RRLAB
THE ROBOTICS RESEARCH LAB

Autonomous Mobile Robots (AMR)

1. Overview and History of AMR

Prof. Dr. Karsten Berns
Robotics Research Lab
Department of Computer Science
University of Kaiserslautern, Germany

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Contents

Overview

About the Lecture

- Lectur3
  - Monday 8:15 – 9:45, Room 48-453
  - Tuesday 15:30 – 17:00, Room 48-453
- Exercise
  - Friday 13:45 – 15:15 at 11-262
- Start: 20.04.2019
- Final examination: Oral exam, written exam (CVT)
- Consultation hours: Wednesday 10.00 – 12:00
  (Please give notification in advance)
- Course material
  - agrosy.informatik.uni-kl.de
  - Login: vorlesung
  - Password: robotik

Exercises and Exam

- Exercise sheets: Available every Friday on the website
- Discussion: Each sheet will be discussed in the following week during exercise hours
- Oral Exam (for all others)
- Appointments available through secretary
- Written Exams (for CVT)
  - will soon be published !!

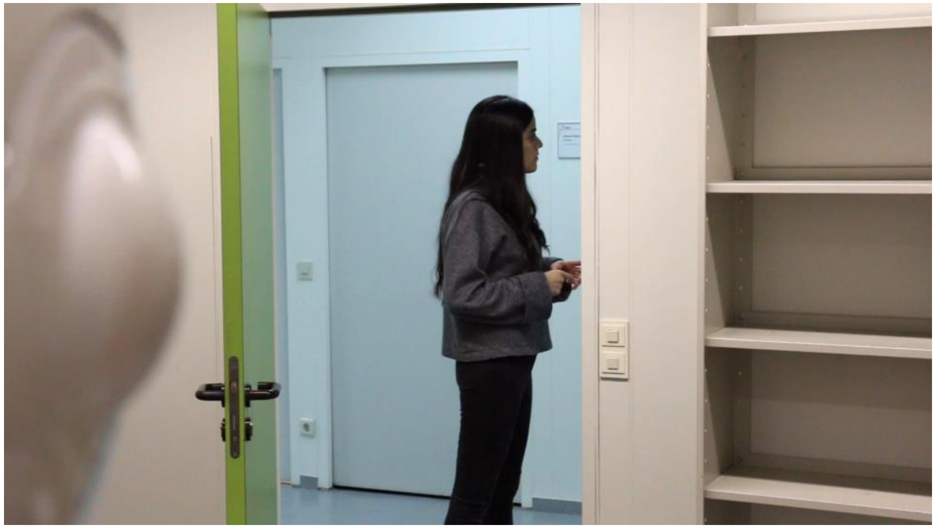
Other Courses due to Topics in Robotics

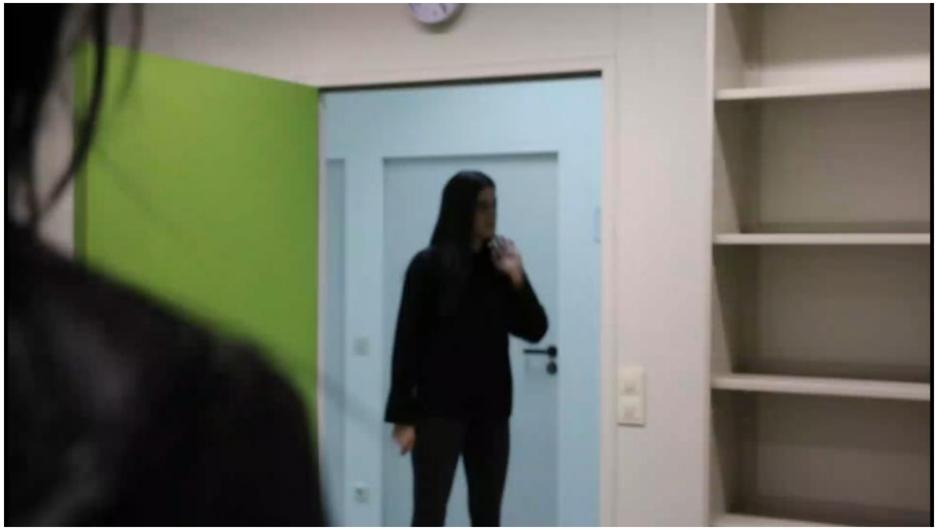
- Lectures
  - Fundamentals of Robotics (WS 2020)
  - Biologically Inspired Robots (WS 2020)
- Master seminar (WS 2020)
  - Embedded Systems and Robotics
- Master project (all the year)
  - Service Robots and Assistance Systems
  - Introduction and presentation of topics
    Wednesday 22.4.2020, 13:45 room 48/379
- Bachelor- and Master-Theses

Thesis Topics

- Control architectures (iB2C)
- Sensor systems
- Simulation
- Outdoor Robots
  - Navigation, localisation, perception
  - RAVON, Backhoe-loader, tractor, Gator, rescue-vehicle, Unimog, Tandem Roller (s), autonomous bus, ASV(boot)
  - UAV
- Humanoid Robots
  - Bipedal locomotion, social interaction
  - Testleg, RoboThespian

Humanoid Robots





Personality Assessment Using Humanoid Robot

Robotics Research Lab
TU Kaiserslautern, Germany

RRLAB THE ROBOTICS RESEARCH LAB

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

RRLAB THE ROBOTICS RESEARCH LAB

CARL

The CompliAnt Robotic Leg

demonstrating its first coordinated behavior-based walking motion

Steffen Schütz, Atabak Nejadfard, Krzysztof Mianowski, Patrick Vonwirth, Christian Kötting, Karsten Berns

Autonomous Mobile Robots

at RRLab

MARVIN

- **M**obile **A**utonomous **R**obotic **V**ehicle for **I**ndoor **N**avigation
- Research Tasks
  - Mobile vehicle platform for various service robot applications
  - Exploration of an unknown environment

