and can operate in rain, snow, wind, waterlogged rooms, and dusty environments.

CREATOR
ETH Zurich and ANYbotics

COUNTRY
Switzerland

YEAR
2016

TYPE
Industrial, Research, Disaster Response

Source: https://robots.ieee.org/robots/anymal/

Types of Mobile Robots

Legged

transport robot

AlphaDog

AlphaDog is a quadruped robot the size of a mule (a big, mean mule). It's powered by a hydraulic actuation system and is designed to assist soldiers in carrying heavy gear over rough terrain.

CREATOR
Boston Dynamics

COUNTRY
United States 🇺🇸

YEAR
2011

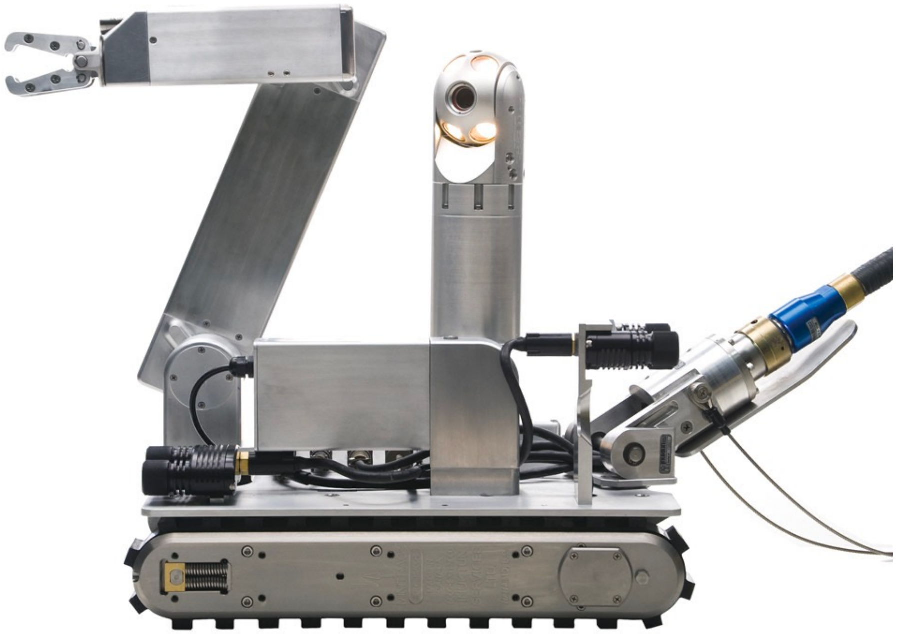
TYPE
Military & Security, Research

Source: https://robots.ieee.org/robots/alphadog/

Types of Mobile Robots

Tracked

transport robot



Versatrax

Versatrax 450 TTC is a mobile robot designed for hazardous environments. It allows users to locate, inspect, and safely remove dangerous materials from any site faster than by conventional means.

CREATOR
Inuktun Services

COUNTRY
Canada

YEAR
2012

TYPE
Industrial, Military & Security, Disaster Response

Source: https://robots.ieee.org/robots/inuktun/

Types of Mobile Robots

Tracked

disaster response robot

Kobra

Kobra is a rugged, remote control robot designed to search for explosives and carry out reconnaissance missions. It rolls on tank-like treads, and its manipulator arm can lift heavy payloads.

CREATOR
Endeavor Robotics
(Originally created by iRobot)

COUNTRY
United States 🇺🇸

YEAR
2011

TYPE
Military & Security, Disaster Response

Source: https://robots.ieee.org/robots/kobra/

Types of Mobile Robots

Airborne delivery robot

Zipline

Zipline is an autonomous fixed-wing aircraft drone used to carry blood and medicine from a distribution center to wherever it's needed. It can launch within minutes, and travel in any weather.

