

UNIVERSITY OF MINNESOTA  
DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING  
SPRING 2012

**CSci 5552: SENSING AND ESTIMATION IN ROBOTICS**

**3 Credits**

**Class Schedule:** Tu. and Th. 12:45-2:00pm, MechE 108

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

**Instructor:** Prof. Stergios Roumeliotis

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**Office Hours:** Mon. and Wed. 1:00-2:00pm, or, by appointment

## 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, Unmanned Aerial Vehicles (UAVs), such as autonomous helicopters and spacecraft, and Autonomous Underwater Vehicles (AUVs), such as submarines.

UGVs, UAVs, and AUVs 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 (static or moving), 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 where 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 create 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 mostly lectures (based on material in the the notes) and few research paper presentations.

Background: Basic knowledge of probability & statistics and robot kinematics (a brief overview of these subjects will be given at the beginning of class).

## 2 Topics Covered

During this course the following topics will be covered:

- Bayesian Estimation
- Maximum Likelihood Estimation
- Kalman Filter
- Unscented Kalman Filter
- Particle Filter
- Laser Scan Matching
- Image-based Motion Estimation
- Sensor Modeling
- Localization
- Representations for Mapping
- Simultaneous Localization and Mapping (SLAM)
- Multi-robot Localization & SLAM
- Inertial Navigation

## 3 References

### 3.1 Notes

Provided by the Instructor (available on the class website).

### 3.2 Papers

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

## 4 Grading

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

Homeworks	30%
Midterm Exam	30%
Project Presentation	10%
Project Demonstration	10%
Project Report	20%

### 4.1 Homeworks

Homeworks will include a mixture of theory problems and short programming assignments. These will help you understand the material and monitor your progress. Programming assignments should be implemented either in Matlab or C/C++. There will be 4-5 homework assignments during the semester, depending on the material covered.

Homeworks are due at the **beginning** of the lecture, usually 1-2 weeks after the hand out. Homeworks submitted one class session late will be penalized by a 20% grade reduction. No homeworks will be accepted after that point. Solutions to the homework problems will be distributed.

### 4.2 Midterm Exam

The Midterm Exam will be during the 1-2 weeks after the spring break on material covered up to that point.

### 4.3 Project

Projects should take one of the following forms:

- Simulation and/or experiments. Examples will be given during the course of the class (e.g., 3D Localization or 2D Simultaneous Localization and Mapping, etc). Suggestions are also welcome; please contact the instructor for discussing your topic idea.
- Theoretical work (problem description & formulation, mathematical derivation of the solution, comparison to related work).

You may decide to work in groups of 3-4 if the content of the proposed work is sufficient for the size of the group (**consult with the instructor**).

Students should write a 5-7 page description (technical report) of their project and give a short presentation during the last week of the semester. This report and presentation will count for 30% of the total class grade. The project demonstration accounts for 10% of the total grade.

If you choose to do experimental work, you may use the Pioneer robots and sensors of the Undergraduate Robotics Laboratory (EE/CSci 2-140B) of the Department of Computer Science & Engineering.

#### 4.3.1 Project Schedule

- March 1: Initial report; 1 page project proposal.
- March 22: Intermediate report; 2-3 pages describing your current progress on the project.
- May 9: Final report; 5-7 page detailed description including results and list of references to related work.

## 5 Cheating and Plagiarism

The homeworks 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 homework 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 report, 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>

## 7 Other References (Not Required)

### 7.1 Robotics

- [1] Roland Siegwart, Illah R. Nourbakhsh, “Introduction to Autonomous Mobile Robot,” MIT Press 2004.
- [2] J. M. Selig, “Geometric Fundamentals of Robotics,” Springer.

- [3] Richard M. Murray, Zexiang Li, S. Shankar Sastry, “A Mathematical Introduction to Robotic Manipulation,” CRC Press, 1994.
- [4] M.W. Spong, M. Vidyasagar, “Robot Dynamics and Control,” John Wiley & Sons, 1989.
- [5] G.A. Bekey, “Autonomous Robots: From Biological Inspiration to Implementation and Control,” MIT Press, 2005.
- [4] S. Thrun, W. Burgard, D. Fox, “Probabilistic Robotics,” MIT Press 2005.
- [6] H. Choset, K.M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L.E. Kavraki, S. Thrun, “Principles of Robot Motion: Theory, Algorithms, and Implementations,” MIT Press 2005.
- [7] G. Dudek and M. Jenkin, “Computational Principles of Mobile Robotics,” Cambridge University Press, 2000.
- [8] J. A. Castellanos, J. D. Tardos, “Mobile Robot Localization and Map Building: A Multisensor Fusion Approach,” Kluwer Academic Publishers, 2000.
- [9] H. R. Everett “Sensors for Mobile Robots: Theory and Application,” A K Peters, 1995.
- [10] M. A. Abidi, R. C. Gonzalez, “Data Fusion in Robotics and Machine Intelligence,” Academic Press, 1991.
- [11] J. Craig, “Introduction to Robotics: Mechanics and Control,” Pearson Prentice Hall, NJ, 3rd edition, 2003.

## 7.2 Probability & Estimation

- [1] S. Kay, “Fundamentals of Statistical Signal Processing, Vol. I - Estimation Theory,” Prentice Hall, 1993.
- [2] P. S. Maybeck, “Stochastic Models, Estimation and Control,” vols. 1-3, Mathematics in Science and Engineering, vol. 141, Academic Press, 1979.
- [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

### 7.3 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.

## 8 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>