

**ECE 5397/6397: Introduction to Robotics**

**Spring 2016**

**Location:** [Class](https://fp.my.uh.edu/psc/saprd_fp/EMPLOYEE/HRMS/c/COMMUNITY_ACCESS.CLASS_SEARCH.GBL): 11:30am-1:00pm, Tues & Thurs in [D3](http://www.uh.edu/maps/buildings/?short_name=d3) [W205](http://www.uh.edu/infotech/php/classrooms.php?class_id=63), 01/19/2016 - 05/13/2016

Office hours: 2:00-3:30pm, Tues & Thurs in N386, or by appointment

**Instructor:** [Dr. Aaron T. Becker](https://www.youtube.com/user/aabecker5), email: [atbecker@uh.edu](mailto:atbecker@uh.edu), phone: (713) 743-6671

**Teaching Assistant: Li Huang** email: [lihuang.mech@gmail.com](mailto:lihuang.mech@gmail.com), phone: (713) 743-7296

Office hours: 2:00-3:30pm, Mon & Wed in N386, or by appointment

**Course Description:** Fundamentals of robotics including *rigid motions*; *homogeneous transformations*; *forward* and *inverse kinematics*; *velocity kinematics*; *motion planning*; *trajectory generation*; *sensing*, *vision*; *control*. Also, introduction to *swarm programming*, *search strategies*, and *distributed planning* and *control.*

**Project 1, Swarmathon:** The University of Houston was selected as a finalist for the NASA Swarmathon Challenge, <http://nasaswarmathon.com/>. As a finalist, we have been awarded three ‘swarmie’ robots, as well as access to a simulator environment in ROS for testing algorithms. Students will form 3 to 4-person teams. Each team will complete three challenges in ROS, concluding with an in-class competition on the Swarmathon challenge. Winning teams will be allowed to implement on the hardware robots and will compete in the national competition. **Before class begins**, please complete the introductory modules at <http://nasaswarmathon.com/outreach/> and install ROS, <http://www.ros.org/>, on your computer.

**Project 2, Robot Arm:** Students will form 2-person teams. Each team will build and control their own robot arm, powered by servos. The instructor will provide standard laser-cut arm components; teams will purchase their own servos & Arduino Mega (or suitable clone). We will use these arms to implement automatic controllers, forward and inverse kinematics, and forward/inverse velocity control. Teams may design their own laser-cut components for the final stage of the project.

**Prerequisites:**

Credit for or *concurrent enrollment* in **(**[MATH 3321](mailto:http://catalog.uh.edu/preview_course_nopop.php%3Fcatoid=8%26coid=25883) **or** **{**Calculus III ([MATH 2433](http://catalog.uh.edu/preview_course.php?catoid=6&coid=20461)), Linear Algebra ([Math 2331](http://catalog.uh.edu/preview_course.php?catoid=6&coid=20460)), Differential Equations ([MATH 3331](http://catalog.uh.edu/preview_course_nopop.php?catoid=6&coid=20471))**})** **and** **{**Automatic Controls [(ECE 4375)](http://catalog.uh.edu/preview_course_nopop.php?catoid=6&coid=19213) **or** Dynamics and Control of Mechanical Systems ([MECE 3338](http://catalog.uh.edu/preview_course_nopop.php?catoid=6&coid=20527))**}**

**Textbook:** [Robot Modeling and Control](http://www-cvr.ai.uiuc.edu/~seth/index.php?u=spongbook)   
**Mark W. Spong, Seth Hutchinson, M. Vidyasagar,**   
John Wiley and Sons, Inc., 2005

Readings and assignments will come from this book. You may share a book with a classmate. Over the next 14 weeks we will intensively learn from chapters 1, 2, 3, 4, 5, 11, 12.

**ROS textbook**: [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/). Free at <https://cse.sc.edu/~jokane/agitr/>. Print version at $12.50 at http://www.amazon.com/Gentle-Introduction-ROS-Jason-OKane/dp/1492143235

**Grading:** Grades will be determined on the basis of exams, quizzes, attendance, and submitted homework grades with the following **approximate** weights. The actual weights will be fixed at the end of the semester.