Indoor platform MARVIN

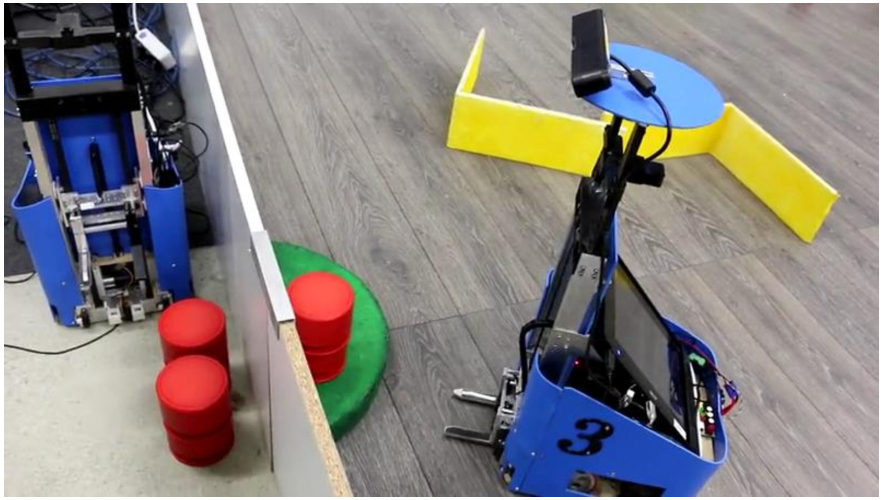
ARTOS

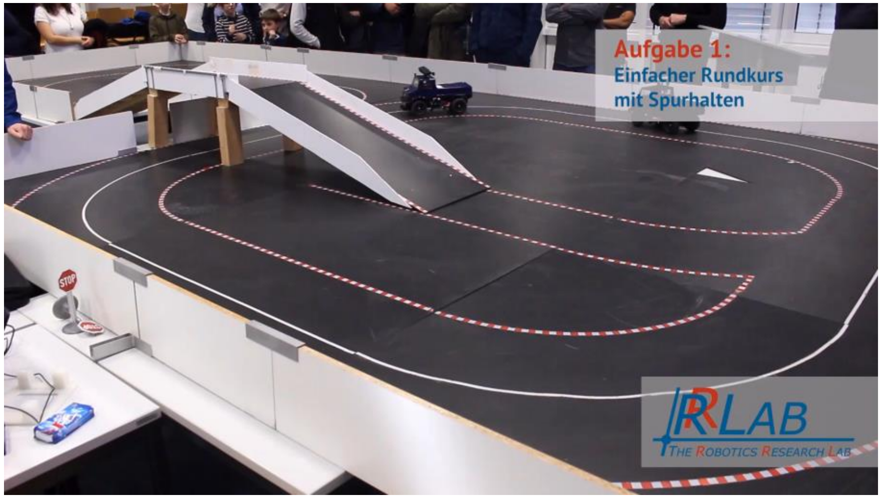
- **A**utonomous **R**obot for **T**ransport **o**r **S**ervice
- Research Tasks
  - Service robot for assisted living
  - Monitoring of humans
  - Localization and mapping in household environments
  - Interaction with ambient environment

Assistant robot ARTOS

Forklift and RC-Unimog

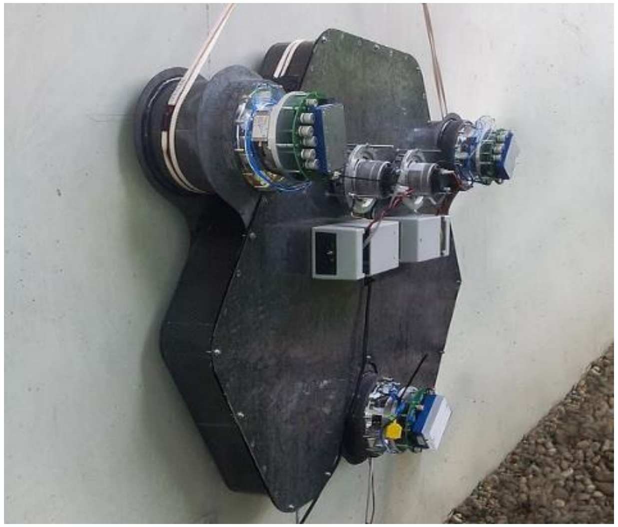
- Research Tasks
  - Realized by students during a lab class
  - Assembly of robot hardware
  - Implementation of control software
  - Competition at the end as final presentation





CROMSCI/Crea

- **C**limbing **R**obot with **M**ultiple **S**ucking **C**hambers for **I**nspection tasks
- Research Tasks
  - Basic vehicle for the inspection of huge concrete walls like dams and bridges
  - Examination of an underpressure-based adhesion system



Off-road Vehicle Applications at RRLab

Test Vehicles




Agricultural Vehicles



Construction Machines



Rescue Robots



RAVON

- **R**obust **A**utonomous **V**ehicle for **O**utdoor **N**avigation
- 2.4m × 1.4m × 0.8m
- Weight: 850 kg
- Four wheel drive with independent DC motors
- Front and rear steering
- Max. speed: 7 km/h
- Floor clearance: 30 cm
- Max. slope: 100%

