

Introduction to Robotics

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Lecture 01

B4M36UIR – Artificial Intelligence in Robotics

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Course Goals Means of Achieving the Course Goals Evaluation and Exam

Course and Lecturers

B4M36UIR – Artificial Intelligence in Robotics

- <https://cw.fel.cvut.cz/wiki/courses/b4m36uir/>
- Department of Computer Science – <http://cs.fel.cvut.cz>
- Artificial Intelligence Center (AIC) – <http://aic.fel.cvut.cz>
- Lecturers

doc. Ing. Jan Faigl, Ph.D.

- Center for Robotics and Autonomous Systems (CRAS)
<http://robotics.fel.cvut.cz>
- Computational Robotics Laboratory (ComRob)
<http://comrob.fel.cvut.cz>



Mgr. Branislav Bošanský, Ph.D.

- Head of Game Theory (GT) research group
- Adversarial planning, Sequential Games, Dynamic Games, Stackelberg Equilibrium, Equilibrium Computation



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Resources and Literature

Textbooks

Introduction to AI Robotics, Robin R. Murphy, MIT Press, 2000, ISBN 978-0262133838

First lectures for the background and context



The Robotics Primer, Maja J. Mataric, MIT Press, 2007, ISBN 978-0262633543

First lectures for the background and context



Planning Algorithms, Steven M. LaValle, Cambridge University Press, 2006.

<http://planning.cs.uiuc.edu>



- Lectures – “comments” on the textbooks, slides, and your notes
- Laboratory Exercises – labs’ tasks and homeworks
- Selected research papers – further specified during the course

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Overview of the Lecture

- Part 1 – Course Organization
 - Course Goals
 - Means of Achieving the Course Goals
 - Evaluation and Exam
- Part 2 – Introduction to Robotics
 - Robots and Robotics
 - Challenges in Robotics
 - What is a Robot?
 - Locomotion

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Course Goals Means of Achieving the Course Goals Evaluation and Exam

Course Goals

- Master (yourself) with applying AI methods in robotic tasks
Labs, homeworks, exam
- Become familiar with the notion of intelligent robotics and autonomous systems
- Acquire knowledge of robotic data collection planning
- Acquire experience on combining approaches in autonomous robot control programs
Integration of existing algorithms (implementation) in to mission planning software and robot control program
- Experience solution of robotic problems
Your own experience!

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Further Books 1/2

Principles of Robot Motion: Theory, Algorithms, and Implementations, H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. E. Kavraki and S. Thrun, MIT Press, Boston, 2005.



Introduction to Autonomous Mobile Robots, 2nd Edition, Roland Siegwart, Illah R. Nourbakhsh, and Davide Scaramuzza, MIT Press, 2011, ISBN 978-0521692120



Computational Principles of Mobile Robotics, Gregory Dudek and Michael Jenkin, Cambridge University Press, 2010, ISBN 978-0262015356



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Part I

Part 1 – Course Organization

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Course Organization and Evaluation

- B4M36UIR and BE4M36UIR – Artificial intelligence in robotics
- Extent of teaching: 2(lec)+2(lab);
- Completion: Z,ZK; Credits: 6;
Z – ungraded assessment, ZK – exam
- Ongoing work during the semester – labs’ tasks and homeworks
- Exam: test and exam
Be able to independently work with the computer in the lab (class room)
- Attendance to labs and successful evaluation of homeworks

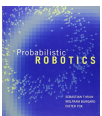
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Further Books 2/2

Robot Motion Planning and Control, Jean-Paul Laumond, Lectures Notes in Control and Information Sciences, 2009.
<http://homepages.laas.fr/jpl/book.html>



Probabilistic Robotics, Sebastian Thrun, Wolfram Burgard, Dieter Fox, MIT Press, 2005, ISBN 978-0262201629
<http://www.probabilistic-robotics.org/>



Robotics, Vision and Control: Fundamental Algorithms in MATLAB, Peter Corke, Springer, 2011, ISBN 978-3642201431
<http://www.petercorke.com/RVC/>



