Robotics

Erwin M. Bakker| LIACS Media Lab

11-2 2025

Universiteit Leiden

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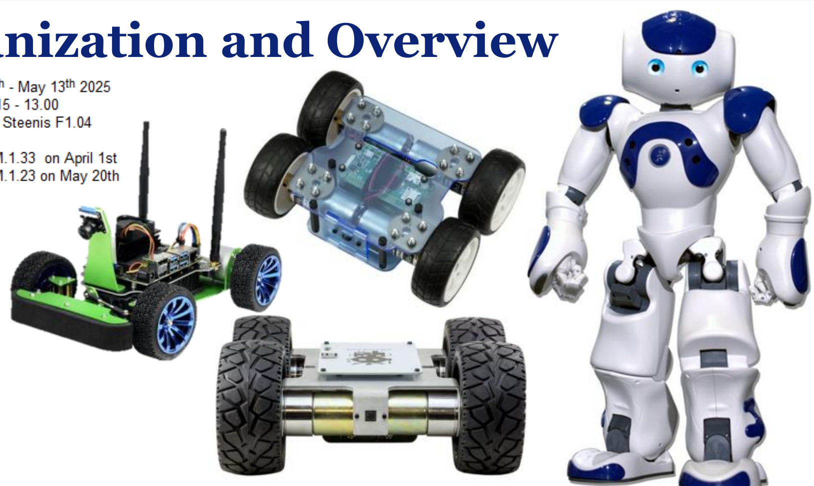
Organization and Overview

Lecturer:
Dr Erwin M. Bakker (erwin@liacs.nl)
Room LIACS Media Lab (LML)
Please email for a meeting.

Teaching assistants:
TBA

Period: February 11th - May 13th 2025
Time: Tuesday 11.15 - 13.00
Place (Rooms): Van Steenis F1.04
Exceptions:
Gorlaeus Building BM.1.33 on April 1st
Gorlaeus Building BM.1.23 on May 20th



Schedule (tentative, visit regularly):

Date	Subject
11-2	Introduction and Overview
18-2	Locomotion and Inverse Kinematics
25-2	Robotics Sensors and Image Processing
4-3	SLAM + Workshop@Home
11-3	Robotics Vision + Introduction Mobile Robot Challenge
18-3	Project Proposals I (by students)
25-3	Project Proposals II (by students)
1-4	Robotics Reinforcement Learning + RL Workshop@Home
8-4	Project Progress Reports I
15-4	Project Progress Reports II
22-4	Mobile Robot Challenge I
29-4	Mobile Robot Challenge II
6-5	TBA
13-5	Project Demos I
20-5	Project Demos II
27-5	Project Deliverables

Website: http://liacs.leidenuniv.nl/~bakkerem2/robotics/

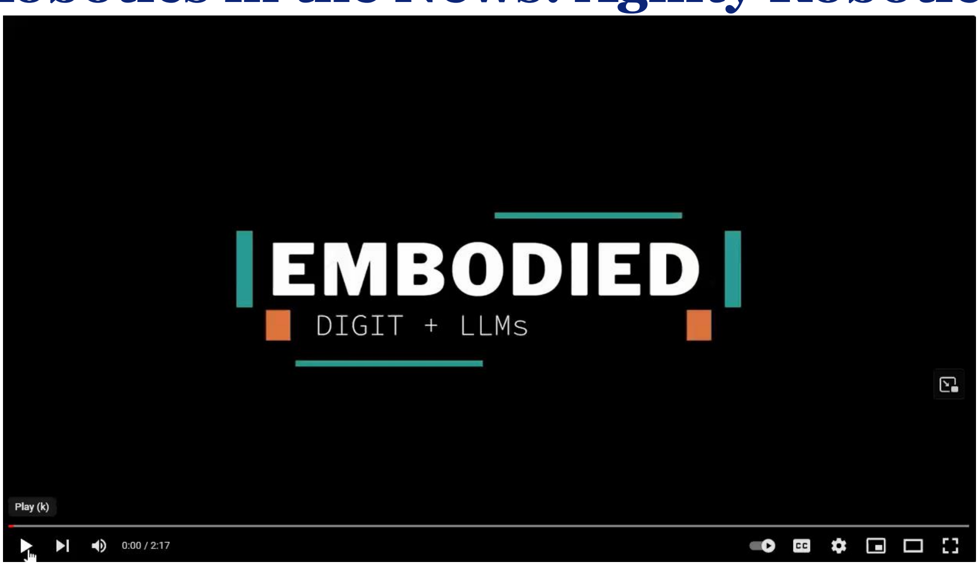
Grading (6 ECTS):

- Presentations and Robotics Project (60% of grade).
- Class discussions, attendance, 2 assignments (pass/no pass)
- 2 Workshops (0-10) (20% of the grade).
- Mobile Robot Challenge (0-10) (20% of the grade)
- ***It is necessary to be at every class and to complete every workshop and assignment.***

Robotics in the News: Agility Robotics

Cassie sets a Guinness World Record. (**No cameras or external sensors**.)
Sept. 28 2022, https://agilityrobotics.com/news/2022/cassie-sets-a-guinness-world-record
https://agilityrobotics.com/news

Robotics in the News: Agility Robotics



Digit + Large Language Model – Embodied Artificial Intelligence
https://www.youtube.com/watch?v=CnkMoAecxYA

Robotics in the News: Unitree

Unitree G1

Unitree B2-W

https://www.unitree.com/

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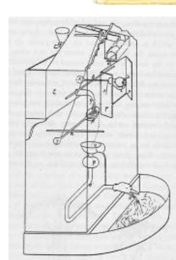
Philo of Byzantium (~280 – 220 BC) Al-Jazari (1136 – 1206)

- Mechanisms and methods for automation
- Water-raising machines
- Clocks
- Automata
  - Drink-serving waitress
  - Hand-washing automaton with flush mechanism
  - Peacock fountain with automated servants
  - Musical robot band





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Leonardo da Vinci
(1452 – 1519)

