

UNIVERSITY OF MINNESOTA
DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING

Spring 2004: CSci 5552
Class number: 65902 - 3 credits

“SENSING AND ESTIMATION IN ROBOTICS”

Class Schedule: Monday and Wednesday 4:00-5:15pm, EE/CSci 3-111

Instructor: Prof. Stergios Roumeliotis

Office: EE/CSci 5-189

Phone: 6-7507

E-Mail: stergios@cs.umn.edu

Office Hours: Mon. 5:30-6:30pm, Th. 2:30-3:30pm, or, by appointment

Teaching Assistant: Yukikazu Hidaka

Office: EE/CSci 2-140B (Undergraduate Robotics Lab)

Phone: 4-8954

E-Mail: yuki0005@umn.edu

Office Hours: Tu. 4:00-5:00pm, Wed. 2:00-3:00pm, or, by appointment

Class URL: <http://www.cs.umn.edu/~stergios/classes/csci5552>

1 Course Objective

The purpose of this course is to provide students with basic knowledge about sensing and estimation techniques employed for navigation of Unmanned Ground Vehicles (UGVs), such as mobile robots and space exploration rovers, and Unmanned Aerial Vehicles (UAVs), such as autonomous helicopters and spacecrafts.

UGVs and UAVs are equipped with sensors, e.g., accelerometers, gyroscopes, cameras, laser scanners, GPS receivers etc, for tracking their position and mapping the area they navigate in. Sensor signals contain noise while the interpretation of the scene a sensor observes can be uncertain. In order for autonomous vehicles to perform tasks such as (i) estimate their motion, (ii) plan their path, (iii) track objects of interest (friends or foes), and (iv) create 3D representations of their environment, they must be able to extract, filter, and combine information from a number of sensors distributed across one or more robots. In this class, we will study sensor modeling and sensor fusion techniques for achieving precisely these tasks. These are general estimation and filtering methodologies that can also be employed in related engineering problems when analysis and noise filtering of sensor signals is required.

Throughout the course we will analyze real and simulated robot sensor data, model their noise profile, extract application specific information, and examine special cases of estimation and filtering problems, such as:

- How can we track the position of a mobile robot while exploring an unknown area and creating a map of it?
- What sensors are necessary for estimating the state of a spacecraft during the Entry, Descent, and Landing (EDL) phases of its flight?
- How can a robot determine its path from an initial to a goal location through an area populated by static and moving obstacles?
- Which representations are appropriate for modeling the surroundings of a robot?
- How does the environment of a robot affect the selection of sensors and representations (e.g., inside an office building vs. on the surface of Mars)?
- How is positioning information processed within a group of robots?

Format: Classes will have mixed lectures and paper presentations. Grading is based on (i) 1-2 paper presentations, (ii) class participation, (iii) homeworks, and (iv) a choice of a term project using the robots at the undergraduate robotics laboratory. Work Load: Students are expected to read 10-15 pages per week and participate in class discussions. Background: Basic knowledge of probability & statistics and robot kinematics (some of these subjects will be reviewed in class).

2 Topics Covered

During this course the following topics will be covered:

- Bayesian Estimation
- Maximum Likelihood Estimation
- Kalman filtering
- Multiple Hypothesis Tracking
- Particle Filtering
- Laser Scan Matching
- Image-based Motion Estimation
- Gyroscope Noise Modeling
- Odometry Propagation
- Localization
- Representations (Mapping)
- Simultaneous Localization and Mapping (SLAM)
- Multi-robot Localization & SLAM

3 References

3.1 Notes

Provided by the Instructor.

3.2 Papers

<http://www.cs.umn.edu/~stergios/classes/csci5552/schedule.html>

3.3 Textbook

G. Dudek and M. Jenkin, “Computational Principles of Mobile Robotics,” Cambridge University Press, 2000.

3.4 Other References (Not Required)

3.4.1 Probability & Estimation

- [1] P. S. Maybeck, “Stochastic Models, Estimation and Control,” vols. 1-3, Mathematics in Science and Engineering, vol. 141, Academic Press, 1979.
- [2] S. Kay, “Fundamentals of Statistical Signal Processing, Vol. I - Estimation Theory,” Prentice Hall, 1993.
- [3] J. M. Mendel, “Lessons in Estimation Theory for Signal Processing, Communications, and Control,” Prentice Hall, 1995.
- [4] T. Kailath, A. H. Sayed, B. Hassibi, “Linear Estimation,” Prentice Hall, 2000.
- [5] A. Papoulis, “Probability, Random Variables and Stochastic Processes,” McGraw-Hill 2001.
- [6] Y. Bar-Shalom, X.-R. Li, “Estimation and Tracking: Principles and Techniques,” Artech House, 1995
- [7] A. Gelb, “Applied Optimal Estimation,” MIT Press, 1974.
- [8] H. Stark, J. W. Woods, “Probability, Random Processes, and Estimation Theory for Engineers,” Prentice-Hall, 1994

3.4.2 Robotics

- [1] J. Craig, “Introduction to Robotics: Mechanics and Control”, Addison-Wesley, Reading, MA, 1989.
- [2] Richard M. Murray, Zexiang Li, S. Shankar Sastry, “A Mathematical Introduction to Robotic Manipulation,” CRC Press, 1994.