* 30% Homework
* 25% Lab /ROS
* 20% Exam 1
* 25% Exam 2
* You are allowed to discuss the homework problems and projects with your classmate but you cannot copy your classmate’s homework and project.
* Suspected cases of dishonesty will be promptly submitted to department’s hearing officer, as per the University of Houston’s [Academic Honesty](http://catalog.uh.edu/content.php?catoid=6&navoid=1025%23Article_3._Categories_of_Academic_Dishonesty) policy.

[**Exam Schedule**](http://www.uh.edu/academics/courses-enrollment/final-exam-schedules/): The FINAL EXAM will be given on Tues., May 10 from 11:00 am-2:00 pm,

Late Policy: Paper copies of your homework are due by 11:35am. A homework drop box will be physically locked after that time, and we will discuss the answers.

**Goals:** By the course end, you will be able to implement and use:

*Coordinate transforms,* [*rotation matrices*](https://en.wikipedia.org/wiki/Rotation_matrix)*,* [*Denavit-Hartenberg convention*](https://en.wikipedia.org/wiki/Denavit%E2%80%93Hartenberg_parameters)*, Robotics* [*kinematics*](https://en.wikipedia.org/wiki/Forward_kinematics) *and* [*inverse kinematics*](https://en.wikipedia.org/wiki/Inverse_kinematics)*,* [*velocity kinematics*](https://en.wikipedia.org/wiki/Robot_kinematics#Velocity_kinematics) *and inverse velocity kinematics, basic* [*computer vision*](https://en.wikipedia.org/wiki/Computer_vision)*,* [*path planning*](https://en.wikipedia.org/wiki/Motion_planning)[*artificial potential fields*](https://www.youtube.com/watch?v=r9FD7P76zJs)*,* [*sampling-based methods*](http://planning.cs.uiuc.edu/ch5.pdf)*. A lab component will integrate these topics with robotic hardware.*

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| **Note: Reading assignments should be completed *before* the lecture for which they are assigned.**  **ROS assignments are due each Thursday.** |