CREATOR
Zipline

COUNTRY
United States

YEAR
2016

TYPE
Drones, Medical

Source: https://robots.ieee.org/robots/zipline/

Video

Video

Video

Types of Mobile Robots

Airborne surveillance robot

Global Hawk

The Global Hawk is an unmanned aerial vehicle that's used for high-altitude, long-duration surveillance. You tell it what to do, and it can take off, fly, spy, and return without any human input.

CREATOR
Northrop Grumman

COUNTRY
United States

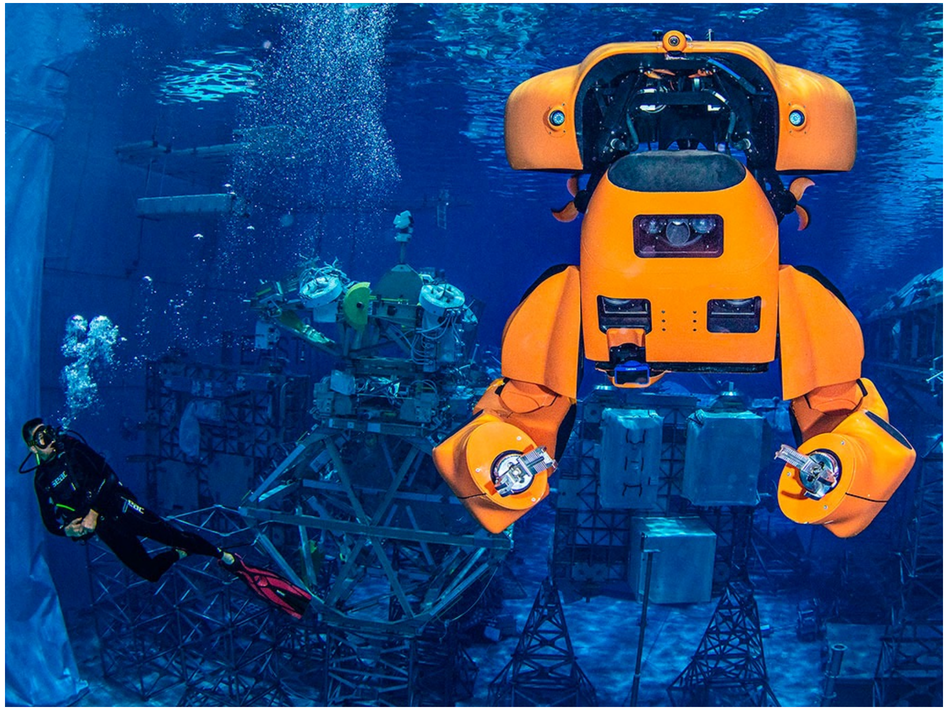
YEAR
2001

TYPE
Aerospace, Military & Security, Drones

Source: https://robots.ieee.org/robots/globalhawk/

Types of Mobile Robots

Underwater manipulation & inspection robot



Aquanaut

Aquanaut is an unmanned underwater vehicle that can transform itself from a nimble submarine designed for long-distance cruising into a half-humanoid robot capable of carrying out complex manipulation tasks. It can inspect subsea oil and gas infrastructure, operate valves, and use tools.

CREATOR
Houston Mechatronics Inc.

COUNTRY
United States

YEAR
2019

TYPE
Underwater, Industrial

Source: https://robots.ieee.org/robots/aquanaut/

Navigation is Hard

"Getting from one place to another is remarkably challenging for a robot.

...

Getting any body part where it needs to be is hard, and the more complicated the robot's body, the harder the problem."

M. Mataric, The Robotics Primer, MIT Press, 2007

Locomotion vs. Navigation

Locomotion

- How to control the mobile robot motors so that the robot moves towards some well-specified target location

- How to control the mobile robot motors so that the robot moves along some well-defined path or trajectory

Navigation

- How to determine the strategy required to get from one point in the environment to another by planning an effective and efficient path

Locomotion vs. Navigation

Locomotion

- Following an arbitrary given path or trajectory is harder than having to get to a particular destination by using any path
  - Some paths are impossible to follow for some robots because of their holonomic constraints
  - For others, some paths can be followed, but only if the robot is allowed to stop, change directions (in place or otherwise), and then go again
- A large subarea of robotics research deals with enabling robots to follow arbitrary trajectories.