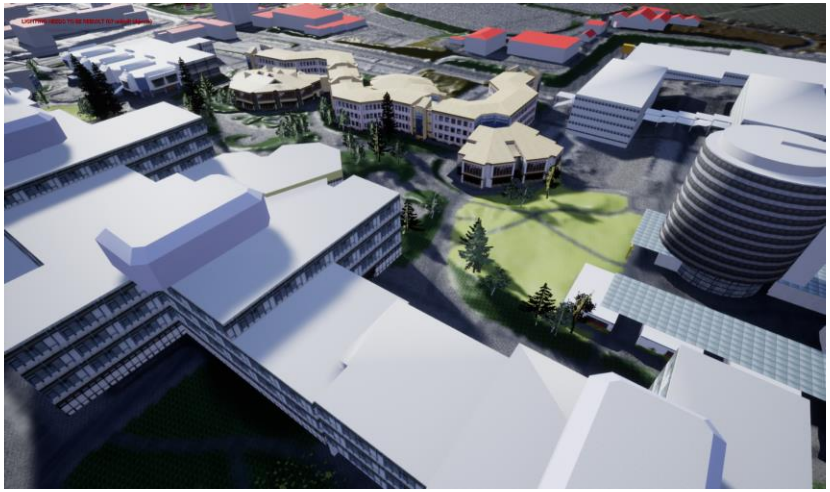
Outdoor robot RAVON

Gator

Research Tasks

- Offroad Navigation
- Sensor Processing
- Control Architectures
- Safety

Autonomous Bus

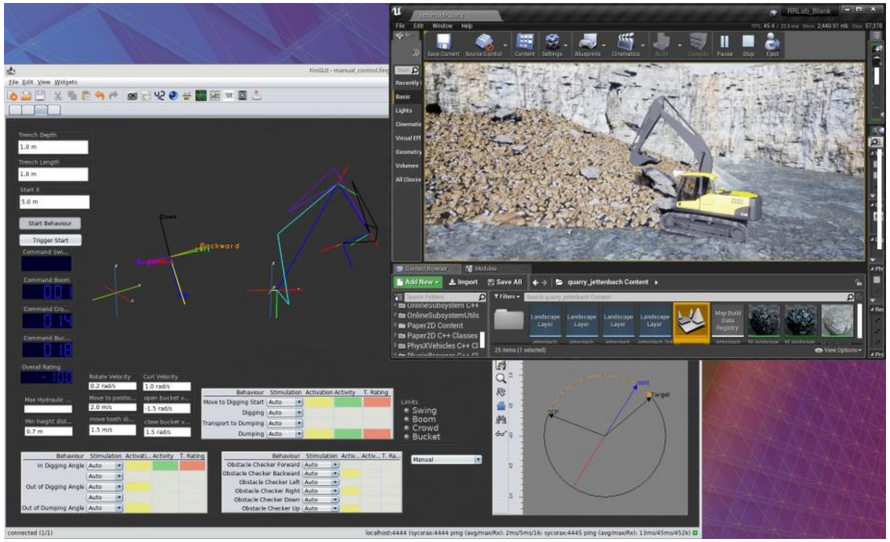


- Min-bus with 10 places
- Navigation in pedestrian zones
- Social avoidance behavior
- Interaction with pedestrians

Excavators

- **T**erraforming **H**eavy **O**utdoor **R**obot (THOR)
- 6.6m × 2.7m × 3.9m
- Weight: 18t
- Arm with six DOF
- Max. speed: 25 km/h

- Excavator for stone quarry
- Classification and segmentation
- Strategy for excavation stones



Backhoe-loader

Research Tasks

- Autonomous excavation
- Sensor and perception concept
- Arm control
- Safety
- Trench digging

Backhoe-loader of the company John Deere

Drum Roller

- Navigation of drum Rollers
- Coordination
- Environmental perception
- Localisation
- Simulation of operational environment, vehicle and sensor system

Unimog – Simulation and real System

- Sensor system
- Mapping of rough environment
- Collision avoidance
- Navigation

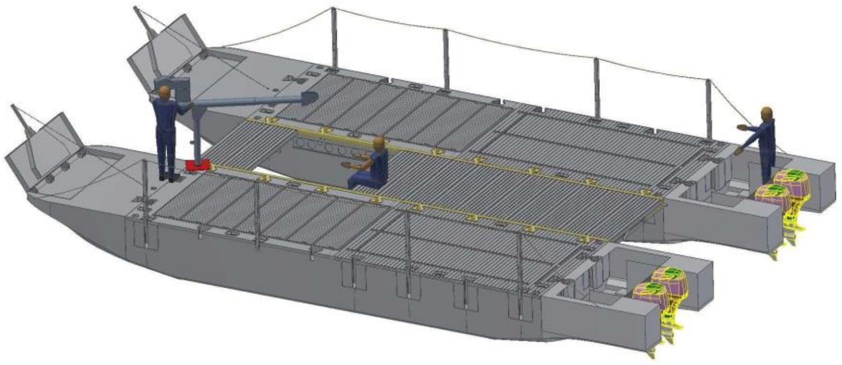
EUROPÄISCHE UNION
EUROPÄISCHER FONDS FÜR REGIONALE ENTWICKLUNG
RheinlandPfalz

RRLAB
THE ROBOTICS RESEARCH LAB

Inspection and 3D Reconstruction with Drones

- Gerneration of 3D maps of fields
- Basic measurement with the help of drones or agricultural vehicles
- Collection of 3D point clouds and textures
- Filtering and image stiching
- SLAM approach for preceise map building
- 3D path planning
- Mapping of terrain

PoBo – Autonomous Ponton Boot



- Sensor system
- Simulation flood areas
- Tele-operated control
- Navigation

About Autonomous

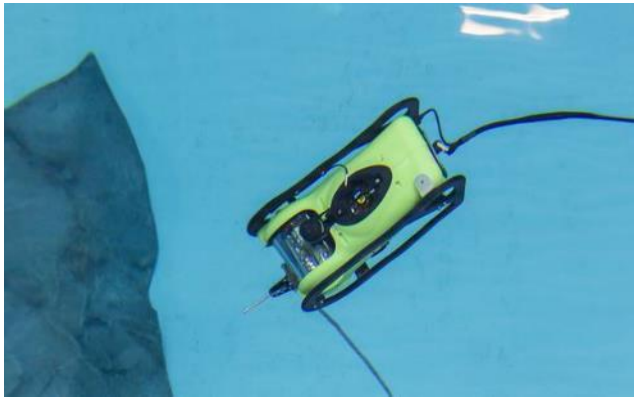
Mobile Robots

Definitions

- Autonomous mobile robot (AMR)
  - Robot able to navigate through environment autonomously while performing goal-oriented tasks
- Autonomy
  - System able to make decisions about approach to fulfill task self-dependently (semi or fully autonomous)
- Autarchy
  - Energy supply carried along on the robot

