

# Homework 2:

## Rotation Matrices and Homogeneous Transformations

MEAM 520, University of Pennsylvania  
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This paper-based assignment is due on Tuesday, September 17, by midnight (11:59:59 p.m.) You should aim to turn it in during class that day. If you don't finish until later in the day, you can turn it in to Professor Kuchenbecker's office, Towne 224, in the bin or under the door. Late submissions will be accepted until Thursday, September 19, by noon (11:59:59 a.m.), but they will be penalized by 10% for each partial or full day late, up to 20%. After the late deadline, no further assignments may be submitted.

You may talk with other students about this assignment, ask the teaching team questions, use a calculator and other tools, and consult outside sources such as the Internet. To help you actually learn the material, what you write down should be your own work, not copied from any other individual or a solution manual. Any submissions suspected of violating Penn's Code of Academic Integrity will be reported to the Office of Student Conduct. If you get stuck, post a question on Piazza or go to office hours!

These problems are from the textbook, *Robot Modeling and Control* by Spong, Hutchinson, and Vidyasagar (SHV). Please follow the extra clarifications and instructions when provided. Write in pencil, show your work clearly, box your answers, and staple together all pages of your assignment. This assignment is worth a total of 20 points.

1. SHV 2-6, page 65 – Verifying Three Properties of  $R_{z,\theta}$  (2 points)  
The three equations to verify are (2.3), (2.4), and (2.5); they appear on page 42 of SHV.
2. SHV 2-10, page 66 – Sequence of Rotations (2 points)  
Please specify each element of each matrix in symbolic form and show the order in which the matrices should be multiplied; as stated in the problem, you do not need to perform the matrix multiplication.
3. SHV 2-14, page 67 – Rotating a Coordinate Frame (4 points)  
Sketch the initial, intermediate, and final frames by reading the text in the problem. Make your drawings big, and remember the right-hand rule. Then find  $R$  in two ways: by inspection of your sketch and by calculation. Check your solutions against one another.
4. SHV 2-23, page 68 – Axis/Angle Representation (4 points)  
Be careful with the sketch, and remember the right-hand rule.
5. SHV 2-39, page 70 – Homogeneous Transformations (4 points)  
Treat frame  $o_2x_2y_2z_2$  as being located at the center of the cube's bottom surface (as drawn in Figure 2.14), not at the center of the cube (as stated in the problem). Be careful with notation; you are looking for  $H_1^0$ ,  $H_2^0$ ,  $H_3^0$ , and  $H_2^3$ .
6. SHV 2-43, page 71-72 – Commutativity of Homogeneous Transformations (4 points)