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Lectures – Winter Semester (WS) Academic Year 2017/2018

- Schedule for the academic year 2017/2018
<http://www.fel.cvut.cz/en/education/calendar.html>
- Lectures:
 - Karlovo náměstí, Room No. KN:E-126, Monday, 9:15–10:45
- 14 teaching weeks 13 lectures
- New Year's Day – 1.1.2018 (Monday)

Teachers

■ Ing. Petr Čížek



- Hexapod walking robots – design and motion control
- Vision based Simultaneous Location and Mapping (SLAM)
- Image processing and robot control on FPGA
- Motion planning and terrain traversability assessment

Communicating Any Issues Related to the Course

- Ask the lab teacher or the lecturer
- Use e-mail for communication
 - Use your **faculty e-mail**
 - Put **UIR or B4M36UIR, BE4M36UIR** to the subject of your message
 - Send copy (Cc) to lecturer/teacher

Computers and Development Tools

- Network boot with home directories (NFS v4)
Data transfer and file synchronizations – ownCloud, SSH, FTP, USB
- Python or/and C/C++ (**gcc** or **clang**)
- V-REP robotic simulator
<http://www.coppeliarobotics.com/>
- Open Motion Planning Library (OMPL)
<http://ompl.kavrakilab.org/>
- Sources and libraries provided by **Computational Robotics Laboratory**
- Any other open source libraries
- Gitlab FEL – <https://gitlab.fel.cvut.cz/>
- FEL Google Account – access to Google Apps for Education
See <http://google-apps.fel.cvut.cz/>
- Information resources (IEEE Xplore, ACM, Science Direct, Springer Link)
 - *IEEE Robotics and Automation Letters (RA-L), IEEE Transactions on Robotics (T-RO), International Journal of Robotics Research (IJRR), Journal of Field Robotics (JFR), Robotics and Autonomous Robots (RAS), Autonomous Robots (AuRo), etc.*

Grading Scale

Grade	Points	Mark	Evaluation
A	≥ 90	1	Excellent
B	80–89	1,5	Very Good
C	70–79	2	Good
D	60–69	2,5	Satisfactory
E	50–59	3	Sufficient
F	<50	4	Fail

Homeworks

- TBD

Overview of the Lectures

1. Course information, Introduction to (AI) Robotics and Robotic Paradigms
2. Navigation and path planning
3. Path Planning - Grid based methods
4. Path Planning - Grid based methods
5. Motion Planning - Sampling-based methods
6. Motion Planning - Randomized Sampling-based methods
7. Robotic information gathering and data collection planning
8. Data collection planning and multi-goal path planning problems
9. Robotic exploration and multi-robot exploration
10. Data collection planning with curvature-constrained vehicles (DTSP(N) and DOP(N))
11. Game Theory in Robotics
12. Game Theory in Robotics
13. Game Theory in Robotics

Course Evaluation

Points	Maximum Points	Required Minimum Points
Lab tasks	20	10
Homeworks	30	20
Exam test	30	15
Exam	20	10
Total	100 points	55 points is E!

- **30** points from the semester are required for awarding ungraded assessment
- The course can be passed with **ungraded assessment and exam**
- All homeworks must be submitted and pass the evaluation

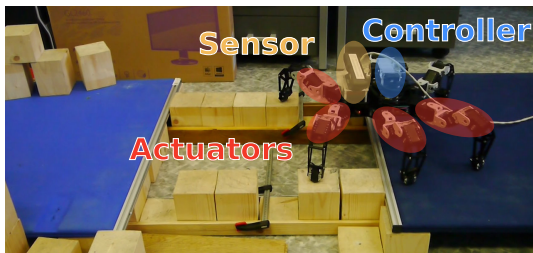
Part II

Part 2 – Introduction to Robotics

What is a Robot?