Examples of AMR Systems

HRP-4c,
AIST, Japan



Underwater-Robot
DFKI Bremen

GRASP Lab, University
of Pennsylvania

Google's self driving car

Climber Univ. Osnabrück

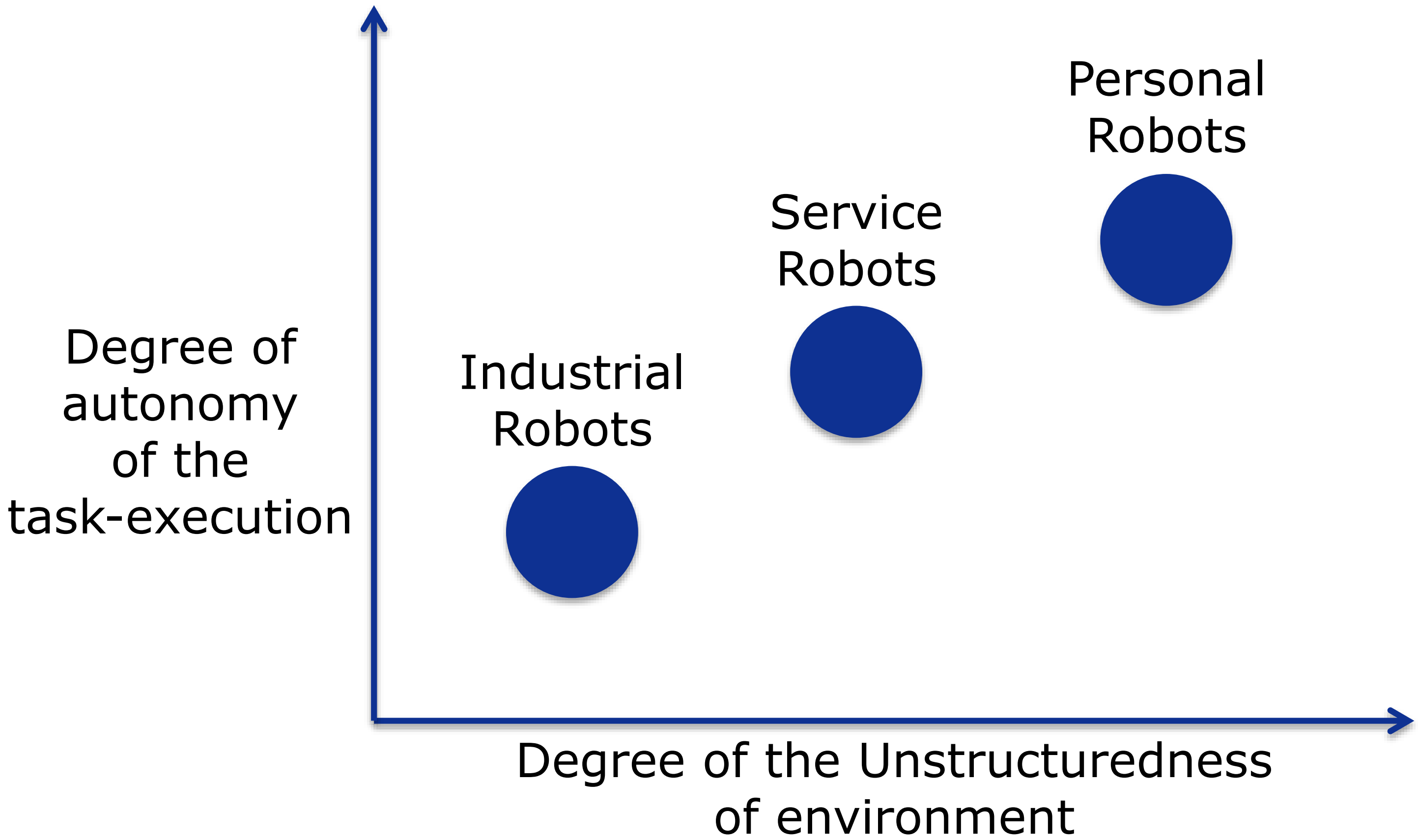
Goals in AMR Research

- Autonomous navigation
- Mapping and localization in unknown terrain
- Perception of the environment
- Computer- and software architecture able to deal with hard real-time requirements
- Safety aspects (system may not be destroyed, humans may not be hurt)
- Cost-efficient, robust systems
- Development of dedicated AMR for special applications

Areas of Research in AMRs

- Modeling of AMRs: How can an AMR be modeled?
- Obstacle recognition: Where can collisions occur?
- Localization: Where am I?
- Modeling of the operational environment: How do I see my surroundings?
- Navigation: How to smartly navigate in an environment?
- Object recognition: Where is the target object?
- Control Architectures: How can control software be structured?
- Software Frameworks: How can the software developer be supported?

Classification with respect to Applications



Classification AMR-systems with respect to field of application

Application of AMRs

- Cleaning robot (Floor, Windows, Tanks etc.)
- Sewer inspection robot (cleaning, inspection, maintenance)
- Climbing robot (inspection, cleaning)
- Underwater robots (inspection, maintenance)
- Flying robots (mapping, inspection, transportation)
- Autonomous wheelchair
- Transportation robot in an industrial environment
- Hotel robot
- Museum guide
- Rescue robots
- Robot for planetary exploration missions
- Robots for forestry and agriculture

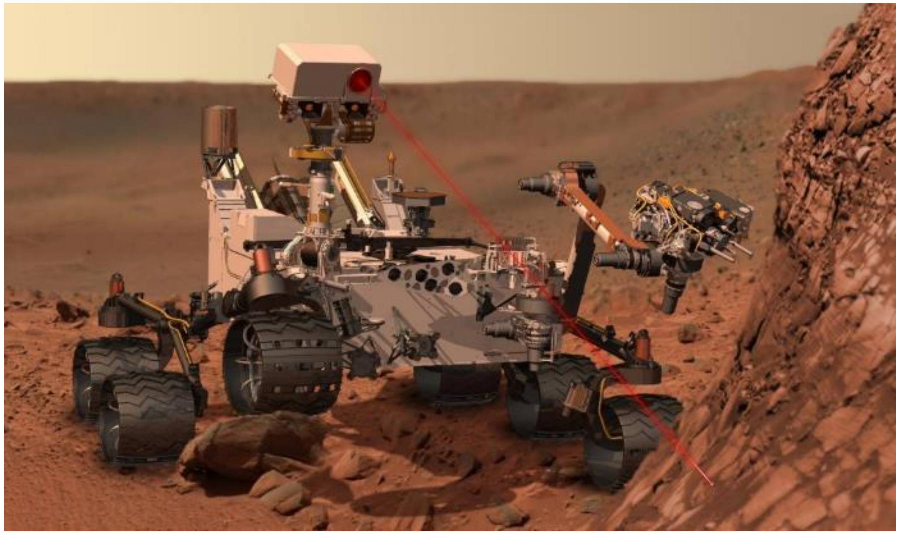
Application Example: Fire Fighting

- Developed by
  Tokio Fire Brigade
- Teleoperated by cable
  or wireless
- Suited for large scale fires
- Width $2\ \mathrm{m}$
- Length $4\ \mathrm{m}$
- TV cameras

Rainbow 5

Application Example: Exploration

- Developed by NASA -JPL in 2011
- Exploration of Mars surface
- Mass 900 kg
- Cameras, X-ray spectrometer
- Laser Scanner, Accelerometers



Mars rover Curiosity, JPL

Application Example: Construction

- Developed by
  Fujita Corp., Japan
- Teleoperated (2 km away)
- GPS
- Load measuring system
- Up to $2.75\mathrm{m}^3$ per day can be excavated

Unmanned construction machine

Application Example: Underwater

- $6.1\ \text{m} \times 2.4\ \text{m} \times 2.4\ \text{m}$ $(L \times W \times H)$
- 2.4m
- Weight: $4785\ \text{kg}$
- Range of operation: $10\ \text{km}$
- Max. operating depth: $3000\ \text{m}$
- Payload: $2000\ \text{kg}$

Swimmer

Lecture Overview

Contents of the Lecture

- Introduction
  - Definition of AMRs
  - Applications
  - Historical overview
- AMR Systems
  - Computer Architecture and Electronics
  - Close Loop Control
  - User interface / Middleware

