ENSC894:Introduction to Robotics – Spring 2024

Two-Contact Force Closure Project Report

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1. ALGORITHM

Step 1. Basic setup

With the given facet number (says N) set in variable 'FRICTION_CONE_APPROX', we calculate the angles between two neighboring friction cone facets.

Step 2. Build friction cone boundary vectors

With surface normals and the corresponding friction coefficient, we can calculate a friction cone boundary vector using the following relationship:

$$u = atan2(CoF)$$

, where CoF is the given friction coefficient, and u is the angle between the surface normal and friction cone vector.

Then, we rotate this first vector about the surface normal (N-1) times to get the rest of the friction cone's boundary vectors. After getting all the friction cone vectors, we visualize the friction cones and corresponding normal vectors.

Step 3. Construct grasp wrench space (GWS)

For each friction cone boundary vector *Fi*, we convert it into a grasp wrench:

$$Grasp\ wrench\ Wi = [Fi, Fi \times D]$$

Where *D* is the distance between the point contact and the center of mess (CoM), in this project, the CoM is assumed to be at the origin of the object frame. The grasp wrench is a 1 x 6 vector in which the first 3 elements (*Fi*) represent the force, and the last 3 elements (*FixD*) represent the torque. With all the grasp wrenches, we now have the grasp wrench space.

Step 4. Determine force-closure

Now we have 2 contacts * N vertex-per-friction-cone = 2*N wrenches. Using these 2*N points, we can construct a convex hull. To determine if force closure is satisfied, we can simply see if the CoM (origin in our case) is located inside the hull.

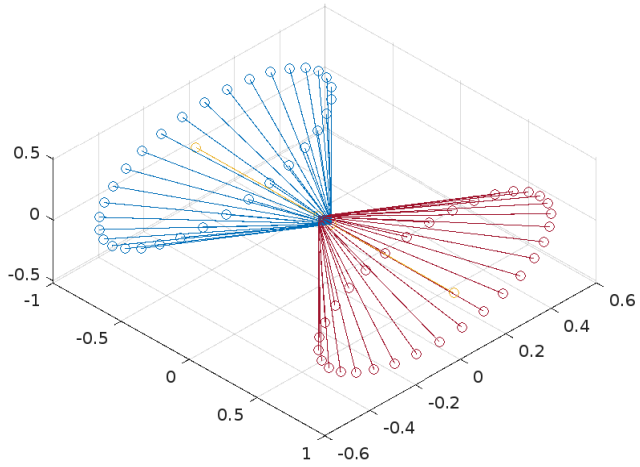
Limitations

The object's center of mass should be known in advance, but it is not always available. The surface's friction coefficient and precise normal are also prerequisites. Also, all of the contacts should be exerted at the same time. In computation, the time complexity increases exponentially with the contact number.