A robot is an autonomous system which exists in the physical world, can sense its environment, and can act on it to achieve some goals

- The robot has a physical body in the physical world – **embodiment**
- The robot has **sensors** and it can **sense/perceive** its environment
- A robot has effectors and actuators – it can **act** in the environment
- A robot has **controller** which allows it to be **autonomous**



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Robots and Robotics

Challenges in Robotics

What is a Robot?

Locomotion

Sensors

- **Proprioceptive sensors** – measure internal status, e.g., encoders, inclinometer, inertial navigation systems (INS), compass, but also Global Positioning System (GPS)
- **Exteroceptive (proximity) sensors** – measure objects relative to the robot
- **Contact sensors** – e.g., mechanical switches, physical contact sensors that measure the interaction forces and torques, tactile sensors etc.
- **Range sensors** – measure the distance to objects, e.g., sonars, lasers, IR, RF, time-of-flight
- **Vision sensors** – complex sensing process that involves extraction, characterization, and information interpretation from images



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Robots and Robotics

Challenges in Robotics

What is a Robot?

Locomotion

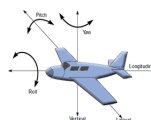
Degrees of Freedom (DOF)

- **Degree of Freedom (DOF)** is the minimal required number of independent parameters to completely specify the motion of a mechanical system

It defines how the robot can move

In 3D space, a body has usually 6 DOF (by convention)

- **Translational DOF** – x, y, z
- **Rotational DOF** – *roll, pitch, and yaw*



- **Controllable DOF (CDOF)** – the number of the DOF that are controllable, i.e., a robot has an actuator for such a DOF

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Embodiment

- The robot body allows the robot to act in the physical world
E.g., to go, to move objects, etc.
- Software agent is not a robot
- Embodied robot is under the same physical laws as other objects
 - Cannot change shape or size arbitrarily
 - It must use actuators to move
 - It needs energy
 - It takes some time to speed up and slow down
- Embodied robot has to be aware of other bodies in the world
 - Be aware of possible collisions
- The robot body influences how the robot can move

Notice, faster robots look smarter

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Robots and Robotics

Challenges in Robotics

What is a Robot?

Locomotion

Action

- **Effectors** enables a robot to take an action
 - They use underlying mechanism such as muscles and motors called **actuators**
- Effectors and actuators provides two main types of activities
 - **Locomotion** – moving around
 - **Manipulation** – handling objects
- Locomotion mechanisms – wheels, legs, modular robots, but also propellers etc.

Mobile robotics – robots that move around

Robotic arms



With more and more complex robots, a separation between mobile and manipulator robots is less strict and robots combine mobility and manipulation

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Robots and Robotics

Challenges in Robotics

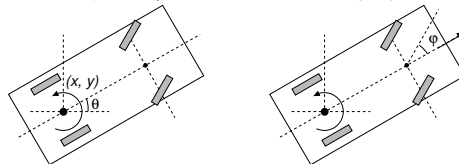
What is a Robot?

Locomotion

DOF vs CDOF

- If a vehicle moves on a surface, e.g., a car, it actually moves in 2D
- The body is at the position $(x, y) \in \mathbb{R}^2$ with an orientation $\theta \in \mathbb{S}^1$
- A car in a plane has $\text{DOF} = 3, (x, y, \theta)$ but $\text{CDOF} = 2, (v, \varphi)$

Only forward/reverse direction and steering angle can be controlled



That is why a parallel parking is difficult

- A car cannot move in an arbitrary direction, but 2 CDOF can get car to any position and orientation in 2D
- To get to a position, the car follows a **continuous trajectory (path)**, but with **discontinuous velocity**

Uncontrollable DOF makes the movement more complicated

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Sensing / Perception

- Sensors are devices that enable a robot to perceive its physical environment to get information about itself and its surroundings
- Exteroceptive sensors and proprioceptive sensors
- Sensing allows the robot to know its **state**
- State can be **observable, partially observable, or unobservable**
 - State can be **discrete** (e.g., on/off, up/down, colors) or **continuous** (velocity)
 - **State space** consists of all possible states which the system can be
 - **space** refers to all possible values
 - **External state** – the state of the world as robot can sense it
 - **Internal state** – the state of the robot as the robot can perceive it