Contents of the Lecture

- Sensors Systems
  - Tactile Sensors
  - Pose Measurement
  - Inertial Sensors
  - Distance Measuring Sensors
  - Vision Sensors
- Modeling
  - Modeling of Robots and Space
  - Vehicle Kinematics
  - Rigid Vehicle Dynamics
  - Trajectory Control

Contents of the Lecture

- Feature Extraction and Object Recognition
  - Feature Extraction
  - Separation of Connected Objects
  - Identification of Objects
- Localization
  - Local Positioning (Odometry, INS, Optical Flow)
  - Landmarks
  - Global Positioning
  - Kalman Filter

Contents of the Lecture

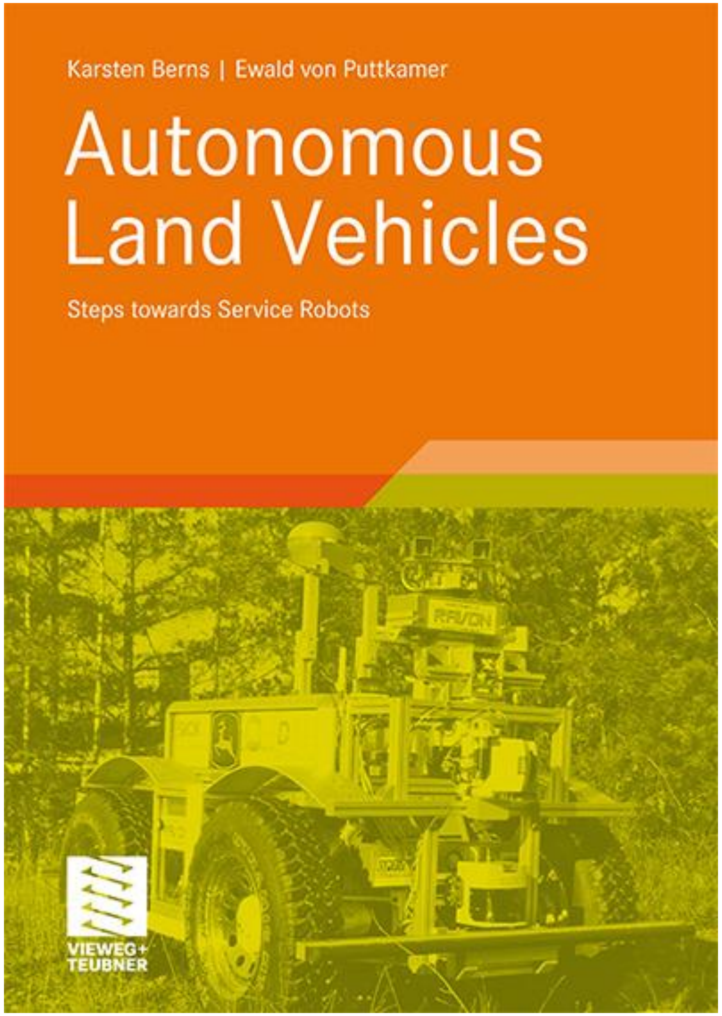
- Mapping
  - Fundamentals of map generation
  - Metrical maps
  - Grid maps
  - Sector maps
  - Topological maps
  - Hybrid maps
- Simultaneous Localization and Mapping (SLAM)

Contents of the Lecture

- Navigation
  - Fundamentals
  - Global path planning
  - Local path planning
- Control Architectures
  - Task-oriented Control Architectures
  - Behavior-based Control Architectures
- Applications

Literature

- Autonomous Land Vehicles
- Berns, Karsten/
  Puttkamer, Ewald von
- Steps towards Service Robots
- 2009. vi, 283 pp. With 246 Fig. and 4 Tab. and 16 algorithms Softc.
- ISBN: 978-3-8348-0421-1
- Discover the potential of mobile service robots through the methodology and practices of basic research

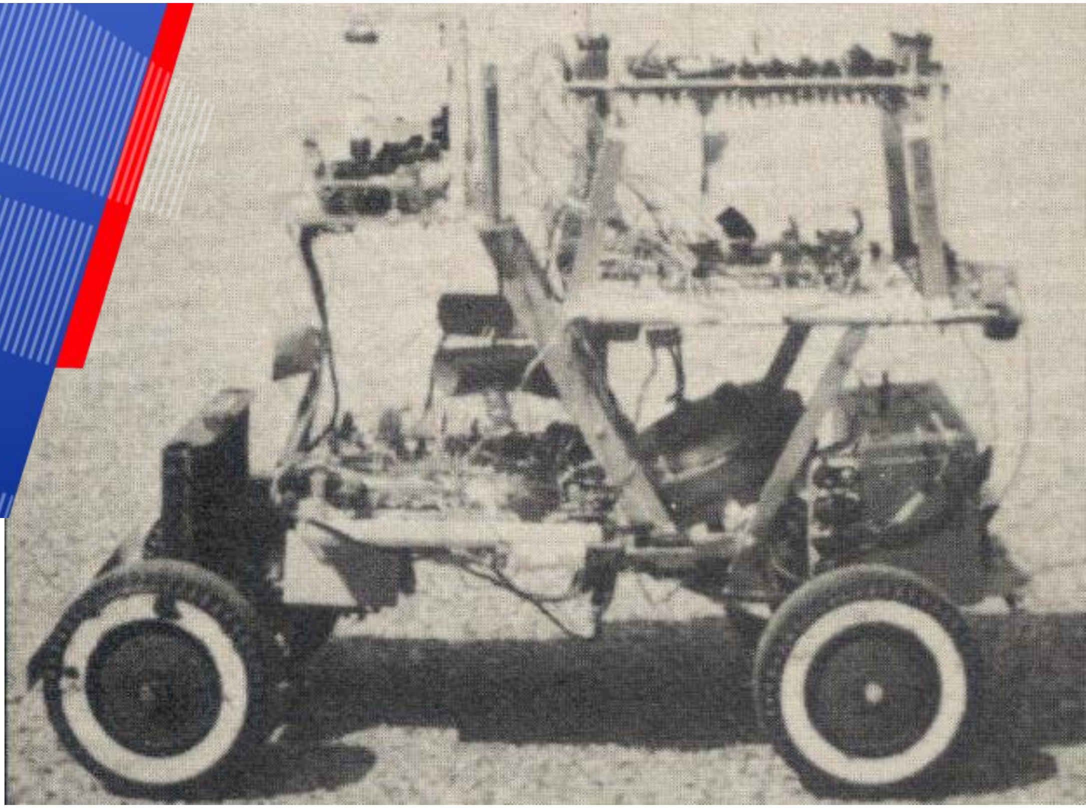


Literature

- Mechanics of Terrestrial Locomotion [Zimmermann09]
- Computational Principles of Mobile Robotics [Dudek10]
- Geometric fundamentals of robotics [Selig05]
- Autonomous Land Vehicles [Berns09a]
- Theory of Applied Robotics [Jazar07]
- Robot Evolution [Rosheim94]
- Service Roboter Visionen [Schraft04a]
- Introduction to Robotics [Craig05]