Locomotion vs. Navigation

Locomotion

- Trajectory planning, also called motion planning, is a computationally complex process
  - Involves searching through all possible trajectories and evaluating the to find one that will satisfy the requirements
  - Depending on the task, it may be necessary to find the very best (shortest, safest, most efficient, etc.), so-called optimal trajectory
- Since robots are not just points, we need to take into account their
  - Geometry (shape, turning radius)
  - Steering mechanism (holonomic properties)

Locomotion vs. Navigation

Locomotion

- Trajectory planning is used in
  - Mobile robots, in two dimensions
  - Robot arms, in three dimensions, where the problem becomes even more complex
- Depending on their task, practical robots may not be so concerned with following specific trajectories as with just getting to the goal location
- The ability to get to the goal is quite a different problem from planning a particular path and is called navigation

Challenges of Robot Navigation

The goal of navigation

- To reach a given location P
- Examples
  - Go to $[x = 100, y = 200, \theta = 90]$ ← Which frame of reference?
  - Go to room T 2224 ← Where is this room?
  - Go to the cafeteria ← Where is the cafeteria? Where in the cafeteria?
  - Go to the city centre ← Where is the city centre? Which city?
  - Go to a good observation position ← For observing what? What is a criterion for "good"?

Challenges of Robot Navigation

The goal of navigation

- To reach a given location P

- Possible ways to complicate the problem

  - Go to P in shortest time (optimal control)
  - Go to P with least energy (optimal control)
  - Go to P with max speed 1 m/s (constraints)
  - Be at P at 4:12 pm (deadlines)

Challenges of Robot Navigation

Facets of the navigation problem

- Get a map of the environment
- Make a navigation plan using this map
- Execute the plan
  - move in a stable and safe way
  - keep track of your position in the map
  - detect and avoid obstacles and dangers
  - notice exceptional situations and modify the plan
- All this needs the use of sensors

Challenges of Robot Navigation

Environment map

A topological map:
a graph or network of
connected locations

– Must include topological information

Which aisles are blocked and which provide a connection?

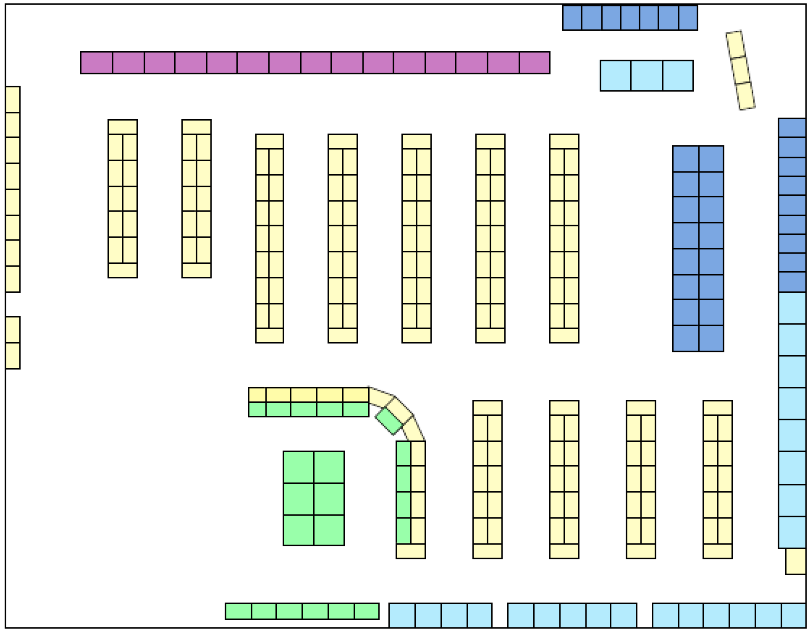
A metric map,
showing locations and
distances between
locations

– Must include geometric information

How many meters to travel before turning left?