- Robotic Carts
- Studies on locomotion
- Robotic Soldier
- Robotic Lion

Pictures from:
http://www.leonardo3.net
http://brunelleschi.imss.fi.it

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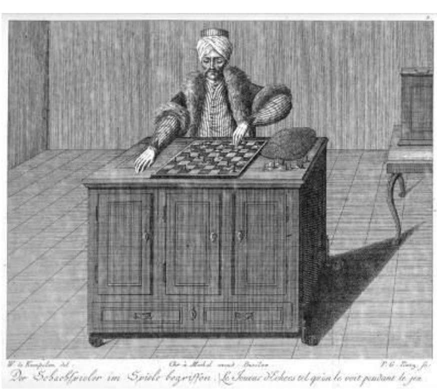
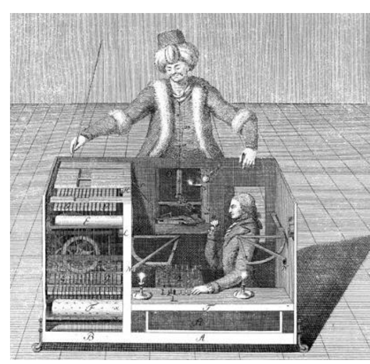
The Turk
Constructed and unveiled in 1770
by Wolfgang von Kempelen (1734–1804)





Pictures from:
http://en.wikipedia.org/wiki/The_Turk

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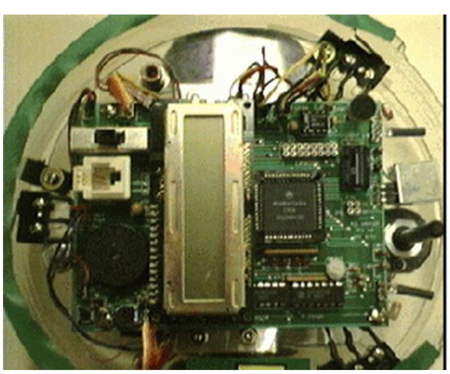
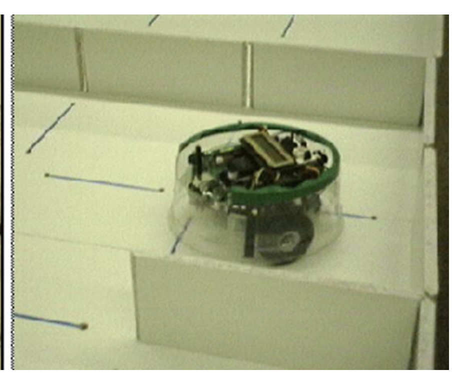
LOCOMOTION & INVERSE KINEMATICS

EARLY ROBOTS

South Pointing Chariot
by Ma Jun (circa 200–265)
was the first reliably documented version.

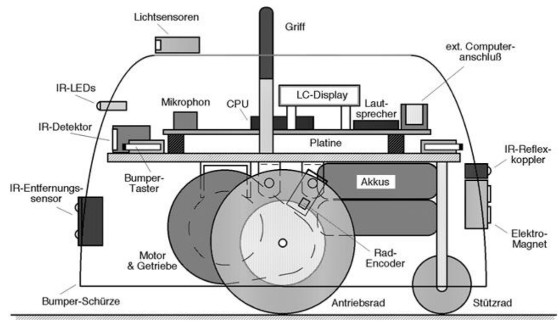
Autonomous Robots for Artificial Life (MIT, T. Braunl, Stuttgart University) ‘Rug Warrior’



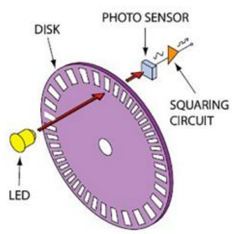


Autonomous Robots for Artificial Life

- Motorola MC68HC11 microcontroller
- Sensors
- Bumper
- Photoresistors (2)
- Infrared Obstacle Detectors w. 2 infrared LED’s
- Microphone
- Two Shaft-Encoders



Tekening van: http://ag-vp-www.informatik.uni-kl.de



https://www.analogictips.com/rotary-encoders-part-1-optical-encoders/

Autonomous Robots for Artificial Life

Software (PC, Macintosh, UNIX)

Interactive C Compiler and Libraries

- **motor(0,speed), motor(1,speed)**
- **music: tone(), analog(micro)**
- **get_left_clicks(), get_right_clicks()**
- **analog(photo_left), analog(photo_right)**
- **left_ir, right_ir**
- **left_, right_, back_bumper**

- Note: Microsoft Robotics Studio 4 (2012†): development environment for different robotic platforms (Lego Mindstorm, Fischertechnik, Lynxmotion, Parallax Boe-Bot, Pioneer P3 DX, iRobot Roomba), Kinect (2014†);
- ROS (Robot Operating System) 50+ robots, etc., written in C++. Python, or LISP www.ros.org

Autonomous Robots for Artificial Life

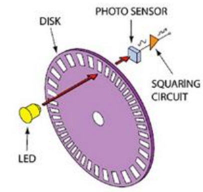
Straight ahead

Straight Ahead

```
void main()
{       int pid_clicks, pid_fahre;
        test_number =! test_number;
        if (test_number)
        {       sleep(1.0); alert_tune();
                pid_clicks=start_process(clicks());
                pid_fahre=start_process(fahre_geradeaus());
                geschwindigkeit = anfangsgeschwindigkeit;
                while (rclicks < 500) {}
                ... code to stop ...
                kill_process(pid_fahre);
                kill_process(pid_clicks);
                printf("max. Abw.: %d",dmax);
 } else  printf("----HALT----\n");   }
```

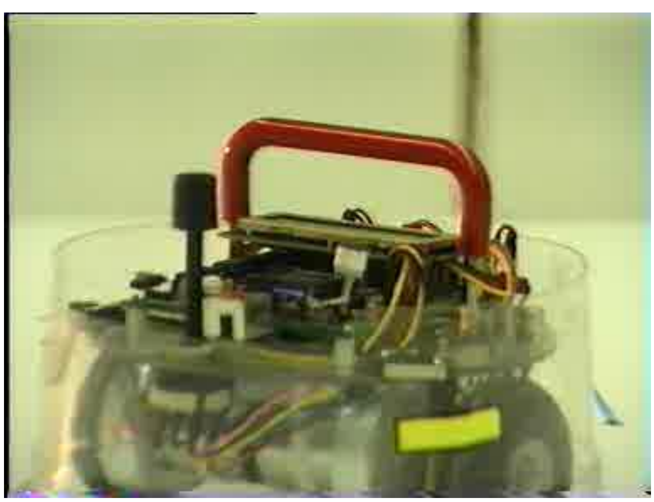
Straight Ahead

```
void clicks()          // Continuously read out odometer clicks
{ init_velocity();
  while(TRUE)
  {
     if (rechts>0.0)
          rclicks+=get_right_clicks();
     else
          rclicks-=get_right_clicks();
     if (links>0.0)
          lclicks+=get_left_clicks();
     else
          lclicks-=get_left_clicks();
          printf("l: %d  r: %d\n",lclicks,rclicks);
  }
}
```




```
void fahre_geradeaus()  // Adapt left and right speed
{  int d;               // to get same number of
   while(TRUE)          // clicks for each wheel
  {  d=rclicks-lclicks;     // Difference
     if (abs(d)>abs(dmax))
           dmax=d;
     links = geschwindigkeit + DELTA*(float) d;
     rechts =geschwindigkeit - DELTA*(float) d;
     drive( 0, links);
     drive( 1, rechts);
     sleep(0.1);
  }
}
```


