



## COURSE DESCRIPTION CARD - SYLLABUS

Course name

Control of mobile robots [S2AiR2-SSiR>SRMo]

### Course

Field of study

Automatic Control and Robotics

Year/Semester

1/2

Area of study (specialization)

Control and Robotic Systems

Profile of study

general academic

Level of study

second-cycle

Course offered in

Polish

Form of study

full-time

Requirements

compulsory

### Number of hours

Lecture

30

Laboratory classes

30

Other

0

Tutorials

0

Projects/seminars

0

### Number of credit points

4,00

### Coordinators

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### Lecturers

### Prerequisites

A student should know fundamentals on robotics (configuration space, task space, kinematics, dynamics, kinematic constraints, trajectory, path, tracking, stabilization, control of servodrives) and on theory of systems and control (state-space description, feedback control, feedforward control, linearization and linear approximation, controllability, Lie bracket, Lyapunov stability analysis, driftless dynamical systems and systems with a drift). Moreover, a student should have skills in Matlab programming, implementation and simulation of block schemes in the Simulink environment; should be able to present the simulation and experimental results by using selected information-communication tools, should have skills to acquire knowledge from indicated sources; should be ready to cooperate in a team.

### Course objective

Course objectives are as follows: systematization of knowledge on mobile robotics and drawing a state of the art in the area of motion algorithmization for wheeled mobile robots; analysis of theoretical and practical problems and their solutions concerning modeling and control of autonomous wheeled vehicles; development of skills for practical implementation and testing of selected control algorithms for wheeled mobile robots, and their multicriterial assessment in the context of various motion tasks; development of skills for the purpose of cooperating in a small team.

## Course-related learning outcomes

### Knowledge

1. Extended knowledge in the area of modeling of wheeled mobile robots on the kinematic and dynamic levels; knowledge on classification and fundamental properties of basic kinematic structures of mobile robots; knowledge on properties of wheeled and wheeled-tracked locomotion; knowledge on fundamental properties of kinematic models of mobile robots and a universal chained-form model. [K2\_W5]  
2. Ordered, theoretically supported, detailed knowledge in the range of designing and analysing of control systems for mobile robots (especially of (2,0) kinematics) for basic motion tasks; knowledge on underlying cascaded structures of control systems for wheeled mobile robots (with an especial emphasis paid on the (2,0) class) and knowledge on functions of their particular blocks; knowledge on fundamental limitations in designing and implementing of control systems for mobile robots of a restricted mobility; knowledge on selected kinematic techniques and algorithms of mobile robot control and their properties; knowledge on practical issues and advantages and limitations concerning practical utilization of particular control methods; knowledge on selected quality criteria useful to assess performance of control algorithms. [K2\_W7]

3. Extended knowledge in the field of mobile robotics, especially concerning wheeled mobile robots; knowledge on mobile robot examples and areas of their applications; knowledge on concepts such as: autonomous/semi-autonomous/teleoperated/intelligent mobile robot; knowledge on basic motion tasks defined for mobile robots and corresponding control tasks; knowledge on practical examples for particular motion tasks, and mathematical formulations of motion tasks for mobile robots of the (2,0) class (a reference signals generator). [K2\_W10]

### Skills

1. Implementing and testing of mobile robot models, generators of reference signals, and basic control algorithms in a simulation environment and in a fast-prototyping system (with utilization of a real mobile platform). [K2\_U9],[K2\_U10]  
2. Analysis of control performance and comparison of selected control algorithms by using selected quality criteria. [K2\_U19],[K2\_U22]  
3. Preparing and appropriate presenting of obtained laboratory results. [K2\_U8]

### Social competences

1. Ability to cooperate in a team with a responsibility for a common task. [K2\_K3]  
2. Consciousness of necessity to professionally approach to technical tasks. [K2\_K4]

## Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

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A) For lectures: Verification of the teaching results during an exam in the form of an individual oral answers (possibly complemented by written schemes, equations, etc.) to three questions chosen from a set of about 30 questions provided to the students before the exam. Every answer is independently assessed and rated. A mean value from all three ratings determines the rating OW, which is positive if  $OW \geq 3.0$ . A final rating from the course, OK, is computed as follows:  $OK = OW \cdot 0.7 + OL \cdot 0.3$ , where OL is a rating obtained from laboratory classes.  $OK \geq 3.0$  implies a positive rating from the course.

B) For laboratory classes: Verification of the teaching results is performed during 'defending' by the students their final experimental results prepared in the second part of classes and presented both on-line and by a written report (assessment of: obtained results, quality of the written report, and answers to questions formulated by an instructor and related to the tested control algorithms).

## Programme content

The program content is as follows:

- introduction to mobile robotics,
- modeling of wheeled mobile robots,
- selected properties of wheeled mobile robot models,
- motion and control tasks defined for mobile robots,
- structures of control systems for mobile robots,
- implementation issues concerning the mobile robots' control systems,
- practical verification of selected control algorithms of mobile robots.