– The problem is to find the right level of detail

- Too abstract ⇒ insufficient information to be useful
- Too detailed ⇒ too much information for stable navigation



Map recreated from the following papers:

Joho, D., Senk, M., & Burgard, W. (2009). Learning wayfinding heuristics based on local information of object maps. Proceedings of the European Conference on Mobile Robots (ECMR) 2009, 117–122.

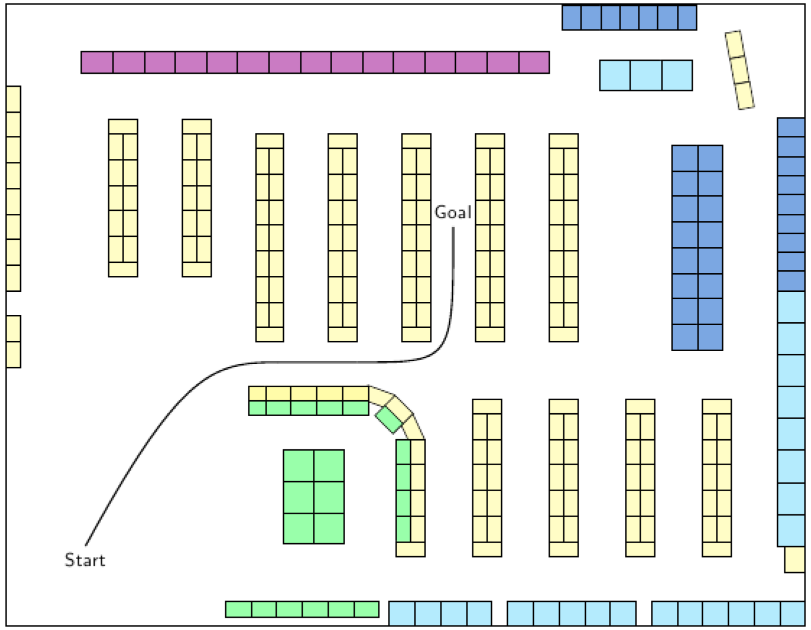
Kalff, C., & Strube, G. (2009). Background knowledge in human navigation: a study in a supermarket. Cognitive Processing, 10(2), 225-228.

Challenges of Robot Navigation

Planning

- Find a path in the map that
  - Goes from the start position to the goal position
  - Is collision-free
  - Is feasible given the robot's kinematics and dynamics
  - Satisfies the extra constraints
- Problem: uncertainty

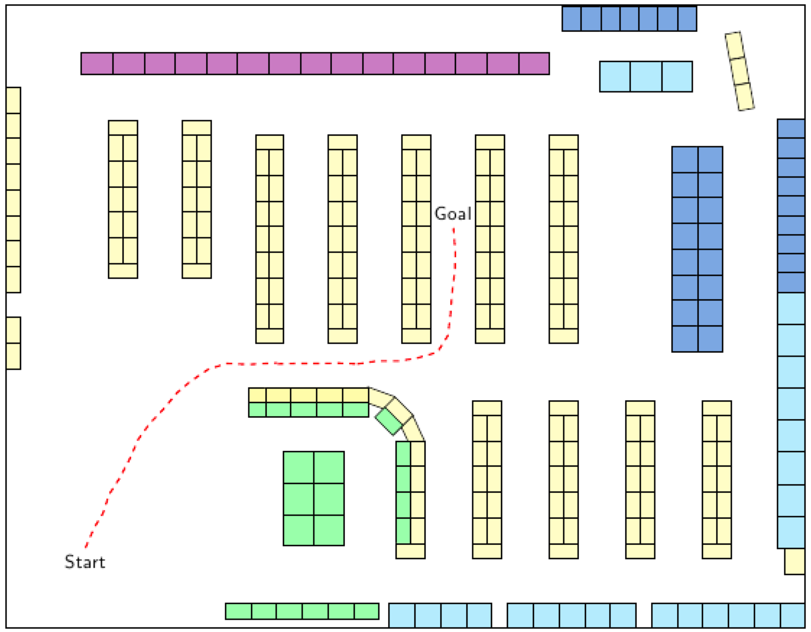
  In real environments, the configuration of the space
  may not be fully known in advance
  and may change at any point



