GDAŃSK UNIVERSITY OF TECHNOLOGY

Subject card

<table>
<tr><td>Subject name and code</td><td colspan="3">3D Vision in Robotics, PG_00068083</td></tr>
<tr><td>Field of study</td><td colspan="3">Automatic Control, Cybernetics and Robotics</td></tr>
<tr><td>Date of commencement of studies</td><td>October 2025</td><td>Academic year of realisation of subject</td><td>2027/2028</td></tr>
<tr><td>Education level</td><td>first-cycle studies</td><td>Subject group</td><td>Optional subject group
Subject group related to scientific research in the field of study</td></tr>
<tr><td>Mode of study</td><td>Full-time studies</td><td>Mode of delivery</td><td>at the university</td></tr>
<tr><td>Year of study</td><td>3</td><td>Language of instruction</td><td>Polish</td></tr>
<tr><td>Semester of study</td><td>6</td><td>ECTS credits</td><td>3.0</td></tr>
<tr><td>Learning profile</td><td>general academic profile</td><td>Assessment form</td><td>exam</td></tr>
<tr><td>Conducting unit</td><td colspan="3">Department of Decision Systems and Robotics -> Faculty of Electronics Telecommunications and Informatics -> Wydziały Politechniki Gdańskiej</td></tr>
<tr><td rowspan="2">Name and surname of lecturer (lecturers)</td><td>Subject supervisor</td><td colspan="2">dr inż. Marek Tatara</td></tr>
<tr><td>Teachers</td><td colspan="2">dr inż. Marek Tatara</td></tr>
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<table>
<tr><td rowspan="3">Lesson types and methods of instruction</td><td>Lesson type</td><td>Lecture</td><td>Tutorial</td><td>Laboratory</td><td>Project</td><td>Seminar</td><td>SUM</td></tr>
<tr><td>Number of study hours</td><td>15.0</td><td>0.0</td><td>15.0</td><td>0.0</td><td>0.0</td><td>30</td></tr>
<tr><td colspan="7">E-learning hours included: 0.0</td></tr>
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<tr><td rowspan="2">Learning activity and number of study hours</td><td>Learning activity</td><td>Participation in didactic classes included in study plan</td><td>Participation in consultation hours</td><td>Self-study</td><td>SUM</td></tr>
<tr><td>Number of study hours</td><td>30</td><td>3.0</td><td>42.0</td><td>75</td></tr>
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Subject objectives	Acquire knowledge of three-dimensional data acquisition techniques and processing algorithms, combined with developing the practical skills to design and implement integrated vision systems for mobile robots and manipulators.

Learning outcomes	Course outcome	Subject outcome	Method of verification
	[K6_W01] knows and understands, to an advanced extent, mathematics necessary to formulate and solve simple issues related to the field of study	The student knows and understands advanced mathematical methods, including linear algebra and geometry, necessary for describing spatial transformations, camera modeling, and 3D reconstruction algorithms. They can use this knowledge to formulate problems in the field of machine vision.	[SW1] Assessment of factual knowledge
	[K6_U12] can analyze the operation of components, circuits and systems related to the field of study, as well as measure their parameters and examine technical specifications, and plan and conduct experiments related to the field of study, including computer simulations and measurements, and interpret obtained results and draw conclusions	The student can plan and conduct experiments to investigate the characteristics of 3D vision system components (e.g., calibration accuracy, point cloud registration error). They can analyze and interpret the obtained results and formulate conclusions about the performance and limitations of the tested methods.	[SU2] Assessment of ability to analyse information [SU5] Assessment of ability to present the results of task
	[K6_W03] knows and understands, to an advanced extent, the construction and operating principles of components and systems related to the field of study, including theories, methods and complex relationships between them and selected specific issues - appropriate for the curriculum	The student knows and understands the principles of operation and limitations of key 3D sensors (e.g., stereo cameras, LiDAR). They understand the fundamental mathematical and algorithmic methods (e.g., epipolar geometry, ICP) used for processing 3D data and can explain the complex relationships within a robot's entire perception system.	[SW1] Assessment of factual knowledge
	[K6_U08] while identifying and formulating specifications of engineering tasks related to the field of study and solving these tasks, can:n- apply analytical, simulation and experimental methods,n- notice their systemic and non-technical aspects,n- make a preliminary economic assessment of suggested solutions and engineering work n	The student can identify and formulate an engineering task that requires 3D perception, select appropriate methods and tools (sensors, algorithms), and then experimentally verify the proposed solution.	[SU1] Assessment of task fulfilment [SU3] Assessment of ability to use knowledge gained from the subject [SU4] Assessment of ability to use methods and tools