## Course topics

The lectures cover the following topics:

- basic concepts: mobility, locomotion, autonomous/intelligent/semi-autonomous/teleoperated mobile robot; basic topics in mobile robotics,
- classification criteria for mobile robots, including wheeled robots; autonomy levels for mobile robots; applications and examples of mobile robots; levels of automation defined for commercial cars; robotization of commercial vehicles with examples,
- properties of wheeled and wheeled-tracked locomotion; types of wheels used in robotic vehicles, the types of drive transmission and motion realization, differential mechanism, Ackermann steering mechanism, omnidirectional motion vs. restricted mobility motion, necessary conditions of a non-degenerated structure of wheeled mobile robot,
- modeling of wheeled mobile robots: posture and configuration vectors, orientation representations for mobile platforms, instantaneous center of rotation, five basic kinematic models of wheeled mobile robots ((3,0), (2,0), (1,1), (1,2), (2,1)), kinematic constraints; dynamical (kinetic) model of a differentially driven robot, friction, rolling resistance, skid-slip effects; a normal form of mobile robot models,
- kinematic indexes: mobility index, steerability index, maneuverability index; degrees of freedom; basic structures of single-body and multiple-body mobile robots (with trailers), two ways of hitching a trailer and their consequences for control, - controllability of mobile robot kinematics,
- canonical chained-form model and its role in the area of mobile robot control,
- properties of mobile robots models in the context of control (linearizability, differential flatness, controllability of a linear approximation of a model),
- fundamental limitations in mobile robots control: consequences of the Brockett's Theorem, nonholonomic constraints and their interpretation, the lack of a universal stabilizer,
- definitions of basic motion tasks and control problems, and practical examples of their utilization: trajectory tracking, path following, stabilization at a point, positional tasks, nonclassical tasks; the problem of collision avoidance with obstacles,
- mathematical formulation of a motion task (reference signals generator - the ways of computing); the concepts of a persistent excitation and an admissible trajectory,
- a general structure of a control system for mobile robots, structures and classification of cascaded control systems with respect to a control signal interpretation; synthesis of the velocity control loops,
- description, derivation, and parametric synthesis of selected control algorithms for all the classical motion tasks (methods resulting from linear approximations and feedback linearization, a time-dependent Pomet's stabilizer, discontinuous controllers of the VFO method); rules for control designing with a utilization of the canonical chained-form model,
- qualitative comparative criteria of control algorithms; types of signal convergence and their relation to control performance obtained in practice; robustness and sensitivity determined by control algorithms,
- practical issues concerning implementation of control systems for mobile robots: control performance in practical (non-ideal) conditions, limitations of control inputs and a velocity scaling block, problems in measuring feedback signals, physical realization of control signals, basic hardware blocks of control systems in wheeled mobile robots; selected examples of practical implementations of control systems for mobile robots.

Laboratory classes are organized in the form of fifteen 2-hour meetings in a laboratory room. The laboratory tasks are realized by teams of 2-3 students. The program is divided into two parts (the simulation one and the experimental one), which address the following topics:

- implementing and testing (in the Matlab-Simulink environment) of the differentially-driven mobile robot model, a velocity scaling block, and a reference signals generator,
- implementing and tuning (in the Matlab-Simulink environment) of the inner-loop velocity controllers with an anti-windup corrector,
- simulation verification (in the Matlab-Simulink environment) of open-loop control for a mobile robot of the (2,0) class,
- testing of testbeds with real mobile platforms in a fast-prototyping system,
- implementing and validating of selected control algorithms for classical motion tasks (trajectory tracking, path following, set-point stabilization, positional tasks) in the fast-prototyping control system equipped with real experimental mobile robots.

## Teaching methods

A) Lectures: Multimedia presentation with slides illustrated by additional examples and derivations provided and analyzed on a blackboard.

B) Laboratory classes: Simulation tasks in the Matlab-Simulink environment (during the first part of classes); implementation and practical testing of selected control algorithms (during the second part of classes) using real mobile robots in a fast-prototyping system.

## Bibliography

### Basic

- [1] Sterowanie robotów mobilnych. Laboratorium, M. Michałek, D. Pazderski, WPP, Poznań, 2012  
[2] Theory of robot control. Part III: Mobile robots, The Zodiak, C. Canudas de Wit, B. Siciliano, G. Bastin, Springer, London, 1996

### Additional

- [3] Wheeled mobile robotics. From fundamentals towards autonomous systems, G. Klancar, A. Zdesar, S. Blazic, I. Skrjanc, B-H, 2017  
[4] Introduction to Autonomous Mobile Robots, R. Siegwart, I. R. Nourbakhsh, The MIT Press, Cambridge, 2004  
[5] Principles of Robot Motion. Theory, Algorithms, and Implementations, H. Choset, K. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. Kavraki, S. Thrun, The MIT Press, Cambridge, 2005  
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[7] Motion control of wheeled mobile robots, P. Morin, C. Samson, Springer Handbook of Robotics, 2008  
[8] Springer Handbook of Robotics, B. Siciliano, O. Khatib (ed.), rozdziały: 17, 34, 51, 54, Springer 2008  
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[10] Manipulatory i roboty mobilne. Modele, planowanie ruchu, sterowanie, K. Tchoń, A. Mazur, I. Dulęba, R. Hossa, R. Muszyński, Akademicka Oficyna Wydawnicza, Warszawa, 2000

## Breakdown of average student's workload

|   | Hours | ECTS |
|---|-------|------|
| Total workload  | 100   | 4,00 |
| Classes requiring direct contact with the teacher   | 60    | 2,50 |
| Student's own work (literature studies, preparation for laboratory classes/ tutorials, preparation for tests/exam, project preparation) | 40    | 1,50 |