COURSE DESCRIPTION CARD - SYLLABUS

Course name

Control of mobile robots

Course

Field of study	Year/Semester
Automatic Control and Robotics	1/2
Area of study (specialization)	Profile of study
Control and Robotics Systems	general academic
Level of study	Course offered in
Second-cycle studies	Polish
Form of study	Requirements
full-time	compulsory

Number of hours

Lecture	Laboratory classes	Other (e.g. online)
30	30	0
Tutorials	Projects/seminars	
0	0	

Number of credit points

4

Lecturers

Responsible for the course/lecturer:

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Responsible for the course/lecturer:

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 selected sources; should be ready to cooperate in a team.

Course objective

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 the modeling and control of autonomous wheeled vehicles; development of skills for practical implementation and testing of selected control algorithms, 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 modleing of wheeled mobile robots on the kinematic and dynamic levels; knowledge of classifications and fundamental properties of basic kinematic structures of mobile robots; knowledge of properties of wheeled and wheeled-tracked locomotion; knowledge of 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 of underlying cascaded structures of control systems for mobile robots (with an especial emphasis paid on the (2,0) class) and knowledge of functions for their particular blocks; knowledge of fundamental limitations in designing and implementing of control systems for mobile robots of a limited mobility; knowledge of selected kinematic techniques and algorithms of mobile robot control and their properties; knowledge of practical issues and advantages and limitations concerning practical utilization of particular control methods; knowledge of selected quality criteria useful to assess performance of control algorithms. [K2_W7]
3. Extended knowledge in the field of mobile robotics, concerning especially wheeled mobile robots; knowledge of mobile robot examples and areas of their applications; knowledge of concepts such as: autonomous/semi-autonomous/teleoperated/intelligent mobile robot; knowledge of basic motion tasks defined for mobile robots and corresponding control tasks; knowledge of 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 platofrm). [K2_U9],[K2_U10]
2. Analysing of control performance and comparing 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 neccessity to professionally approch to technical tasks. [K2_K4]

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

A) For lectures: Verification of the teaching results during an exam in the form of an individual oral answ ers (possibly complemented by written schemes, equations, etc.) to three questions choosen 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>=3.0. A final rating from the course, OK, is computed as follows: OK = OW*0.7 + OL*0.3, where OL is a rating obtained from laboratory classes. OK >= 3.0 implies a positive rating from the course.
B) For laboratory classes: Verification of the teaching results is performed by assessment and 'defending' the final experimental-testing 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 course addresses 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 – examples,
- properties of wheeled and wheeled-tracked locomotion; types of wheels used in robotic vehicles, the ways of driving transmission and motion realization, differential mechanism, Ackermann steering mechanism, omnidirectional motion vs. limited mobility motion, 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 mobite robots ((3,0), (2,0), (1,1), (1,2), (2,1)), kinematic constraints; dynamical (kinetic) model of a differentially driven robot, friction, rolling resistance, and skid-slip effects; a normal form of mobile robot models,
- kinematic indexes: mobility index, steerability index, maneuverability index; degress 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 convergnce 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 2-4 students. The program is divided into two parts (the simulation one and the experimental one), which address the following topics:
- implementing and testing (in Matlab-Simulink environment) of the differentially-driven mobile robot model, a velocity scaling block, and a reference signals generator,
- implementing and tuning of the inner-loop velocity controllers with an anti-windup corrector,
- simulation verification 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 toward 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

[6] Feedback control of nonholonomic car-like robot. Robot motion planning and control (red. J. P. Laumond), chapter 4, A. De Luca, G. Oriolo, C. Samson, Springer, 1998

[7] Springer handbook of robotics, B. Siciliano, O. Khatib (ed.), chapters 17, 34, 51, 54, Springer, 2008

[8] Modeling and control of nonholonomic mechanical systems, A. De Luca, G. Oriolo, Springer, Viena, 1995

[9] Manipulatory i roboty mobilne. Modele, planowanie ruchu, sterowanie, K. Tchoń, A. Mazur, I. Dulęba, R. Hossa, R. Muszyński, AOW, Warsaw, 2000

Breakdown of average student's workload

	Hours	ECTS
Total workload	114	4
Classes requiring direct contact with the teacher	62	2
Student's own work (literature studies, preparation for laboratory classes, testing the programs after classes, preparation of a final report from a second part of classes, preparation to a credit for classes, preparation for an exam) [1]	52	2

[1] delete or add other activities as appropriate