Finding the Light



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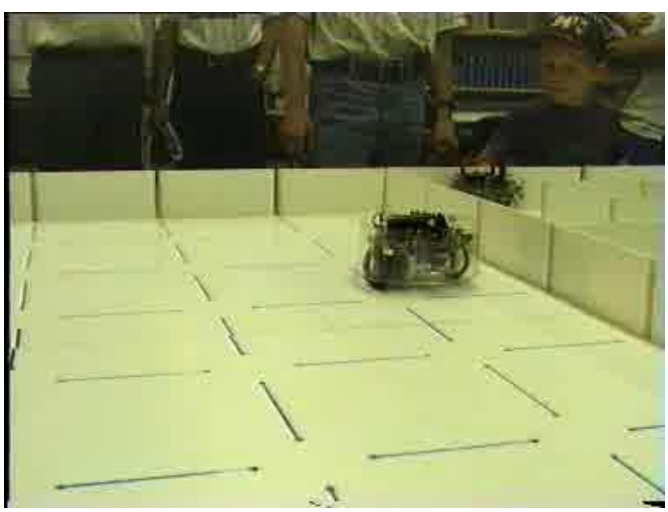
Finding the Light

```
if ( analog(photo_right) < analog(photo_left) )
{
        motor(0, speed);     /* rechtsdrehen */
        motor(1, -speed);
} else
{
        motor(0, -speed);     /* linksdrehen */
        motor(1, speed);
}
clicks = 0;
while( (  (clicks += (get_left_clicks() + get_right_clicks()) / 2)) < 37 && !all_bumper )
        /* eine Umdregung machen solange kein Bumper betaetigt */
{
        printf("FIND MAX  %d   %d\n", clicks, light);
        light = get_light();              /* Lichtwert holen */
        if ( light > max_light )           /* maximum merken */
        {         max_light = light;            }
        sleep(0.2);
 }
```


Finding the Light 2



Mechanical Tortoise (1951)

British Pathé, 1951.
YouTube: https://www.youtube.com/watch?v=wQE82derooc&t=14s

Finding the Light 2

- Drive along the wall until the light source is found.
- Drive with a left curve until the IR-sensors detect an obstacle, then make a correction to the right until no sensor input is read.
- If an obstacle is found that cannot be resolved this way, then drive 1.5 seconds backwards and start over again.

TurtleBot 4

Vacuum Cleaner & Lawn Mower

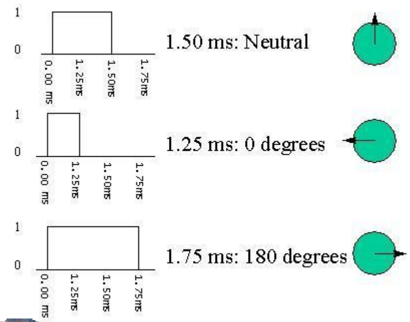
TurtleBot4 with ROS

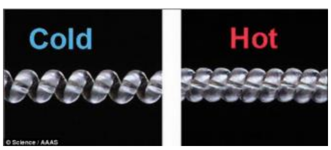
www.ros.org

TurtleBot 4		TurtleBot 4 Lite
341 x 339 x 351 mm	**Dimensions**	341 x 339 x 192 mm
3.9 kg	**Weight**	3.3 kg
15 kg & 0.31 m/s	**Max. Payload & Speed**	15 kg & 0.31 m/s
2.5 - 4.0 hrs (load dependent)	**Operating Time**	2.5 - 4.0 hrs (load dependent)
OAK-D-PRO	**Camera**	OAK-D-LITE
RPLIDAR-A1	**LiDAR**	RPLIDAR-A1
Yes	**Accessible Power & USB Ports**	No
Yes	**OLED Display**	No
Yes	**Mounting Plate**	No
ROS 2	**Software**	ROS 2
Raspberry Pi 4B (4 GB)	**Computer**	Raspberry Pi 4B (4 GB)

Robotics Actuators

- **Electro motors**
- **Servo's**
- **Stepper Motors**
- **Brushless motors**
- Solenoids
- Hydraulic, pneumatic actuator's
- Magnetic actuators
- Artificial Muscles
- Etc.





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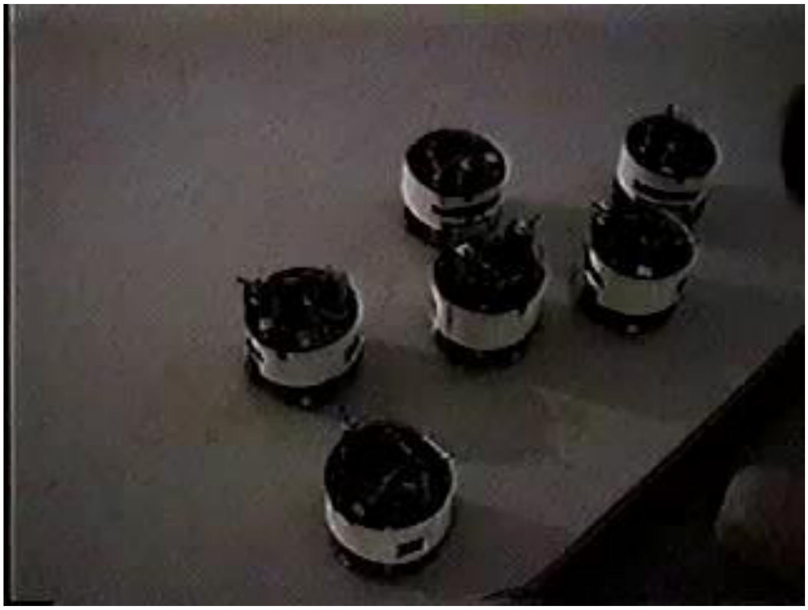