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| [**Date**](http://publications.uh.edu/content.php?catoid=14&navoid=3714) | **Topic** | **Assignments** |
| Jan 19 | General introduction and overview of the course | Read Chap. 1, student registration swarmathon  <https://secor.wufoo.com/forms/swarmathon-student-registration-form/> |
| Jan 21 | Rotation matrices, SO(n) | H#1 Read 2.1, 2.2,  Each team)Make an account and one post on <http://nasaswarmathon.com/qa-forum/>  <http://nasaswarmathon.com/outreach/> |
| Jan 22 | Webinar – Student Orientation / Hardware  live webinar will be January 22, 2016 at 2:00pm EST | <http://nasaswarmathon.com/timeline/> |
| Jan 26 | Coordinate transformations, composition of rotations, homogeneous transformations | H#2 Read 2.3, 2.4, 2.7 |
| Jan 28 | Coordinate transformation examples, Parameterizations of SO(3), Euler angles | H#3 Read 2.5, github checkin #1 |
| Feb 2 | Similarity transformations, rotations w.r.t. the fixed frame, axis/angle representation  Introduction to forward kinematics | H#4 Read 3.1 and 3.2 **HW 1 due** |
| Feb 4 | Forward kinematics: Denavit-Hartenberg convention and the derivation of D-H transformation matrix, assigning link frames using the DH convention. | H#5 Ch1 & 2 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Feb 9 | Forward kinematics examples | H#6  Ch 3 & 4 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Feb 11 | Inverse kinematics: general overview, geometric method, kinematic decoupling | H#7 Read 3.3 **HW 2 due (FWD Kinematics)** |
| Feb 16 | Inverse kinematics examples: Articulated arm, SCARA arm, and spherical wrist. | H#8    Ch 5 & 6 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Feb 18 | Introduction to angular velocity, skew symmetric matrices | H#8 Read 4.1-4.3 **HW 3 due (Inv. Kinematic)** |
| Feb 23 | so(3) and the derivative of a rotation matrix, velocity of a point attached to a moving frame, addition of angular velocities | H#9    Read 4.4-4.6 |
| Feb 25 | The manipulator Jacobian | H#10       Ch 7 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Mar 1 | Jacobian examples | H#11    Ch 8 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Mar 3 | Manipulator singularities | H#12    Read 4.9 **HW4 due (Jacobian)** |
| Mar 8 | Computer vision overview, segmentation | H#13   Read 11.3 |
| Mar 10 | Segmentation by minimizing within-group variance, recursive formulation for within-group variance | H#14    Read 11.3 |
| Mar 15 | SPRING BREAK |  |
| Mar 17 | SPRING BREAK |  |
| Mar 22 | Connected components, moments | H#14 Read 11.4-11.5 **HW5 due (Comp. Vision)** |
| Mar 24 | Position and orientation in binary images | H#15 Ch 9 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Mar 29 | Imaging geometry | H#16 Read 11.1-11.2 |
| Mar 31 | Exam 1 |  |
| Apr 5 | Camera calibration | H#17 Visual servo control Chapter 12 |
| Apr 7 | Introduction to path planning: configuration space obstacles for polygons that translate in the plane, generalized [Vornoi graphs](https://en.wikipedia.org/wiki/Voronoi_diagram), visibility graphs, cell decomposition. | H#18 Read 5.1 **HW6 due (Imaging Geometry)** |
| Apr 12 | Path planning using artificial potential fields | H#19 Read 5.2 |
| Apr 14 | Path planning using artificial potential fields (cont), planning as optimization | H#20 Read 5.3 |
| Apr 18-22 | *Swarmathon* at NASA Kennedy Space Center | H#21 Ch 10 [A Gentle Introduction to ROS](mailto:https://cse.sc.edu/~jokane/agitr/) |
| Apr 19 | Sampling-based methods for path planning | H#22 Read 5.4  **HW7 due (Config. Space)** |
| Apr 21 | Inverse Velocity , projection onto the null space of the manipulator Jacobian | H#23 Read 4.11 |
| Apr 26 | Singular value decomposition, Manipulability | H#24 Read 4.12 & Appendix B |
| Apr 28 | Manipulability, gradient projection to achieve secondary tasks. | H#25 **HW8 due (Interaction Matrix)** |

***Academic Honesty Policy:*** Students in this course are expected to follow the *Academic Honesty Policy* of the University of Houston. It is your responsibility to know and follow this policy. You must sign the Academic Honesty Statement on the last page of this handout, detach it, and submit it. If you fail to do this, you may be dropped from the course. For more information, see the *Academic Honesty* in the *Undergraduate Catalog* which is available on-line at

<http://catalog.uh.edu/content.php?catoid=8&navoid=1352>

***Religious Holy Days:*** Students whose religious beliefs prohibit class attendance on designated dates or attendance at scheduled exams may request an excused absence. To do this, you are **strongly encouraged** to request the excused absence, in writing, by Wednesday, February 3, 2015. Please submit this written request to your instructor to allow the instructor to make appropriate arrangements.

More information can be found at

<http://www.uh.edu/dos/studenthandbook/academicpolicy/a_holydays.html>

***Students with Disabilities:*** Students with recognized disabilities will be provided reasonable accommodations, appropriate to the course, upon documentation of the disability with a *Student Accommodation Form* from the *Center for Students with Disabilities*. To receive these accommodations, you must request the specific accommodations, by submitting them to the instructor in writing, by Wednesday, February 3, 2015. Students who fail to submit a written request will not be considered for accommodations. More information, can be found at

<http://www.uh.edu/dos/studenthandbook/academicpolicy/a_disability.html>

***Attendance:*** Attendance at all classes is expected and required. The instructor may, if he chooses, take attendance in any class, at any time during the class. The instructor may do this as many times per class period as he chooses, without warning. The attendance grade can be included in the grade for the course. Attendance at every class is expected. Roll will be occasionally taken and an in-class exam may be given during any class period. There will be no make-up of missed in-class exams.