Challenges of Robot Navigation

Execution

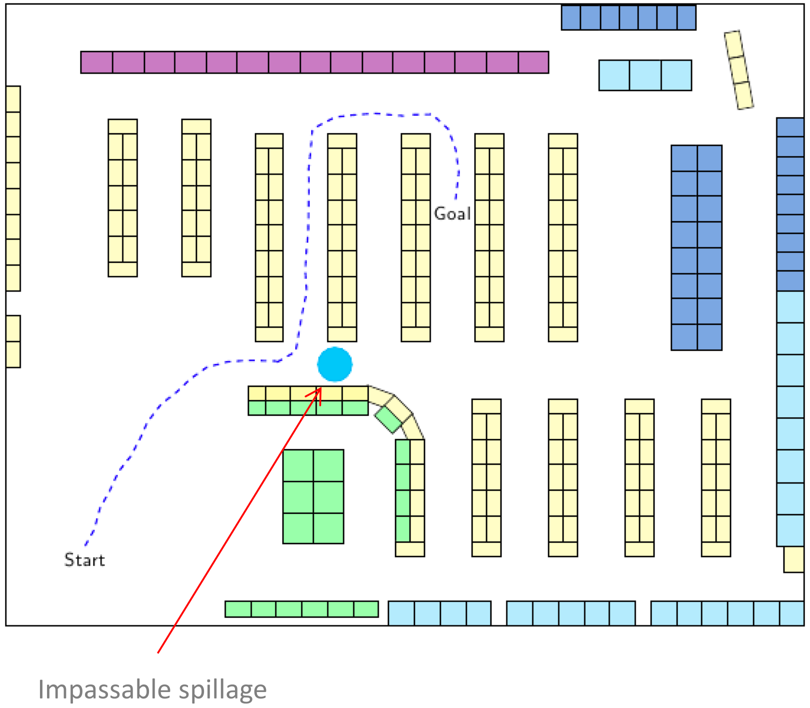
- Follow the planned trajectory
  - Guarantee physical stability
  - Keep track of your position in the map
- React to unexpected events
  - Use sensors to detect obstacles
  - Use sensors to detect failures in the plan
- Problem: uncertainty
  - Sensor data may be noisy
  - Locomotion may be imperfect



Challenges of Robot Navigation

Re-planning

- Detect major discrepancies from the plan
    - the plan is not feasible anymore, or
    - there is a new better opportunity
- Modify the plan
- Problem: when to re-plan?
    - we want to react quickly to any new situation,
      but we do not want to change our mind all the time



Challenges of Robot Navigation

Components of the navigation problem

- Localization: finding out where you are
- Search: looking for the goal location (or target object)
- Path planning: planning a path to the goal location
- Coverage: ensuring the search strategy covers all the possibilities when looking for the goal location.
- SLAM: localization and constructing a map at the same time

Either with a map or without a map

"This is a 'chicken or egg' problem: to make a map, you have to know where you are, but to know where you are, you have to have a map. With SLAM, you have to do both at the same time." M. Mataric.

Types of Robot

Consumer

Roomba

Roomba is an autonomous vacuum and one of the most popular consumer robots in existence. It navigates around clutter and under furniture cleaning your floors, and returns to its charging dock when finished.