Caltech’s Leonardo

Caltech’s Leonardo, Oct. 2021
https://www.youtube.com/watch?v=fh1AsW22Iks

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Humanoid Research Platforms


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LIACS Humanoid Research Platforms

LML

LIACS
MEDIA
LAB

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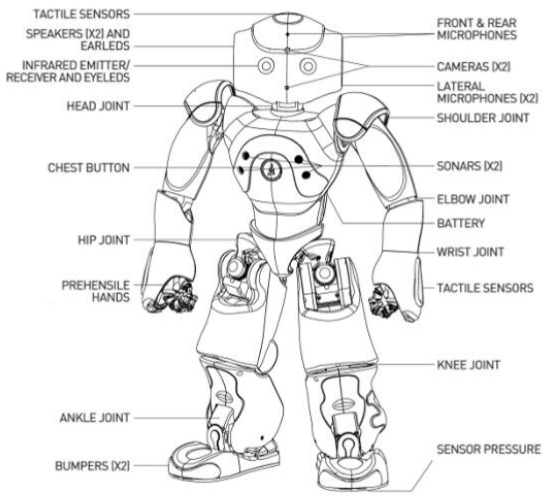
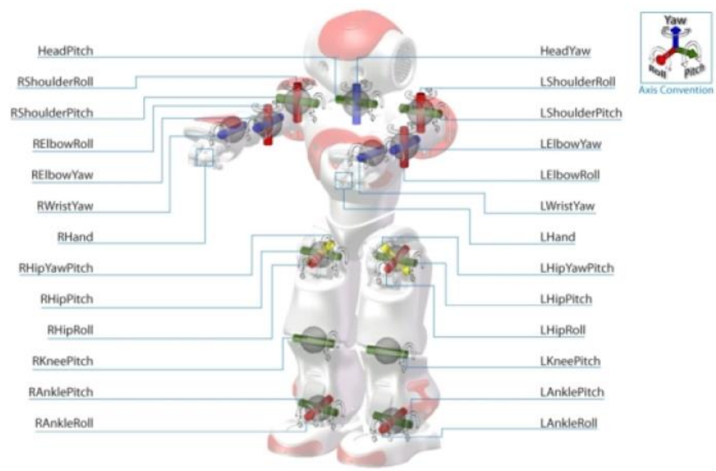
NAO





http://doc.aldebaran.com/2-1/family/nao_dcm/actuator_sensor_names.html

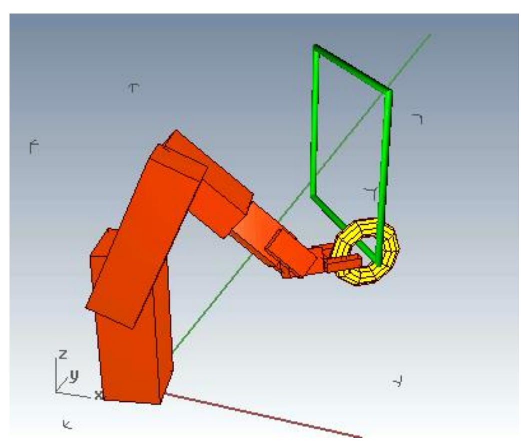
How to move to a goal?

Problem: How to move to a goal?

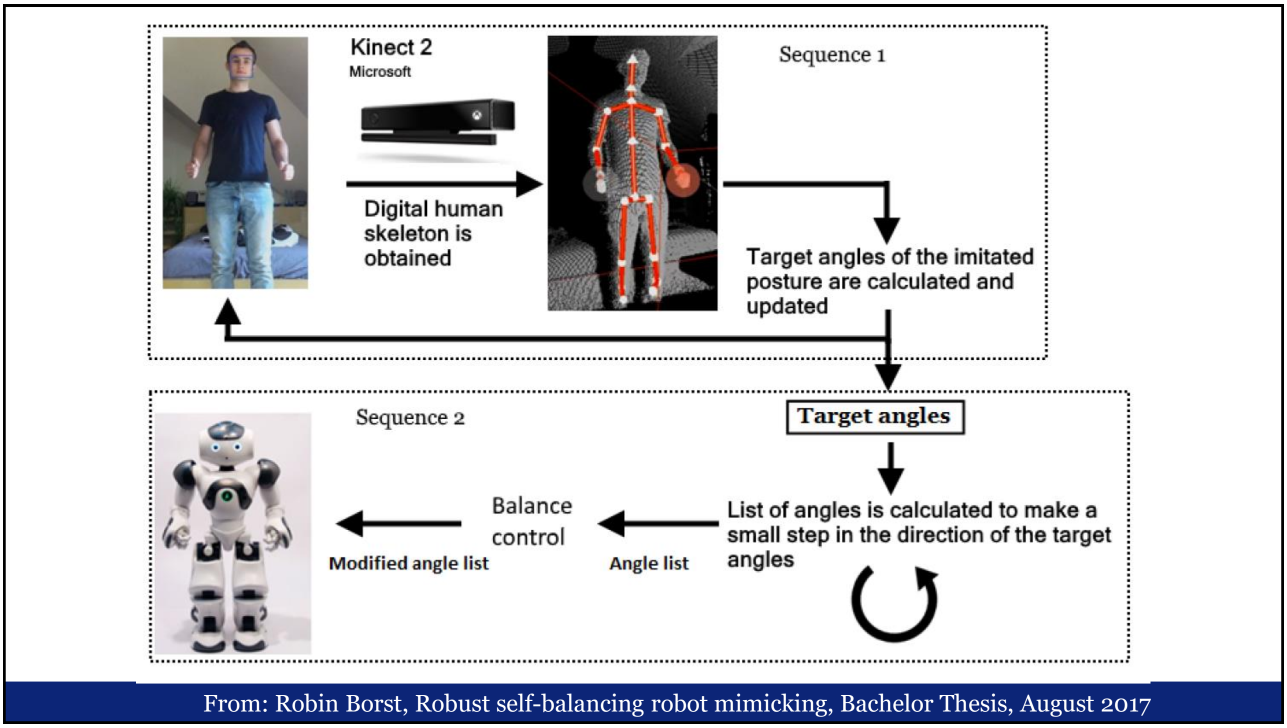
- Grasp, Walk, Stand, Dance, Follow, etc.