E.g., remaining battery

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Robots and Robotics

Challenges in Robotics

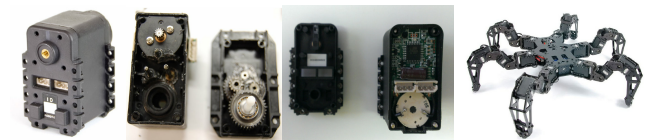
What is a Robot?

Locomotion

Effectors and Actuators

- **Effector** – any device on a robot that has an effect on the environment
- **Actuator** – a mechanisms that allows the effector to execute an action or movement, e.g., motors, pneumatics, chemically reactive materials, etc.
- Electric motors – Direct-Current (DC) motors, gears,
 - **Servo motors** – can turn their shaft to a specific position

DC motor + gear reduction + position sensor + electronic circuit to control the motor



Hexapod with 3 servo motors (joints) per each leg has 18 servo motors in total

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Robots and Robotics

Challenges in Robotics

What is a Robot?

Locomotion

Ratio of CDOF to the Total DOF

- The ratio of Controllable DOF (CDOF) to the Total DOF (TDOF) represents how easy is to control the robot movement
- **Holonomic** ($\text{CDOF} = \text{TDOF}$, the ratio is 1) – holonomic robot can control all of its DOF
E.g., Multirotor aerial vehicle can control each DOF
- **Nonholonomic** ($\text{CDOF} < \text{TDOF}$, the ratio < 1) – a nonholonomic robot has more DOF that it can control
E.g., a car
- **Redundant** ($\text{CDOF} > \text{TDOF}$, the ratio > 1) – a redundant robot has more ways of control



17 CDOF



6 DOF Hexapod



24 TDOF, 18 CDOF Hexapod

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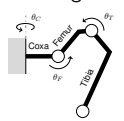

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Locomotion

- **Locomotion** refers how the robot body moves from one location to another location
From the Latin Locus (place) and motion
- The most typical effectors and actuators for ground robots are **wheels** and **legs**
- Most of the robots need to be **stable** to work properly
 - **Static stability** – a robot can stand, it can be static and stable
Biped robots are not statically stable, more legs make it easier. Most of the wheeled robots are stable.
 - **Statically stable walking** – the robot is stable all the times
E.g., hexapod with tripod gait
 - **Dynamic stability** – the body must actively balance or move to remain stable, the robots are called dynamically stable
E.g., inverse pendulum

Locomotion of Hexapod Walking Robot

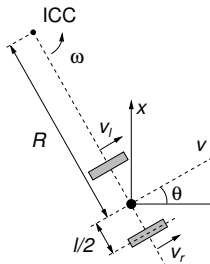
- Let have hexapod robot with six identical legs each with 3 DOF
- Each leg consists of three parts called **Coxa**, **Femur**, and **Tibia**

- The movement is a coordination of the **stance** and **swing** phases of the legs defined by the gait, e.g., tripod

- A **stride** is a combination of the leg movement with the foot tip on the ground (during the **stance phase**) and the leg movement in a particular direction (in the **swing phase**) within one **gait cycle**
- Various gaits can be created by different sequences of stance and swing phases
- $T_{Stance}, T_{Swing}, T_{Stride} = T_{Stance} + T_{Swing}$ defines the **duty factor**
 $\beta = T_{Stance} / T_{Stride}$
Triod $\beta = 0.5$

Control Architectures

- A single control rule may provide simple robot behaviour
Notice, controller can be feed-forward (open-loop) or feedback controller as in the previous example with vision based sensing
- Robots should do more than just avoiding obstacles
- The question is “**How to combine multiple controller together?**”
- **Control architecture** is a set of guiding principles and constraints for organizing the robot control system
 - Guidelines to develop the robotic system to behave as desired
It is not necessary to know control architectures for simple robotic demos and tasks. But it is highly desirable to be aware of architectures for complex robots