***Grade Posting***: You may find out your grade in the course online using PeopleSoft. Normally, the grades are available about one week after the final exam. The instructor is not allowed to give out grades over the phone or by email. During the semester, grades will be posted on Blackboard in a secure manner, i.e., so that only you will have access to your grades. Final grades will also be posted on Blackboard at the end of the semester; however, the official grade reporting is done on PeopleSoft, not on the Blackboard.

***Grade Point Rule***: The following **approximate** grade point scale will be used in determining your grade. This scale may be modified somewhat, but is included here so that you will have a general idea of how well you are doing in the course. The final grade scale will be determined at the end of the semester.

90–100: A's 80–89.9: B's 70–79.9: C's 60–69.9: D's <60: F

***Extra Credit***: However, we also want to do well in the swarmathon competition. For this reason, the team that wins either the physical or the simulated competition will receive 100% in the course. A team that scores nth place receives an additional 15\*1.25(2-n). That means a 2nd place finish gives you 15% extra credit

Mathematica Demonstrations are important to the instructor. A *published* (before the end of the semester), intro-to-robotics-related Mathematica demonstration (with Dr. Becker as the last author), will add 2.5 to 6% to your final grade. Some topics include  demonstration on inverse velocity kinematics as robot traces out a square and circle,  calculation and plot of manipulability ellipse of robot arm at different configurations,  demonstration on DH parameters,  visualization of robot workspace  configuration vs workspace of an RR robot  visualization of workspace singularities.

***Withdrawal Policy:*** The withdrawal dates listed in the Academic Calendar section of the *Class Schedule* will be followed strictly. You may drop the course without receiving a grade until Wednesday, February 4, 2015 which is the University's last day to drop without receiving a grade. After this date and until Monday April 6, which is the University's last day to drop, you may drop with a W if you have not exceeded your total W limit (the limit applies to undergraduate students only). Grades of Incomplete (I) will be given only when a small portion of the course has not been completed for a good reason. If the material has been completed, an “I” grade cannot be given. Detailed information about these issues is available in the University of Houston Undergraduate Catalog.

***Blackboard:*** We will be using the Blackboard Learn web site (<http://www.uh.edu/blackboard>) for posting of grades and email. We will assume that your UH email alias ([joejones@uh.edu](mailto:joejones@uh.edu)) is pointed to a working email server, and that you are available at that address. All documents and handouts will be available on a git repository (<https://en.wikipedia.org/wiki/Git_(software>) ) . You must have a github account <https://github.com/>.

**Related Robotics Courses:**

Consider taking [MECE 3400 “Introduction to Mechanics”](http://catalog.uh.edu/preview_course_nopop.php?catoid=8&coid=25949) ,

COSC 4332 or 6332 - Medical Robots & Interventions, INDE 7361 - Industrial Robotics

ECE 6325 - State-Space Control Systems, ECE 6335 - Digital Control Systems, ECE 6390 - Linear Multivariable Control Systems, ECE 7333 - Optimal Control Systems, ECE 7334 - Advanced Digital Control Systems



**Academic Honesty Statement & Email Agreement**

**Name: (printed)** \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

***Confirm that the following statements are true and then sign and date below.***

Academic Honesty Statement

* I have read the University of Houston Academic Honesty Policy contained in the UH Undergraduate Catalog available at <http://catalog.uh.edu/content.php?catoid=8&navoid=1352>
* and the ECE 2300 Position on Academic Honesty contained in the Course Policy Document and available on the course web site and agree to abide by its provisions. I understand that the *Department of Electrical & Computer Engineering* takes academic honesty very seriously and, in the cases of violations, penalties may include suspension from the University of Houston.

UH E-mail Alias Agreement

* I have read the University of Houston Information Technology website discussing UH e-mail aliases (<http://www.uh.edu/infotech/services/accounts/email/update-student-address/index.php>). I understand how to use this alias to receive e-mail through my outside provider.
* I understand that it is my personal responsibility to configure this alias properly to receive mailings from the university.
* I understand that the ECE department will use this e-mail alias for all official correspondence.

Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

UH E-mail Alias: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Date: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

***Submit this form to your professor by \_\_\_\_.***