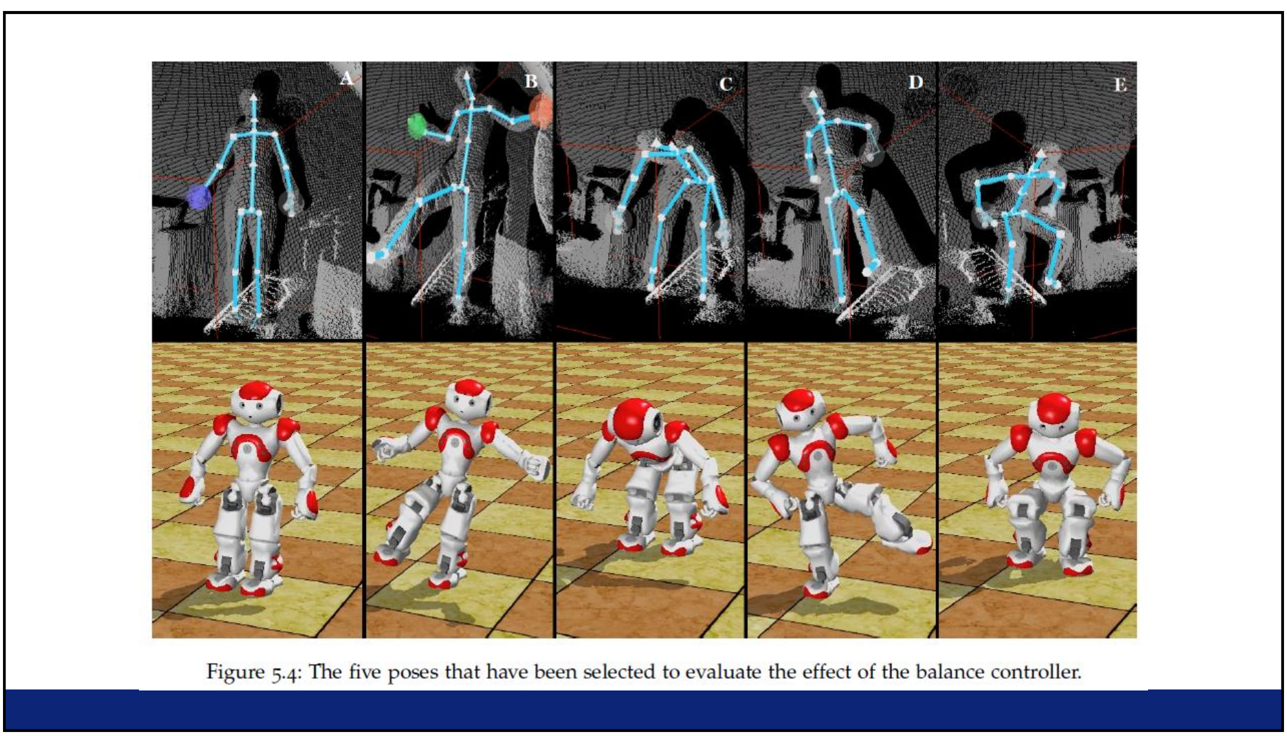
Solution:

- Program step by step.
- Inverse kinematics: take end-points and move them to designated points.
- Trace movements by specialist, human, etc.
- **Learn the right movements:** Reinforcement Learning, give a reward when the movement resembles the designated movement.



https://pybullet.org/wordpress/


Kinect 2
Microsoft
Sequence 1
Digital human skeleton is obtained
Target angles of the imitated posture are calculated and updated
Target angles
Sequence 2
Balance control
List of angles is calculated to make a small step in the direction of the target angles
Modified angle list
Angle list
From: Robin Borst, Robust self-balancing robot mimicking, Bachelor Thesis, August 2017


A
B
C
D
E
Figure 5.4: The five poses that have been selected to evaluate the effect of the balance controller.

OPNNAR


(a) *Start state*

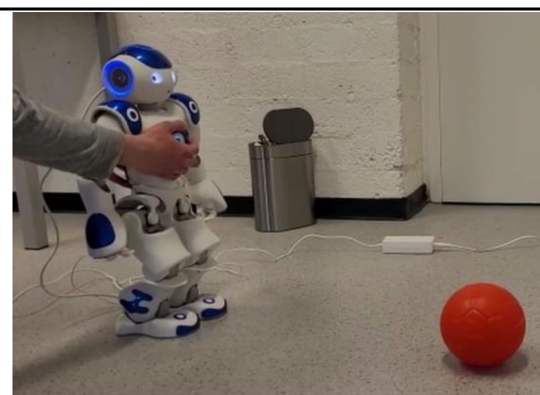

(b) *Raise Arm*


(c) *Swipe*

K. Maas, Full-Body Action Recognition from Monocular RGB-Video:
A multi-stage approach using OpenPose and RNNs, BSc Thesis, 2021.

Nao Kicks a Ball a.k.a. RoNAOldo (2022)

by Hadar Shavit and Evani Lachmansingh



Ball detection:
- OpenCV's HSV detector.

Training NAO to kick the ball:
- PyBullet physics Engine for simulating NAO
- Reinforcement learning algorithm Proximal Policy Optimization (PPO).
- A policy is trained to detect and kick a ball; both in simulation and in real life.

https://www.youtube.com/watch?v=USMyQnJ64D4&list=PL6H6tioh3jl-INGuojoMLhVszvYTFNClN&index=1

Robocup 2022 Humanoid Kid Size: https://www.youtube.com/watch?v=zXyxvgWSAdQ

Robocup 2022 Humanoid Final https://www.youtube.com/watch?v=l-yeuE9hcMY

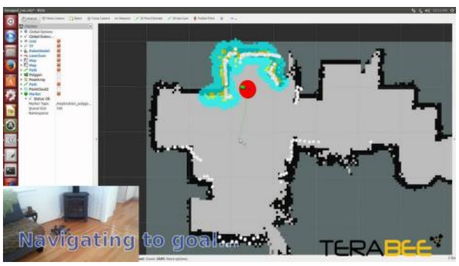
Robocup 2023 Humanoid Final: https://www.youtube.com/watch?v=t7GDILdCRKI

