# Principles of Robot Autonomy II
# Exam 2 Solutions
# February 24, 2023

**Name:**

**SUNet ID:**

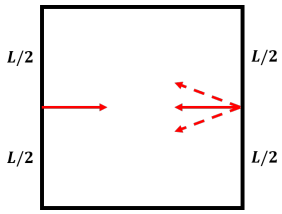
**Instructions**:

- Time allowed: 60 minutes.
- Total Points: 36.
- The exam consists of **three** equally weighted problems.
- Please read all questions carefully before answering. Correct answers with correct explanations will receive full credit.
- **To get partial credit for an incorrect answer, you should explain your reasoning.** Please write all your answers in the provided answer sheet.

Good luck!

1. **Fundamentals of Grasping (12 points)**
For all parts of this question, assume all forces are normal to the surface and a contact has friction if and only if cone edges are drawn with dashed lines. Each of the six questions is worth 2 points.

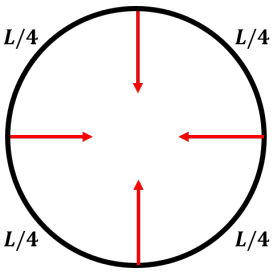
(i) Choose the correct statement about the following grasp on a planar square object where only one surface has friction:




It is neither a force nor a first-order form closure.
It is a force closure, but not a first-order form closure.
It is not a force closure, but a first-order form closure.
It is both a force and a first-order form closure.

*Explain:*

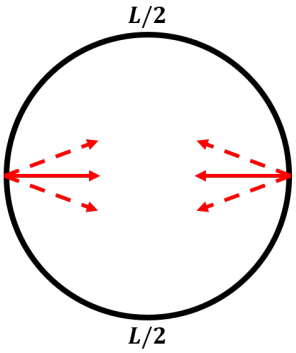
(ii) Choose the correct statement about the following grasp on a planar circle object:




It is neither a force nor a first-order form closure.
It is a force closure, but not a first-order form closure.
It is not a force closure, but a first-order form closure.
It is both a force and a first-order form closure.

*Explain:*

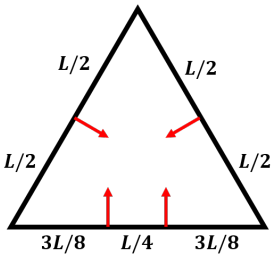
(iii) Choose the correct statement about the following grasp on a planar circle object:




It is neither a force nor a first-order form closure.
It is a force closure, but not a first-order form closure.
It is not a force closure, but a first-order form closure.
It is both a force and a first-order form closure.

*Explain:*

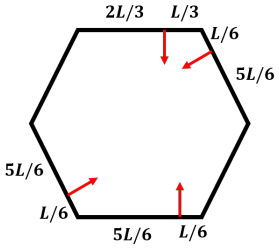
(iv) Choose the correct statement about the following grasp on a planar equilateral triangle object:




It is neither a force nor a first-order form closure.
It is a force closure, but not a first-order form closure.
It is not a force closure, but a first-order form closure.
It is both a force and a first-order form closure.

*Explain:*

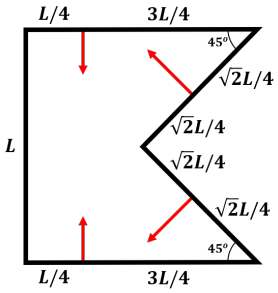
(v) Choose the correct statement about the following grasp on a planar equilateral hexagon object:




It is neither a force nor a first-order form closure.
It is a force closure, but not a first-order form closure.
It is not a force closure, but a first-order form closure.
It is both a force and a first-order form closure.

*Explain:*

(vi) Choose the correct statement about the following grasp on a planar object where a right triangle is cut from a square:




It is neither a force nor a first-order form closure.
It is a force closure, but not a first-order form closure.
It is not a force closure, but a first-order form closure.
It is both a force and a first-order form closure.

*Explain:*

**Solutions:**

(i) (a) It is not a first-order form closure, because there are only 2 forces. It is also not a force closure, because it cannot withstand any torque (or it will move in the vertical direction).