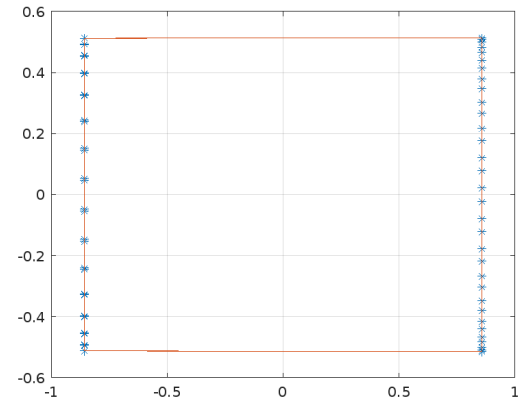
2. SAMPLE TEST RESULTS

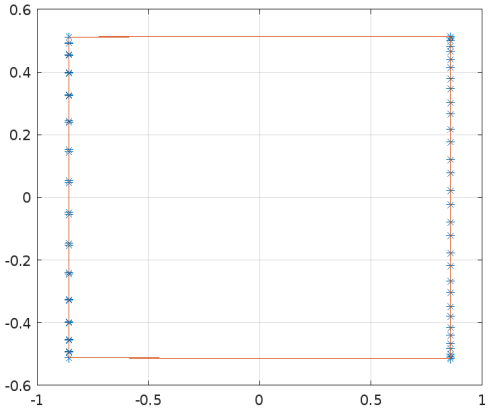
Sample Testcase 1: Is Force-Closure

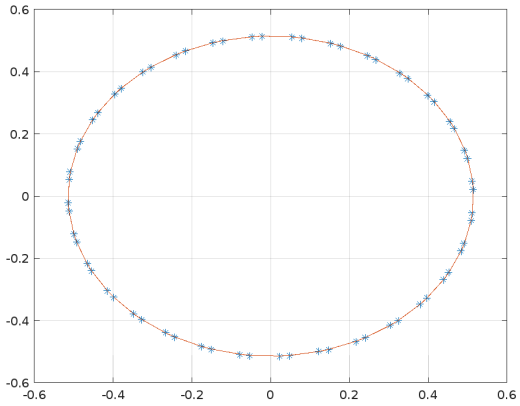
Friction Cone:



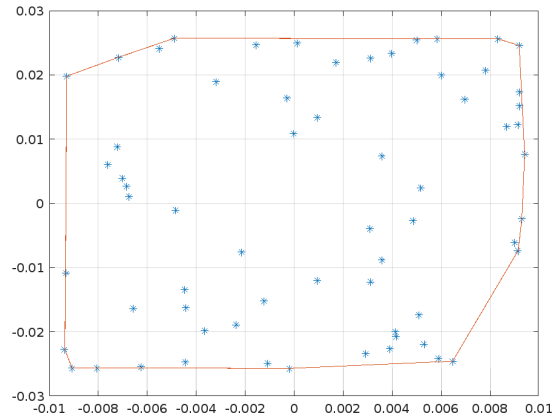
Grasp Wrench (Force) Projected onto XY / XZ / YZ Plane:

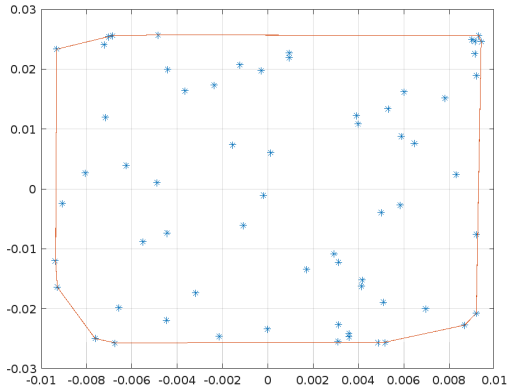


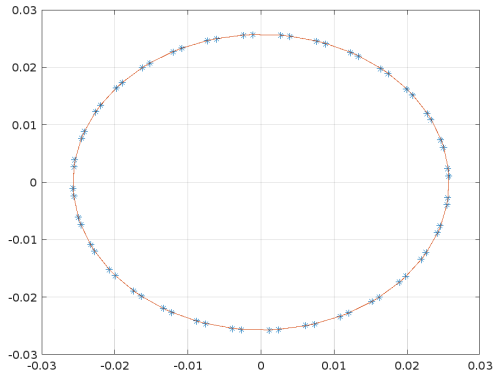




Grasp Wrench (Torque) Projected onto XY/XZ/YZ Plane:

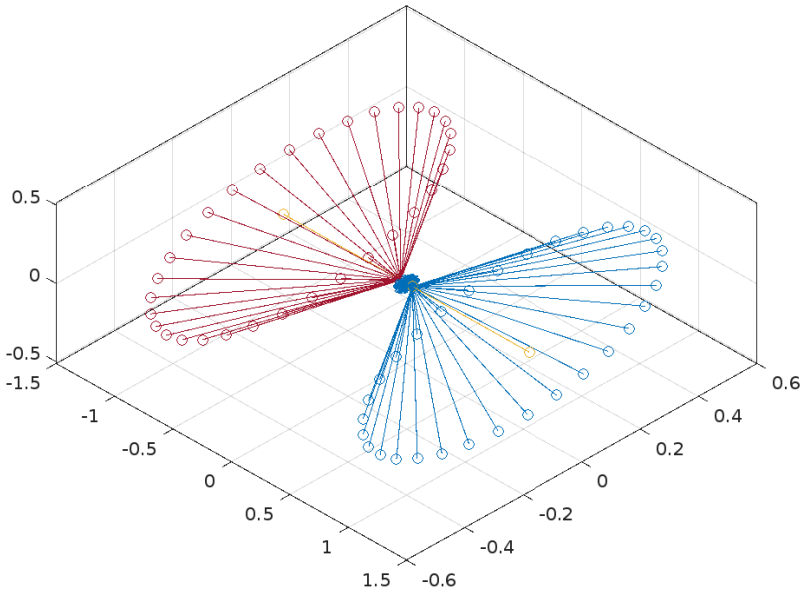




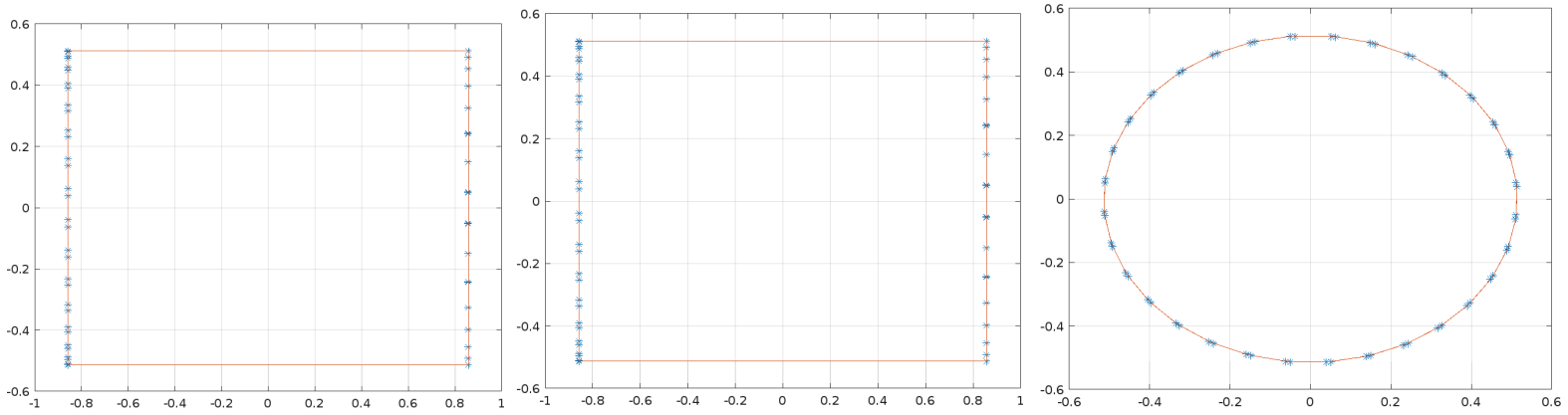


Sample Testcase 2: Is Force-Closure

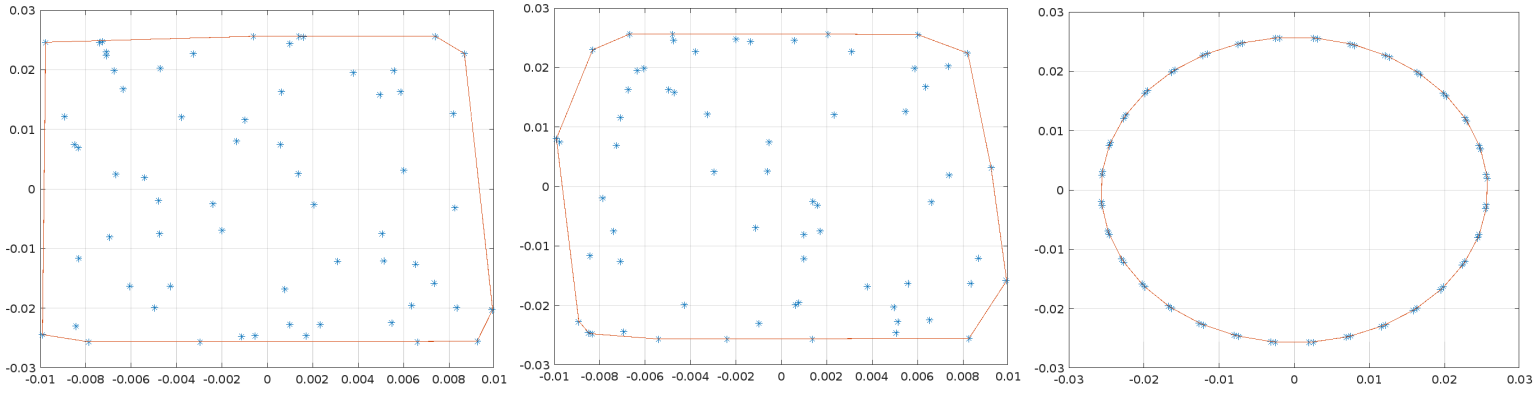