Robocup 2024 Humanoid Final: https://www.youtube.com/watch?v=gtJXGo8WEMY

ROBOTICS SENSORS

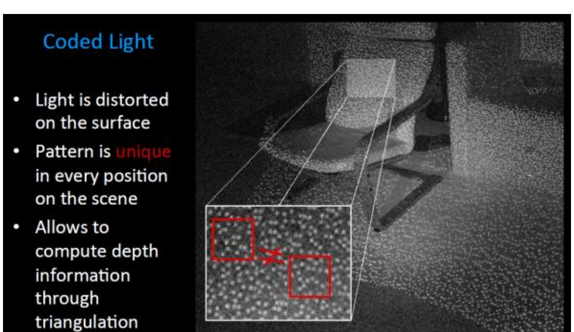
- Bumper switches
- Acceleration, Orientation, Magnetic
- IR/Visible Light
- Pressure, Force
- Ultrasonic, Lidar, Radar
- Camera's, stereo camera's
- Structured Light Camera's

	Ultrasound	Infrared Triangulation	Laser	TeraRanger Time-of-Flight
High reading frequency	✗	✗	✓	✓
Long range	✗	✗	✓	✓
Minimal weight	✓	✓	✗	✓
Small form factor	✓	✓	✗	✓
Eye safety	✓	✓	Class 1 lasers only	✓
Use with multiple sensors	✗	✗	✗	✓

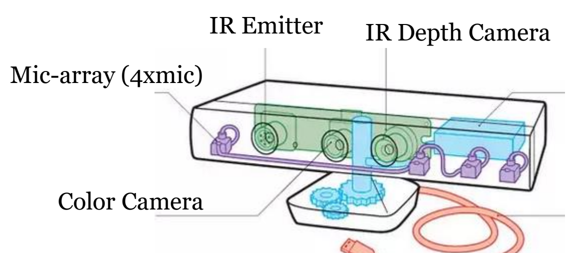


Structured Light

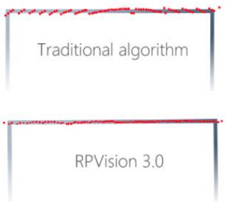
1. Asus X-tion Pro Live
2. Microsoft Kinect v1, v2
3. Intel RealSense F200, R200 (blue), etc.
4. OAK D-Lite, OAK D-Pro

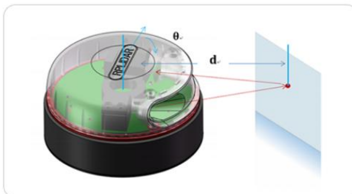


From: Anyline presentation by Peter Sperl

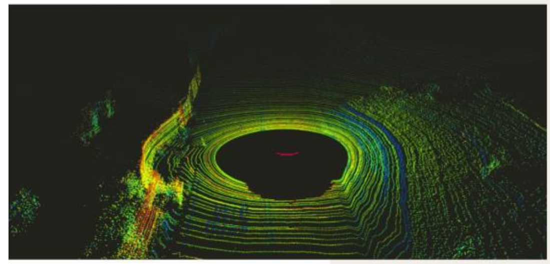


LIDAR Explanation

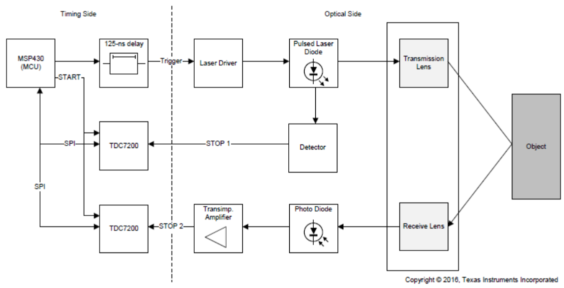




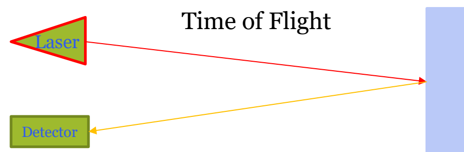
http://www.slamtec.com/en/lidar/A3



https://news.voyage.auto/an-introduction-to-lidar-the-key-self-driving-car-sensor-a7e405590cff



Texas Instruments LIDAR Pulsed Reference Design



- Speed of light ~ 3 x 10^8 m/s
- In 1 picosecond (= 10^{-12} sec) light travels ~ 3 x 10^{-4} m = 0.3 mm
- During 33 picoseconds light travels ~ 1cm

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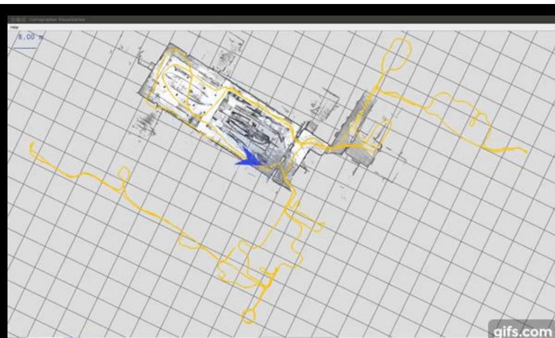
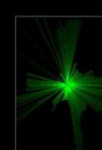
Robotics





- Tiny Object Detection
- Object Tracking
- Human Posture Detection
- SLAM
- Visual Localization
- Autonomous Object Avoidance

Location & Navigation

Problem:

How to locate yourself? How to navigate?

- In unknown or known environment.

With sensors:

- internal, passive, active, gps, beacons, etc.