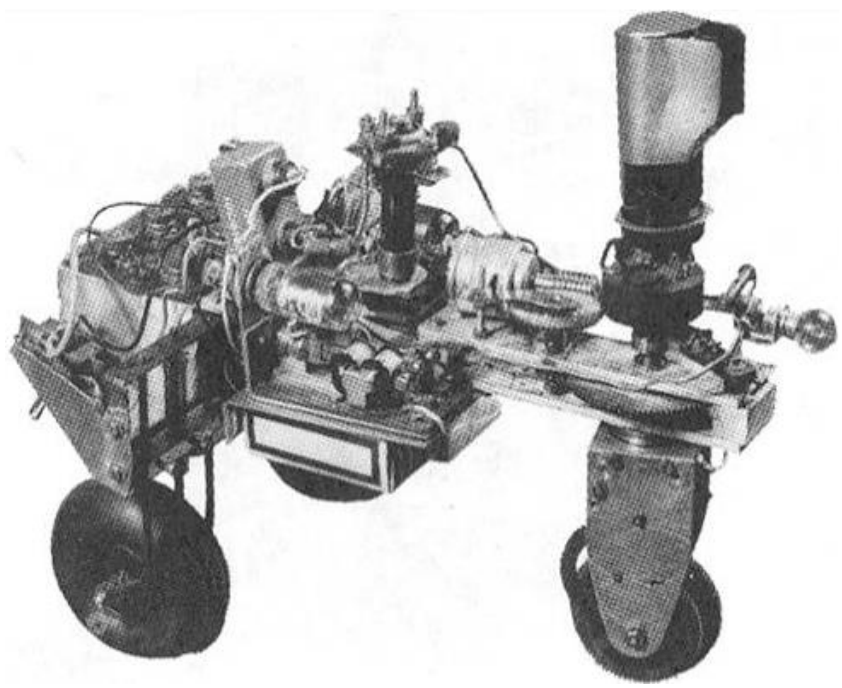
Historical Overview

(see also http://cyberneticzoo.com/mobile-robot-timeline/)



ELSIE (Electro-light-sensitive Internal External)

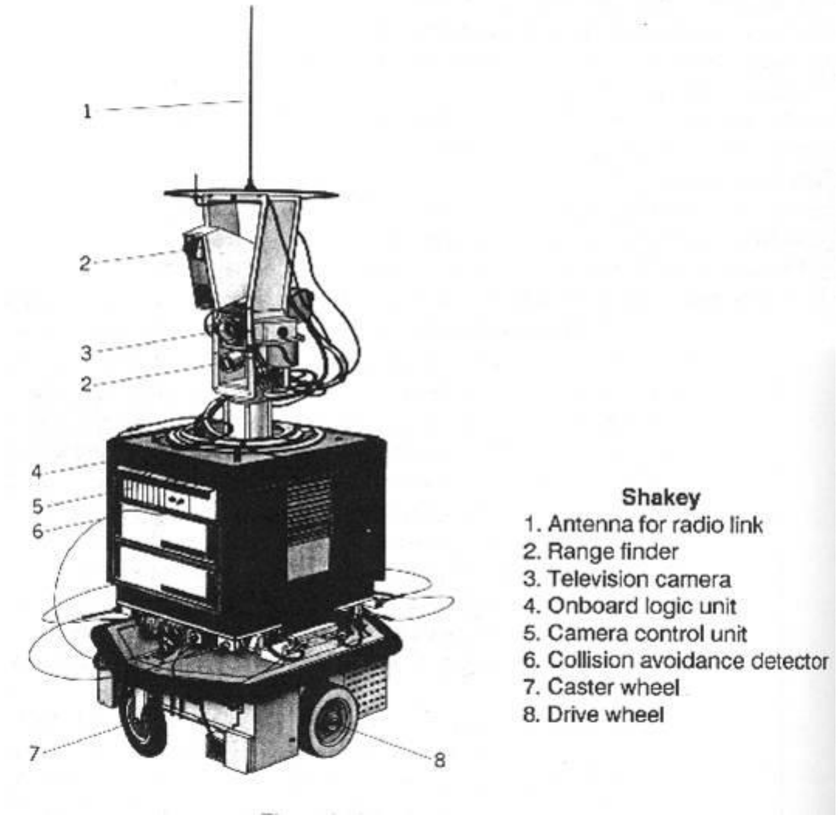
- Developed in England by W.G. Walter in the 1950s
- Designed to follow light sources
- Basic collision avoidance available



ELSIE [Meystel91]

Shakey – Stanford Research Institute (SRI)

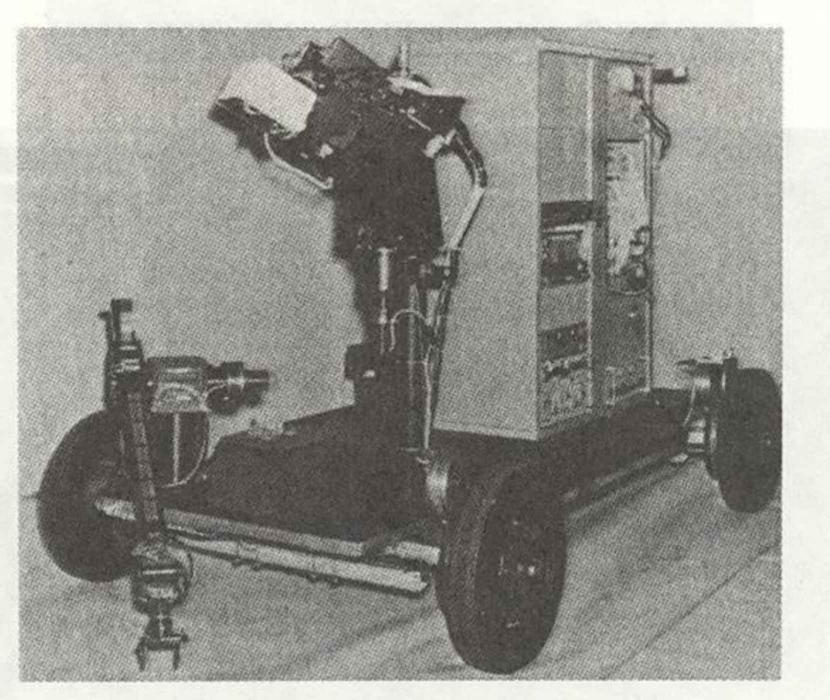
- Lisp, Fortran
- World representation
- Grid model, properties
- STRIPS - General Problem Solver
- Position tracking by Odometry (dead reckoning)
- Simple control set (move, turn)
- Hierarchical control architecture