(ii) (a) It is not a first-order form closure, because a circular object can always rotate. As there is no friction, first-order form closure is equivalent to force closure.

(iii) (b) It is not a first-order form closure, because there are only two forces. It is a force closure, which can be shown by the wrench space analysis. Intuitively, we can force-grasp a circular object with two fingers.

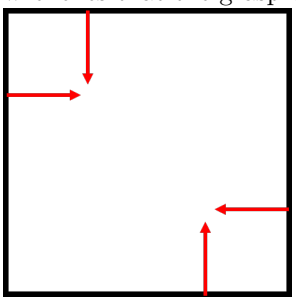
(iv) (d) By graphical planar method, this is a first-order form closure, and so a force closure.

(v) (a) By graphical planar method, this is not a first-order form closure, and so not a force closure. One can also note this by realizing the grasp cannot withstand a torque that tries to rotate in the counter-clockwise direction (the top force must increase, which then requires the bottom two forces to increase for stability in the vertical direction. This further increases the counter-clockwise rotation.)

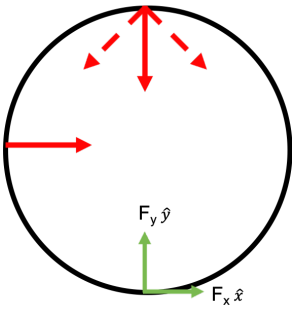
(vi) (a) For the grasp to be stable in the horizontal direction, the forces on the right must be zero. The remaining two forces cannot create a first-order form closure, and so not a force closure.

2. **Grasp force optimization and planar pushing (12 points)**

(i) Consider the grasp below that achieves first-order form closure. True or False: If the fingers can only provide a maximum of 1 Newton of force at the contact points, then there are some external wrenches that the grasp cannot cancel.



(ii) Consider the following object with radius $R = 1$ being grasped at two contacts. An external force (shown in green) is applied with components $F_x$ and $F_y$ in the $\hat{x}$ and $\hat{y}$ directions, respectively. If the friction coefficient for the point contact with friction is $\mu = 1$, then what is the range of external forces $F_x$ and $F_y$ that can be rejected by this grasp?




$F_x \geq 0$ and $F_x \leq F_y$
$F_x \leq 0$ and $|F_x| \leq F_y$
$F_y \geq 0$ and $F_y \leq F_x$
$F_y \leq 0$ and $|F_y| \leq F_x$

*Explain:*

(iii) The Friction Limit Surface is a fundamental concept when modelling how a planar object slides over a planar surface. Select all that apply!

The friction limit surface is a plane that separates the wrenches that cause object motion from those that do not cause motion.

The friction limit surface is typically approximated by an ellipsoid.
The friction limit surface is parameterized by linear and angular velocities.
The friction limit surface is parameterized by forces and torques.

*Explain:*

**Solutions:**

(i) True. An external wrench might require more than 1N.

(ii) (b), by writing out the grasp matrix and performing row reduction, we can calculate the range space and use this to determine which grasps can be rejected.

(iii) (b) and (d).

3. **Learning-based grasping and manipulation (12 points)**

(i) Which of the following is **not** an advantage of any of the learning-based grasping methods discussed in the lectures?

Doesn't require 3D models of objects
Doesn't require physics models of materials
Can generalize to previously unseen objects
Is guaranteed to successfully grasp a previously seen object
Can be computed in simulation environments

*Explain:*

(ii) Which of the following is an advantage of the analytical grasping methods discussed in the lectures?

Doesn't require 3D models of objects
Doesn't require physics models of materials
Is guaranteed to successfully grasp a previously seen object in the real world
Can be computed in simulation environments

*Explain:*

(iii) True or False: Simple models may suffer from bias due to simplifying assumptions about the data, while complex models may suffer from overfitting to training samples from a high variance dataset.

**Solutions:**

(i) (d) There is no guaranteed success with any of the learning methods.

(ii) (d), For analytical grasping methods, we don't have to run real world experiment to test outcome.

(iii) True. Bias-variance trade-off discussed in lecture.