

# Homework 1

## Introduction to Robotics

1. What are the degrees of freedom of a standard, four-wheel, hand-pushed lawnmower? Why are you still able to mow your entire lawn? *1pt*
2. What are the maximum degrees of freedom for objects driving on the plane? *1pt*
3. (a) Calculate the angle between vectors  $(\cos 45^\circ, -\sin 45^\circ, 0)^T$  and  $(\sin 45^\circ, \cos 45^\circ, 0)^T$ . *1pt*  
(b) Provide a third vector that forms a coordinate system with the other two. *1pt*
4. (a) Write out the entries of a rotation matrix  ${}^A_B R$  assuming basis vectors  $X_A, Y_A, Z_A$ , and  $X_B, Y_B, Z_B$ . *1pt*  
(b) Express  $\hat{X}_B = [0, 1, 0]^T$  in frame  $\{A\}$ . *1pt*  
(c) Write out the entries of rotation matrix  ${}^B_A R$ . *2pt*
5. Consider a tri-cycle with two independent standard wheels in the rear and the steerable, actuated front-wheel. Assume  $r$  to be the radius of the front wheel and  $l$  be the distance between the front and rear axle. Choose a suitable coordinate system and use  $\phi$  as the steering wheel angle and wheel-speed  $\dot{\omega}$  (only the steered front-wheel is driven). Provide the forward kinematics of the mechanism. *2pt*