Locomotion – Wheel Robots

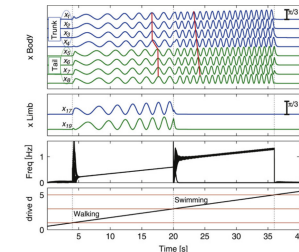
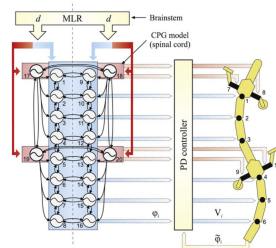
- One of the most simple wheeled robots is **differential drive** robot
 - It has two derived wheels on a common axis
 - It use castor wheels for stability
 - It is nonholonomic robot
Omnidirectional robot is holonomic robot



- v_l and v_r are velocities along the ground of the left and right wheels, respectively
 - $\omega = \frac{v_r - v_l}{l}, R = \frac{l}{2} \frac{v_l + v_r}{v_r - v_l}$
 - For $v_l = v_r$, the robot moves straight ahead
R is infinite
 - For $v_l = -v_r$, the robot rotates in a place
R is zero
 - Simple motion control can be realized in a turn-move like schema
- Further motion control using path following or trajectory following approaches with feedback controller based on the position of the robot to the path / trajectory

Central Pattern Generator (CPG)

- **Central Pattern Generators (CPGs)** – are neural circuits to produce rhythmic patterns for various activities, i.e., locomotor rhythms to control a periodic movement of a particular body parts
- Salamander CPG with 20 amplitude-controlled phase oscillators

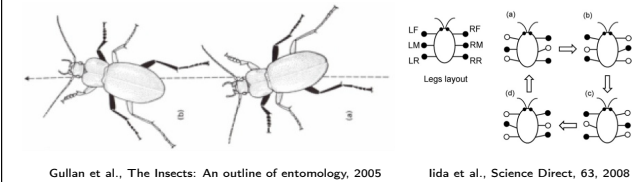


Auke Jan Ijspeert, Neural Networks, 2008

Summary of the Lecture

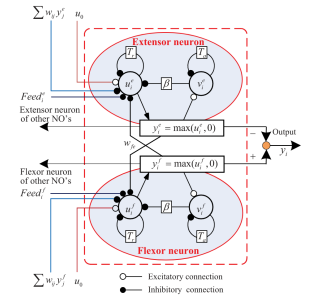
Locomotion – Legged Robots (Gaits)

- **Gait** is a way how a legged robot moves
- A gait defines the order how the individual legs lift and lower and also places of the foot tip on the ground
- Properties of gaits are: stability, speed, energy efficiency, robustness (how the gait can recover from some failures), simplicity (how complex is to generate the gait)
- A typical gait for hexapod walking robot is **tripod** which is stable as all the times at least three legs are on the ground



Example of Rhythmic Pattern Oscillator

- One of the widely used oscillators is the **Matsuoka oscillator** model
- It is based on biological concepts of the extensor and flexor muscles
- The rhythmic patterns defined the trajectory of the leg end point (foot tip)
- The coordinates of the foot tip can be utilized to computed the joint angles using the **Inverse Kinematics**



Matsuoka, K. (1985). Sustained oscillations generated by mutually inhibiting neurons with adaptation. Biological Cybernetics 52, 367–376

An example of simple CPG to control hexapod walking robot will be addressed during the labs

Topics Discussed

- Information about the Course
- Overview of robots, robotics, and challenges
 - Robot – Embodied software agent
 - Sensor, Controller, Actuators
 - Degrees of Freedom (DOF) and Controllable DOF
 - Mobile Robot Locomotion
 - Locomotion Gaits for Legged Robots
 - Central Pattern Generator

■ **Next: Robotic Paradigms and Control Architectures**