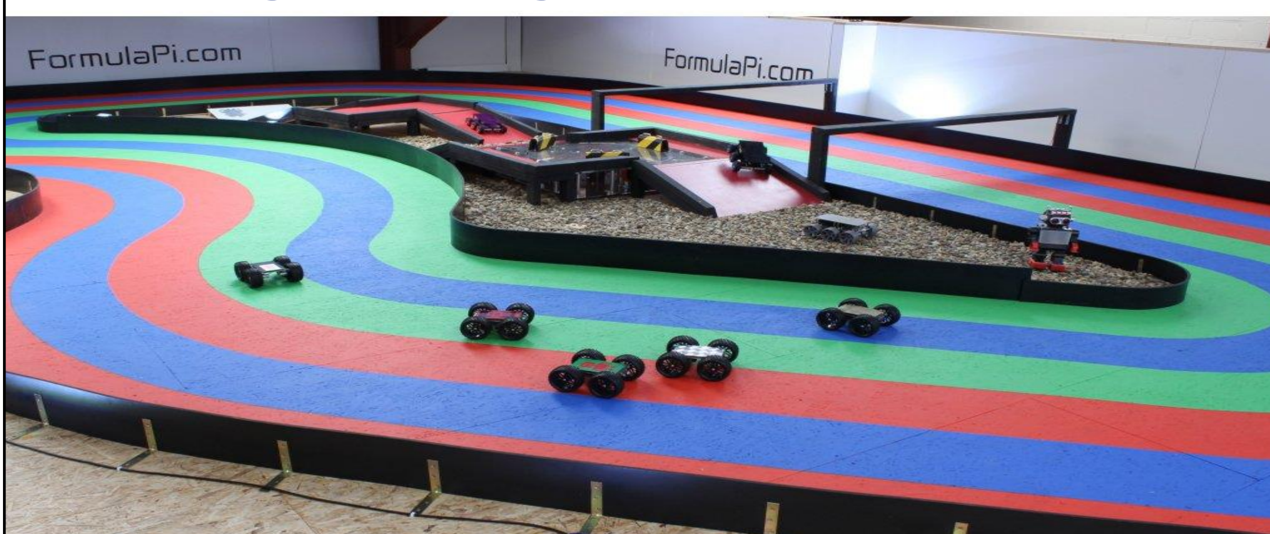
With or without reference points.

Solution:

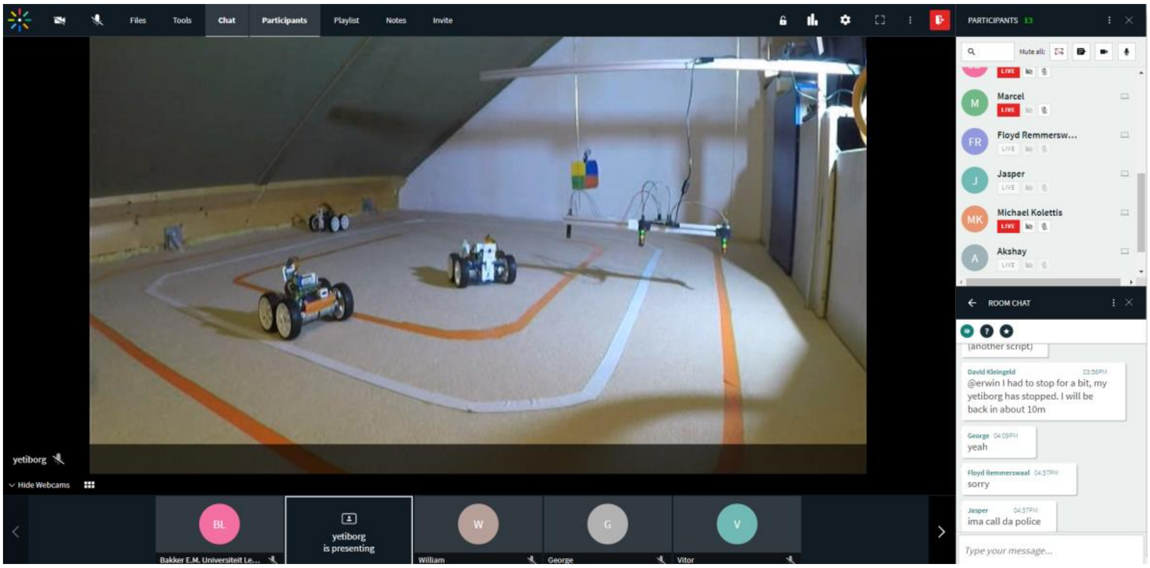
- Collect data to determine starting position, or determine your location.
- Move around while collecting data from your environment.
- Sensor data is noisy => location and map building is a stochastic process.
- SLAM

OpenCV.org

PiBorg: Yetiborg v2



YetiBorg Challenge 2021



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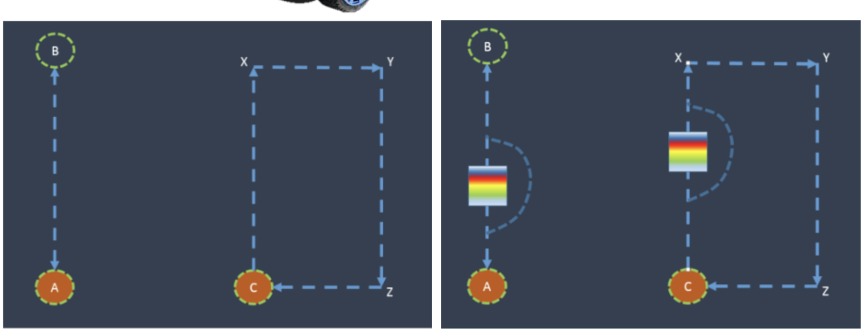
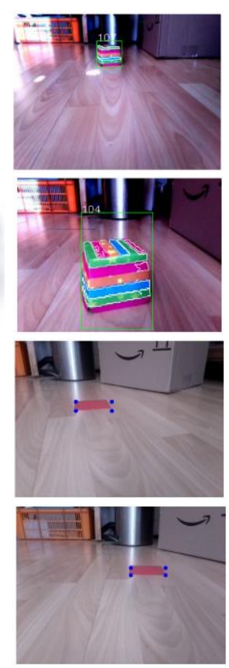
YetiBorg Challenge 2022





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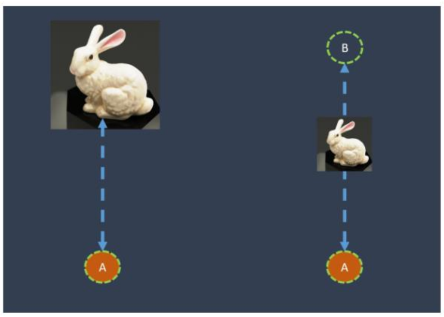
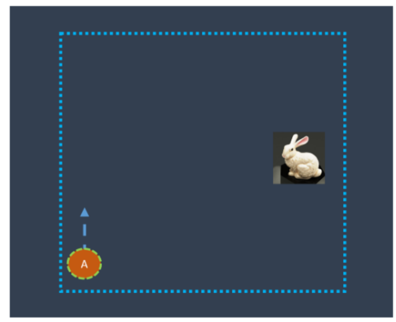
YetiBorg Challenge 2023



Unknown object detection,
distance estimation and avoidance.