<table>
<tr><td>Subject contents</td><td colspan="2">Lecture

1. Comparison of 2D Imaging with 3D Vision

• Limitations of 2D vision and the role of 3D vision in robotics
• Camera models, parameters, and distortions
2. Mathematical Foundations of 3D Description
• 3D space transformations
• Homogeneous coordinates and rotations
• Transitions between coordinate systems
3. Passive Stereovision
• Epipolar plane and epipoles
• Matrix representation
• Triangulation and rectification
4. Active Data Acquisition
• Structured light
• Time-of-Flight
• Laser scanners and LiDAR
5. 3D Data Representation and Basic Processing
• 3D data structures: point clouds, voxels, meshes
• Basic point cloud processing algorithms
6. 3D Data Registration and Matching
• Point cloud matching
• Introduction to SLAM
7. Machine Learning in 3D Vision
• Machine learning tasks on 3D data
• Network architectures for 3D data
8. Applications in Robotics and Vision System Calibration
• Navigation and planning
• Pose estimation
• Camera and robot calibration
Laboratory
1. Camera Calibration: determining intrinsic and extrinsic parameters
2. Stereovision and 3D Reconstruction: distance and dimension measurements
3. Acquisition and Registration of Point Clouds from LiDAR
4. Hand-Eye Calibration
5. Running SLAM on a Mobile Robot</td></tr>
<tr><td>Prerequisites and co-requisites</td><td colspan="2">Knowledge of:

• linear algebra, specifically operations on matrices and vectors
• image processing
• basic Python programming</td></tr>
<tr><td>Assessment methods and criteria</td><td colspan="2"><table><tr><td>Subject passing criteria</td><td>Passing threshold</td><td>Percentage of the final grade</td></tr><tr><td>Laboratory</td><td>60.0%</td><td>40.0%</td></tr><tr><td>Final exam</td><td>60.0%</td><td>60.0%</td></tr></table></td></tr>
<tr><td rowspan="3">Recommended reading</td><td>Basic literature</td><td>[1] Hartley, R., & Zisserman, A. (2003). Multiple view geometry in computer vision (2nd ed.). Cambridge University Press.
[2] Szeliski, R. (2022). Computer vision: Algorithms and applications (2nd ed.). Springer. https://szeliski.org/Book/
[3] Corke, P. I. (2023). Robotics, vision and control: Fundamental algorithms in Python (3rd ed.). Springer. https://doi.org/10.1007/978-3-031-07262-8</td></tr>
<tr><td>Supplementary literature</td><td>[1] Thrun, S., Burgard, W., & Fox, D. (2005). Probabilistic robotics. The MIT Press.</td></tr>
<tr><td>eResources addresses</td><td></td></tr>
</table>

Example issues/ example questions/ tasks being completed	**Lecture** 1. Compare 2D and 3D vision in the context of robotics tasks. Discuss the limitations of 2D systems and indicate the new possibilities offered by 3D perception. 2. Discuss the concept of epipolar geometry. Name the key matrices and discuss their role in 3D reconstruction. 3. Compare active 3D data acquisition techniques: structured light, Time-of-Flight, and LiDAR. Discuss their principles of operation, advantages, disadvantages, and typical applications. **Laboratory** 1. Based on a series of images of a calibration board, determine the camera's intrinsic parameter matrix and distortion coefficients. 2. Implement a program to estimate the distance to and dimensions of an object based on a point cloud generated from a stereo camera. 3. For two point clouds acquired from a LiDAR, implement a procedure for their registration (matching) using the ICP algorithm.
Work placement	Not applicable

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