Shakey [Meystel91]

JPL-AMR (1970–1975)

- Early 1970s by NASA and
- JPL (Jet Propulsion Laboratory)
- Designed for planetary exploration, production automation, transport
- Semi-autonomous
- Extensive simulation system
- Laser ranging, stereo cameras, approaching sensors, tactile sensors



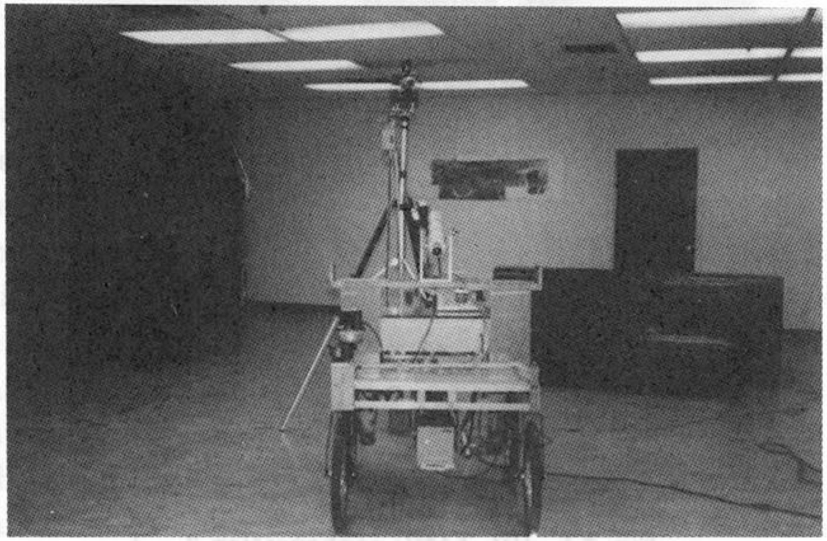
JPL-AMR [Meystel91]

JPL-AMR (1970–1975)

- Navigation based on gyro-compass and encoders (dead reckoning)
- On-board micro-controller with 32K Memory, off-board PDP 10
- Remote System required for world model setup, planning and selection of next control action
- Trajectory calculation based on aim
- World is divided in sectors (no-go, unknown, go)
- List of polygons describes regions
- Simple analysis of world models possible

Stanford Cart (1973–1981)

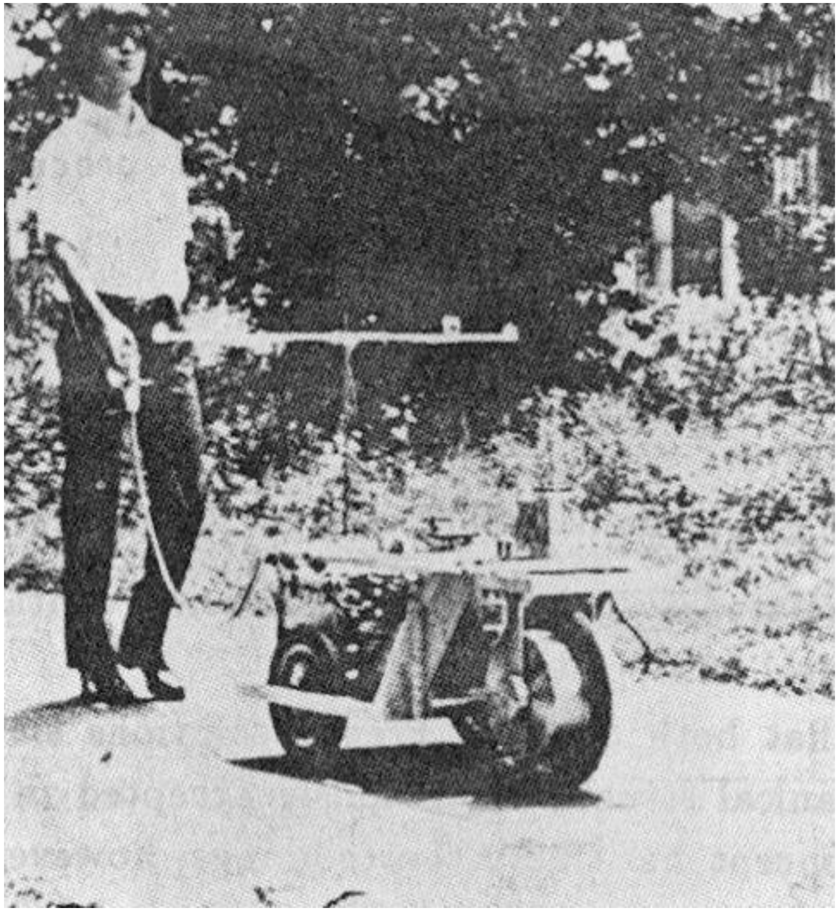
- Hans Moravec AI lab, Stanford
- Semi-autonomous
- TV camera stereo (heavy) image precessing to calculate distances
- Really slow (1m per 10 min)
- Objects are described in polar coordinates
- Tree-search to determine opt. path (concerning distance and energy)



Stanford Cart [Meystel91]

MELDOG (MEL 1979–1983)

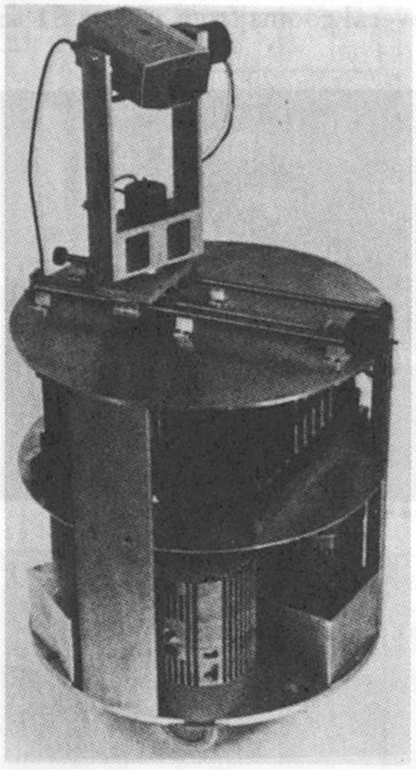
- Mechanical Engineering Lab (MIT)
- Seeing-eye dog
- Ultrasonic sensors for collision avoidance
- Control commands: left, right, straight, stop (via wired link)
- Speed adjustment via ultrasonic sensors (1m distance is maintained)