Unknown object search.

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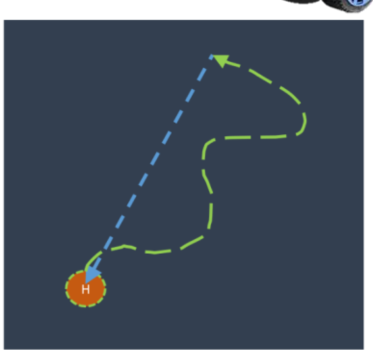
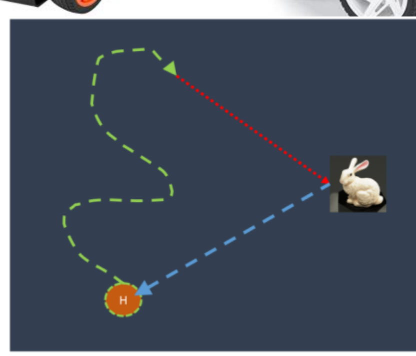
YetiBorg Challenge 2024



Return home after a random manual drive.



Return home after a random drive,
followed by finding and touching the object.

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Hand Gesture Recognition on the JetRacer (2022) by

Bosong Ding, Nan Sai, Yingjie Li, Zilantian Zhu

JetRacer
- Nvidia Jetson Nano
  - CPU Quad-core ARM A57
  - GPU: 128-core Maxwell)
- Yolov3 for detecting objects and hand gestures
- Following objects

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https://www.youtube.com/watch?v=yX_F-Th_Bz4

Autonomous Driving: Real Time Kinematic (RTK) GPS

ZED-F9P Base Station

ZED-F9P Rover

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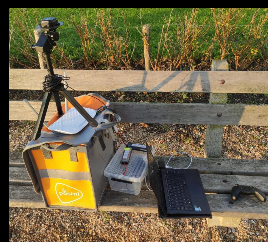
Urban Navigation

- Data Sets: RTK GPS
- Visual Localization
- Autonomous Driving (End-to-End)
- Simulations: Carla




Organization and Overview

Lecturer:
Dr Erwin M. Bakker (erwin@liacs.nl)
Room LIACS Media Lab (LML)
Please email for a meeting.

Teaching assistants:
TBA

Period: February 11th - May 13th 2025
Time: Tuesday 11.15 - 13.00
Place (Rooms): Van Steenis F1.04
Exceptions:
Gorlaeus Building BM.1.33 on April 1st
Gorlaeus Building BM.1.23 on May 20th

Schedule (tentative, visit regularly):

Date	Subject
11-2	Introduction and Overview
18-2	Locomotion and Inverse Kinematics
25-2	Robotics Sensors and Image Processing
4-3	SLAM + Workshop@Home
11-3	Robotics Vision + Introduction Mobile Robot Challenge
18-3	Project Proposals I (by students)
25-3	Project Proposals II (by students)
1-4	Robotics Reinforcement Learning + RL Workshop@Home
8-4	Project Progress Reports I
15-4	Project Progress Reports II
22-4	Mobile Robot Challenge I
29-4	Mobile Robot Challenge II
6-5	TBA
13-5	Project Demos I
20-5	Project Demos II
27-5	Project Deliverables

Website: http://liacs.leidenuniv.nl/~bakkerem2/robotics/

Grading (6 ECTS):
- Presentations and Robotics Project (60% of grade).
- Class discussions, attendance, 2 assignments (pass/no pass)
- 2 Workshops (0-10) (20% of the grade).
- Mobile Robot Challenge (0-10) (20% of the grade)
- ***It is necessary to be at every class and to complete every workshop and assignment.***

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References

1. L. Pinto, J. Davidson, R. Sukthankar, A. Gupta, Robust Adversarial Reinforcement Learning, arXiv:1703.02702, March 2017.
2. S. Gu, E. Holly, T. Lillicrap, S. Levine, Deep Reinforcement Learning for Robotic Manipulation with Asynchronous Off-Policy Updates, arXiv:1610.00633v2 [cs.RO], October 2016.
3. C. Finn, S. Levine, Deep Visual Forsight for Planning Robot Motion, arXiv:1610.00696, ICRA 2017, October 2016.
4. L. Pinto, J. Davidson, A. Gupta, Supervision via Competition: Robot Adversaries for Learning Tasks, arXiv:1610.01685, ICRA 2017, October 2016.
5. K. Bousmalis, N. Silberman, D. Dohan, D. Erhan, D. Krishnan, Unsupervised Pixel–Level Domain Adaptation with Generative Adversarial Networks, arXiv:1612.05424, CVPR 2017, December 2016.
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7. representations in artificial agents, https://doi.org/10.1038/s41586-018-0102-6, Research Letter, Nature, 2018.
8. R. Borst, Robust self-balancing robot mimicking, Bachelor Thesis, August 2017
9. Jie Tan, Tingnan Zhang, Erwin Coumans, Atil Iscen, Yunfei Bai, Danijar Hafner, Steven Bohez, and Vincent Vanhoucke, Sim-to-Real: Learning Agile Locomotion For Quadruped Robots, https://arxiv.org/pdf/1804.10332.pdf , RSS 2018.

Robotics

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Robotics Homework I

Assignment:

Give a link to the coolest, strangest, most impressive, most novel, or technologically inspirational robot you could find. And describe in a short paragraph (< 100 words) why you selected this robot and what its scientific novelty is. Also give, if possible, a reference to a scientific paper related to the robot.

NB Boston Dynamics Robots are excluded this time (I know they are very cool).

Grading: Pass/No Pass

Due: Monday 17-2 2025

See BrightSpace Assignment(s) to upload your answer in a **pdf file**,

NB Add a good title, date, your name, email-address and study.

Journals and Proceedings

IEEE

- **Transactions on Robotics**
- **Transactions on Field Robotics**
- **Transactions on Automation Science and Engineering**
- **Robotics and Automation Letters**
- **Robotics and Automation Magazine**
- **Robotics and Automation Practice**

- **Transactions on Mechatronics**
- **Transactions on Haptics**
- **Transactions on Medical Robotics and Bionics**
- **Transactions on Cognitive and Development Systems**

- **Sensors Journal**
- **Transactions on Mobile Computing**

Robotics Conferences

- Overview by ClearParthRobotics
- IEEE ICRA
- IEEE/RSJ IROS 2025
- ROSCON