- [3] M.W. Spong, M. Vidyasagar, “Robot Dynamics and Control,” John Wiley & Sons, 1989.
- [4] G. Dudek and M. Jenkin, “Computational Principles of Mobile Robotics,” Cambridge University Press, 2000.
- [5] J. A. Castellanos, J. D. Tardos, “Mobile Robot Localization and Map Building: A Multisensor Fusion Approach,” Kluwer Academic Publishers, 2000.
- [6] H. R. Everett “Sensors for Mobile Robots: Theory and Application,” A K Peters, 1995.
- [7] M. A. Abidi, R. C. Gonzalez, “Data Fusion in Robotics and Machine Intelligence,” Academic Press, 1991.
- [8] R. R. Murphy, “An Introduction to AI Robotics (Intelligent Robotics and Autonomous Agents),” MIT Press, 2000.
- [9] F. Martin, “Robotic Explorations: A Hands-on Introduction to Engineering,” Prentice Hall, 2000.
- [10] R. C. Arkin, “Behavior-Based Robotics (Intelligent Robotics and Autonomous Agents),” MIT Press, 1998.

3.4.3 Computer Vision & Pattern Recognition

- [1] D. A. Forsyth, Jean Ponce, “Computer Vision: A Modern Approach,” Prentice Hall, 2002
- [2] R. Hartley, A. Zisserman, “Multiple View Geometry in Computer Vision,” Cambridge University Press, 2000.
- [3] E. Trucco, A. Verri, “Introductory Techniques for 3-D Computer Vision,” Prentice Hall, 1998.
- [4] O. Faugeras, “Three-Dimensional Computer Vision, a Geometric Viewpoint,” MIT Press, 1993.
- [5] R. O. Duda, P. E. Hart, D. G. Stork, “Pattern Classification,” John Willey & Sons, 2001.

3.5 Web Resources

- [1] Stage/Player, <http://sourceforge.net/projects/playerstage/>
- [2] Robotics Internet Resources Page, <http://www-robotics.cs.umass.edu/robotics.html>
- [3] Robotics Online, <http://www.roboticsonline.com/>
- [4] Computer Vision Homepage, <http://www.cs.cmu.edu/afs/cs/project/cil/ftp/html/vision.html>
- [5] CVonline, <http://www.dai.ed.ac.uk/CVonline/CVentry.htm>

4 Grading

The grade for this course will consist of the following components:

Paper Presentation	30%
Class Participation	25%
Homeworks	10%
Project	35%

4.1 Paper Presentations

Each person in the class will present 1 (or 2) paper(s) during the course of this class (a 20-30 minutes presentation).

4.2 Class Participation

Discussion sessions will follow each presentation. In addition, students will be required to turn in 0.5-1 page reviews of selected papers.

4.3 Homeworks

Homeworks include a set of (i) short simulation assignments (using matlab) and (ii) comprehension problems.

4.4 Project

Project Demonstration	15%
Project Report	15%
Project Presentation	5%

Projects should take one of the following forms:

- Simulation and/or experiments. Examples will be given during the course of the class. Suggestions are welcome. Please contact the instructor for discussing your topic idea.
- Theoretical work (problem description & formulation, mathematical derivation of the solution, comparison with similar work).
- Extensive literature survey (with critical evaluation) on a given topic.

You may decide to work in groups of 2-4 if the content of the proposed work is sufficient for the size of the group (**consult with the instructor**).

All students should write a 5-10 page description (technical report) of their project and give a short presentation towards the last weeks of the semester. This report and presentation will count for 20% of the total class grade.

If you choose to do experimental work, you may use the Pioneer robots of the AI, Robotics, and Vision Laboratory or the Undergraduate Robotics Laboratory of the Computer Science & Engineering Department.

4.4.1 Project Schedule

- # March 3: Initial report- 1-2 pages project proposal.
- # March 24: Intermediate report- 2-4 pages describing the current progress on the project.
- # May 5: Final report- 5-10 page detailed description including results and a list of references to related work.

5 Cheating and Plagiarism

The paper presentations and the project must not be the result of cooperative work. Each student must work individually in order to understand the material in depth. You may discuss the issues but by no means, copy the presentation or the project of somebody else. All work in the projects must properly cite sources. For example, if you quote a source in your project, you must include the quote in quotation marks and clearly indicate the source. Any student caught cheating will receive an “F” as a class grade and the University policies for cheating and plagiarism will be followed.

6 Schedule

Check regularly the class webpage for schedule updates and announcements.

<http://www.cs.umn.edu/~stergios/classes/csci5552/schedule.html>