MELDOG [Meystel91]

CMU Mobile Robot (1981–1984)

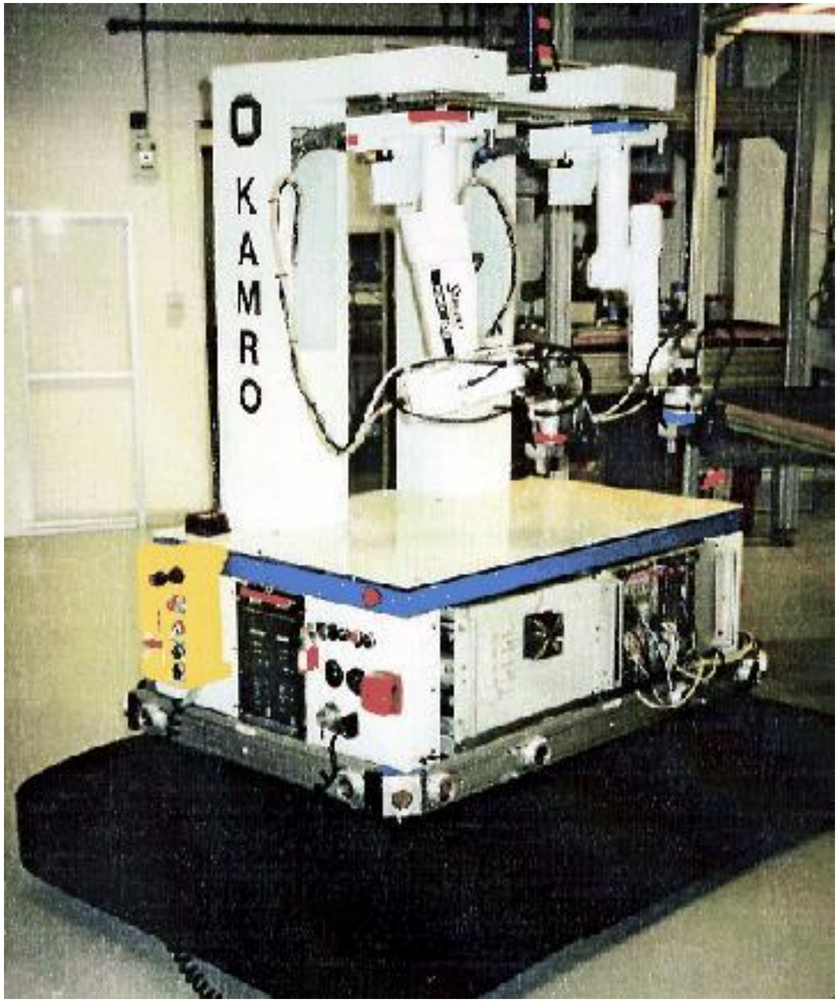
- Enhanced version of Stanford Cart
- Cylindrical shape
  - Height 1 m
  - Diameter 30 cm
- Drive with 3 DOF
- 12 on-board processors
- Hierarchical control with 3 levels (planner, initiator, sensor processing, motor control)
- Communication based on blackboards



CMU Mobile Robot [Meystel91]

KAMRO (1985–1995)

- **K**arlsruher **A**utonomer **M**obiler **Ro**boter
- U. Rembold, IPR Karlsruhe
- Universal robot for production automation
- Two cameras in the gripper’s TCP
- On-board computer
- Extensive simulation system and planning tool
- Provided basis for whole series of AMRs



KAMRO – IPR Karlruhe

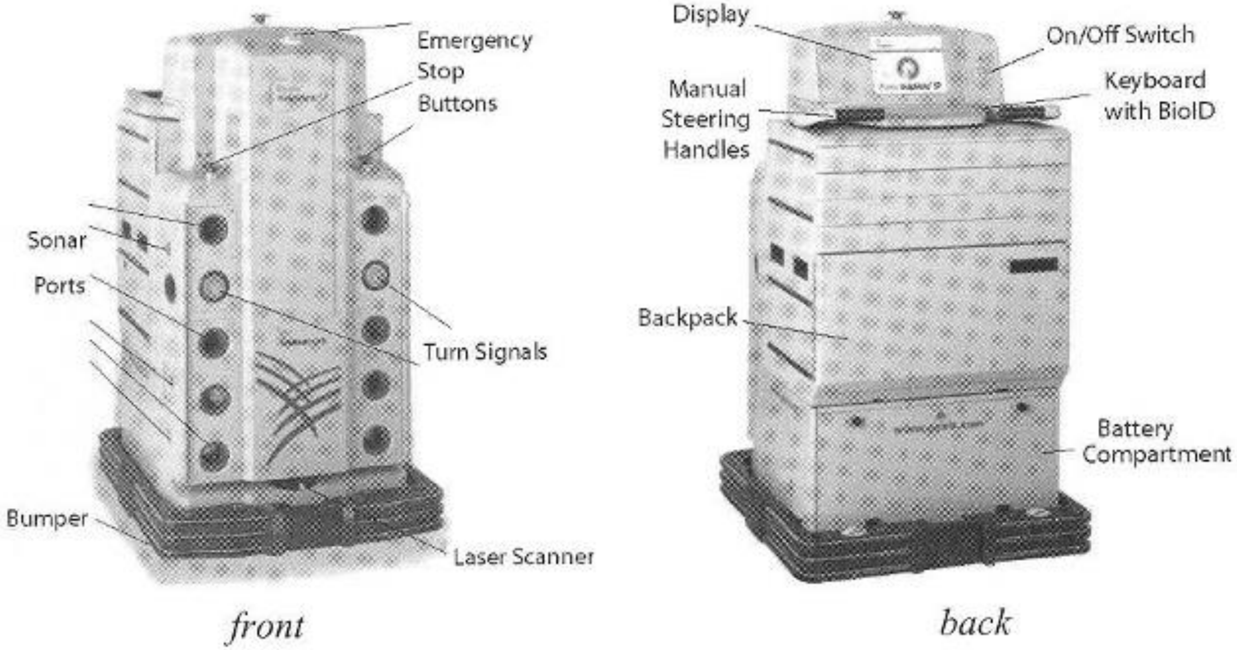
Sojourner – JPL (1994–1997)

- First robot on mars
- Teleoperated from earth
- Obstacle detection and avoidance
- Gripper to collect samples

Stanford Cart [Meystel91]

HELPMATE (1995–2000)

- Designed for use in hospitals
- Autonomous navigation in the corridors
- Navigation based on lights at the ceiling



HELPMATE

Coming Next

AMR Systems