CREATOR
iRobot

COUNTRY
United States

YEAR
2002

TYPE
Consumer

Source: https://robots.ieee.org/robots/roomba/

Video

https://robots.ieee.org/robots/roomba/?gallery=video2

Types of Robot

Education

Roomba

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CREATOR
iRobot

COUNTRY
United States 🇺🇸

YEAR
2002

TYPE
Consumer

Source: https://robots.ieee.org/robots/roomba/

Challenges of Robot Navigation

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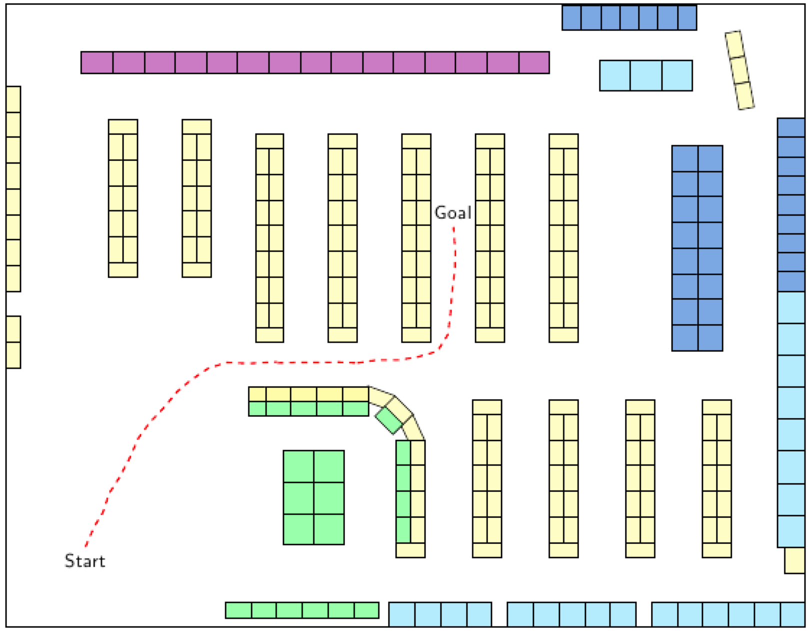
Localization: The Position Estimation Problem

Robot must keep track of its position in the map

- in order to plan a trajectory to the goal
- in order to follow the planned trajectory

This gives rise to the Position Estimation Problem

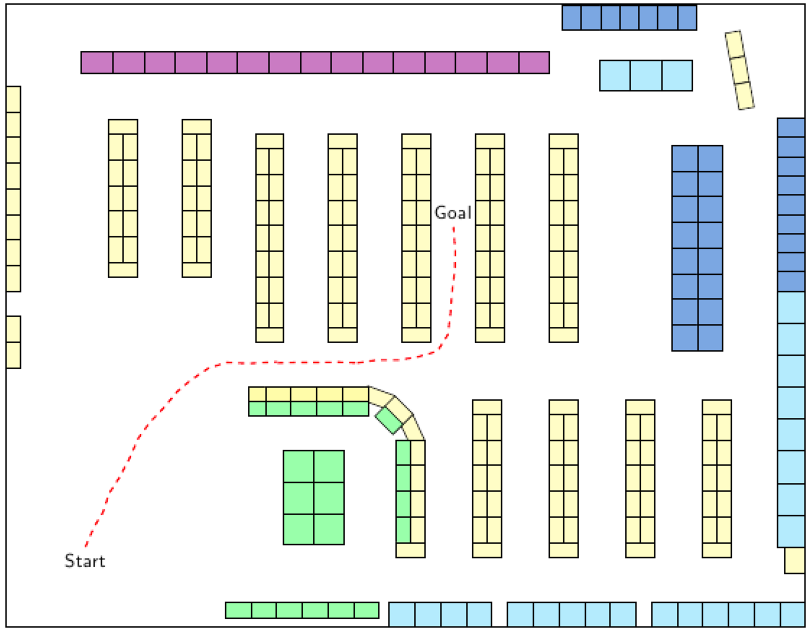
- establish the position of the robot in the environment
- use both proprioceptive and exteroceptive sensors



Localization: The Position Estimation Problem

Two approaches

1. Absolute position estimation
2. Relative position estimation



Reading

M. Mataric, The Robotics Primer, MIT Press, 2007. Chapters 5 and 19.

Videos

Daniel Wolpert's TED Talk on the real reason for brains https://www.youtube.com/watch?v=7s0CpRfyYp8