Friction Cone:



Grasp Wrench (Force) Projected onto XY / XZ / YZ Plane:

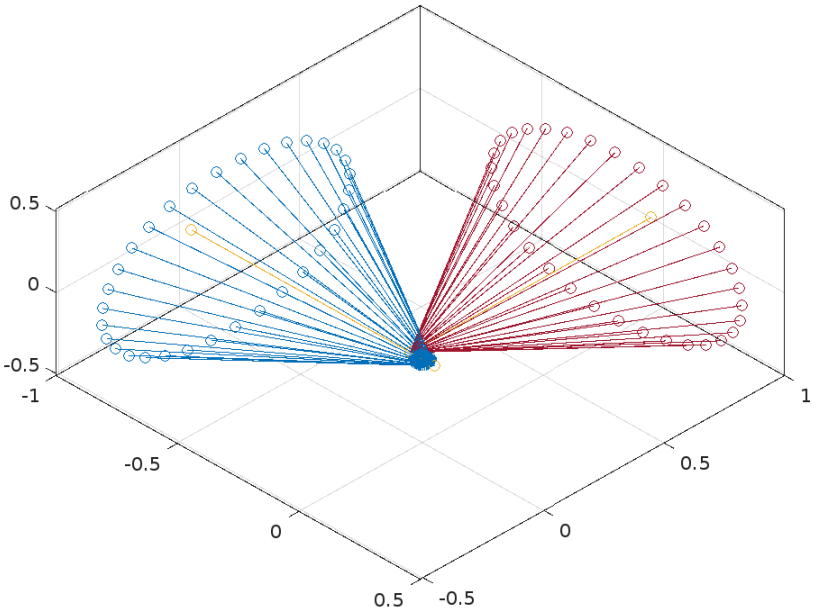


Grasp Wrench (Torque) Projected onto XY/XZ/YZ Plane:

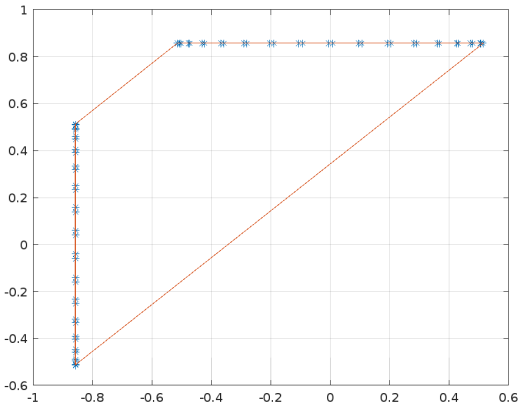


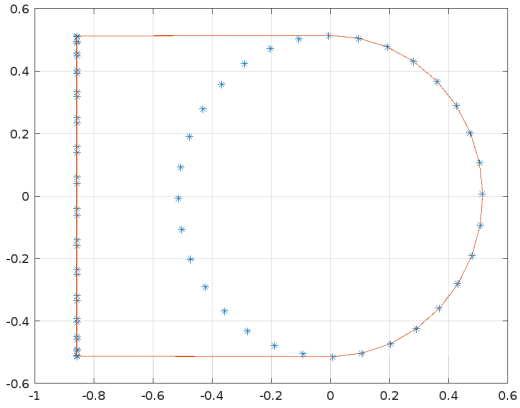
Sample Testcase 3: Is Not Force-Closure

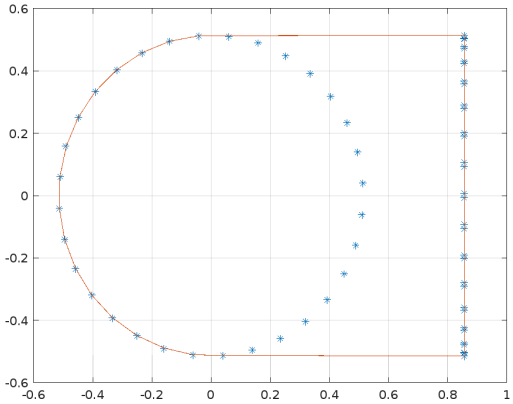
Friction Cone:



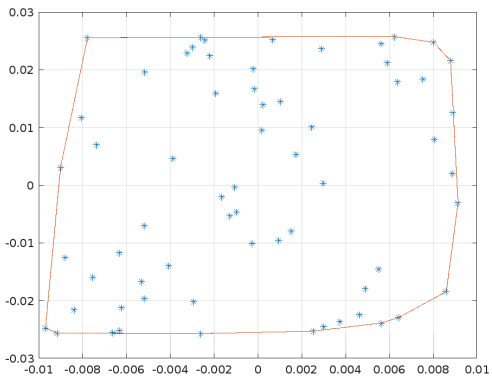
Grasp Wrench (Force) Projected onto XY / XZ / YZ Plane:

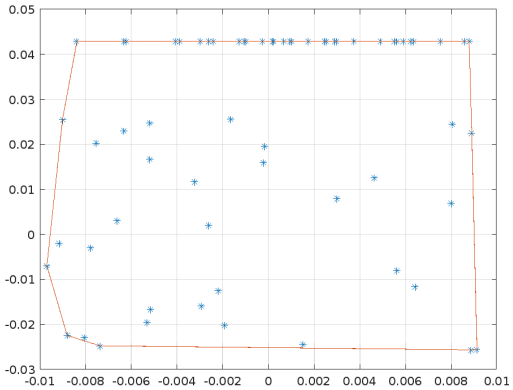


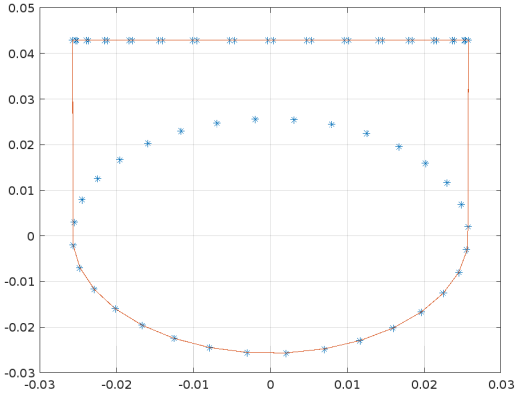




Grasp Wrench (Torque) Projected onto XY/XZ/YZ Plane:

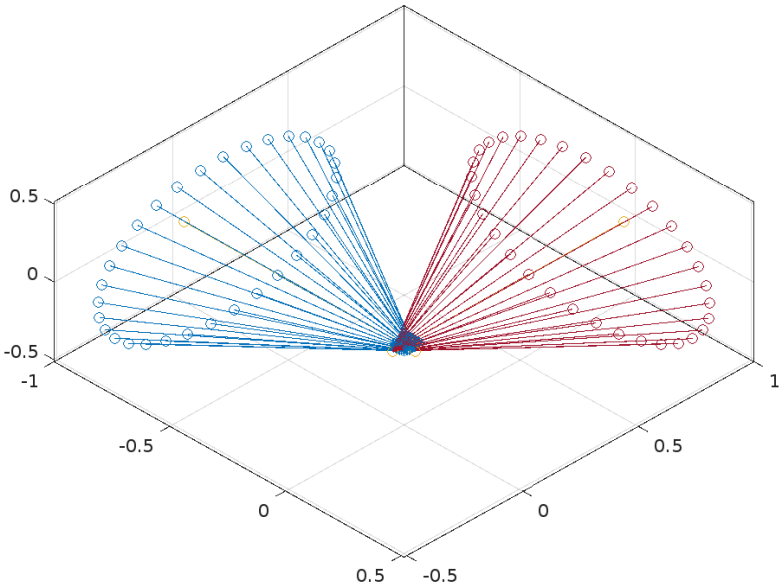




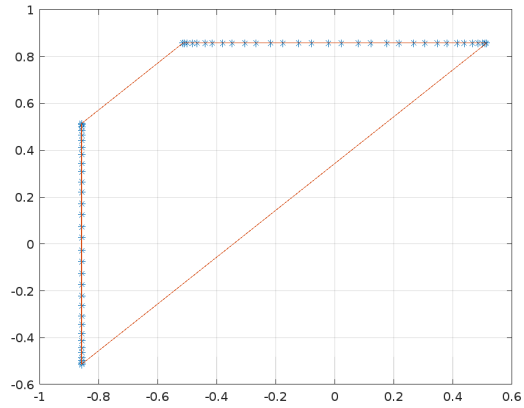


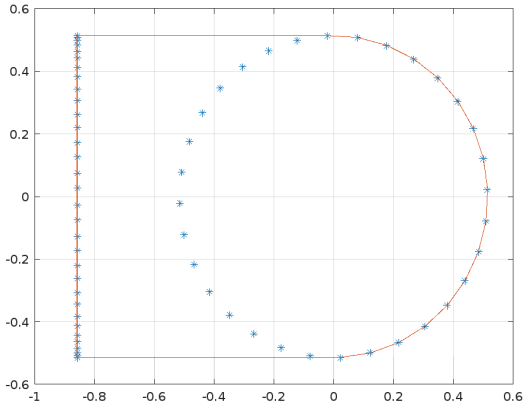
Sample Testcase 4: Is Not Force-Closure

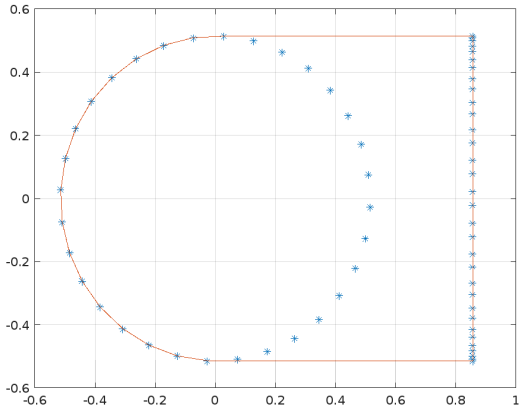
Friction Cone:



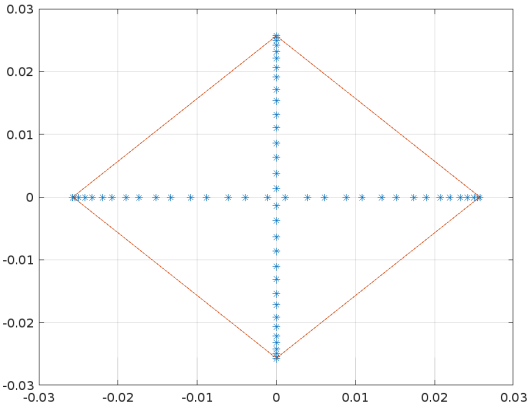
Grasp Wrench (Force) Projected onto XY / XZ / YZ Plane:

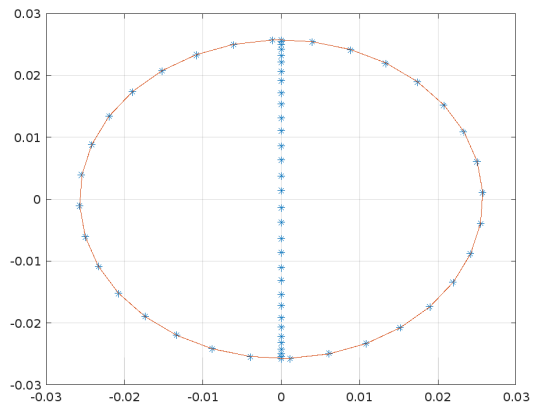


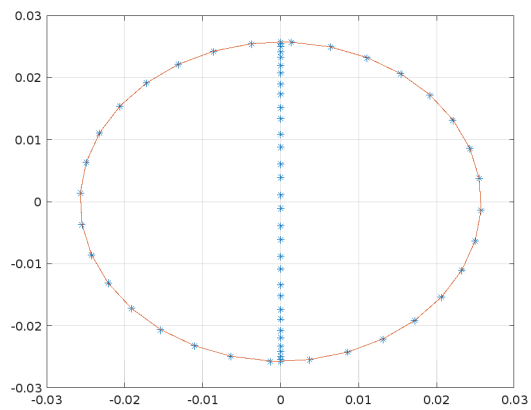




Grasp Wrench (Torque) Projected onto XY/XZ/YZ Plane:

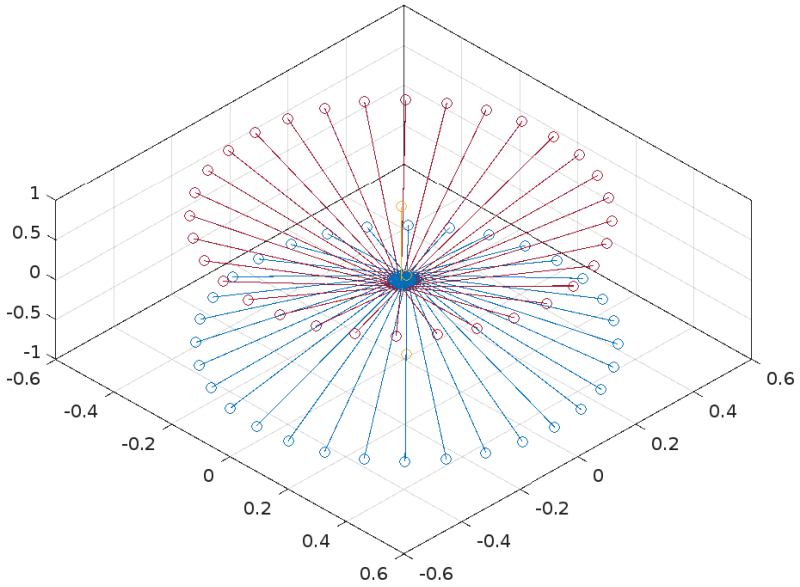




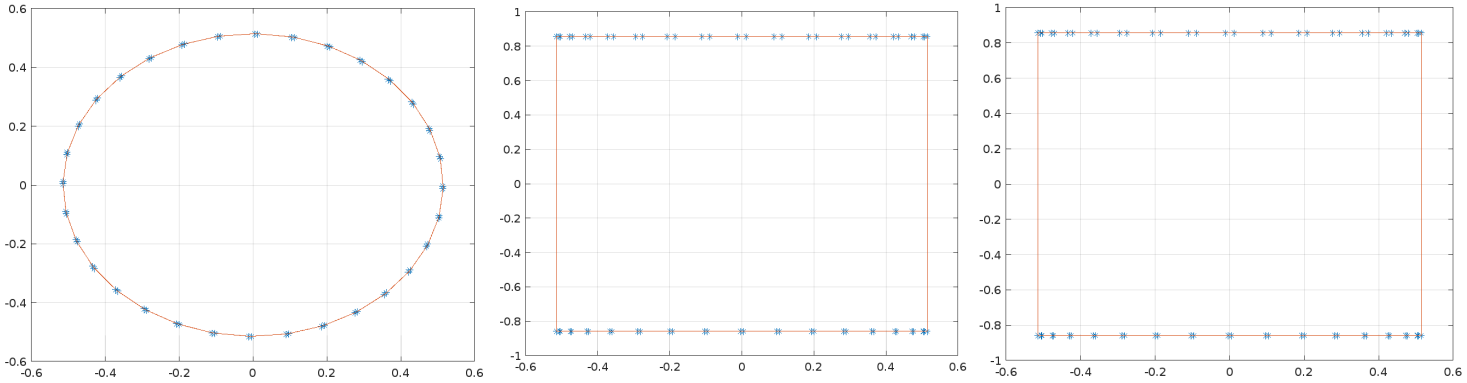


Sample Testcase 5: Is Not Force-Closure

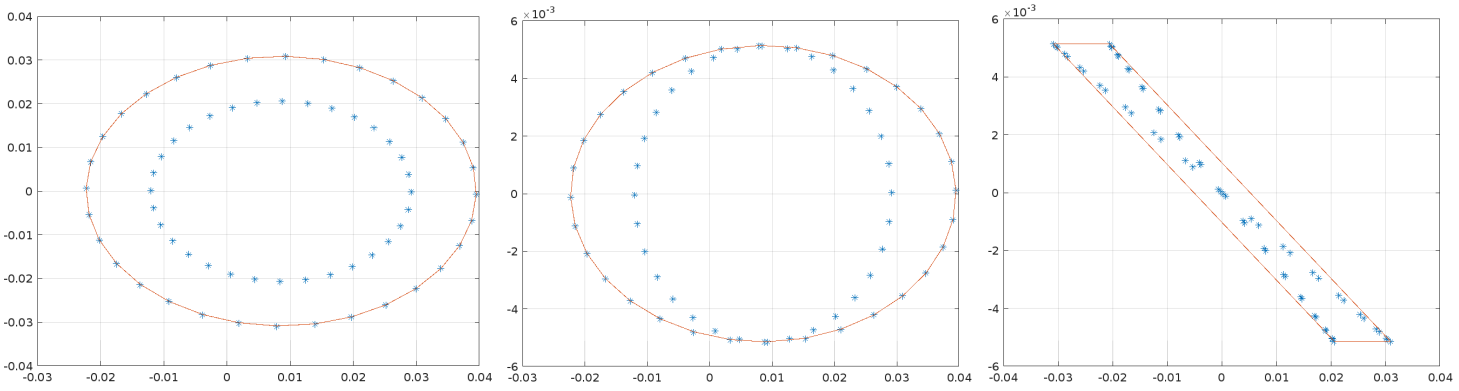
Friction Cone:



Grasp Wrench (Force) Projected onto XY / XZ / YZ Plane:



Grasp Wrench (Torque) Projected onto XY/XZ/YZ Plane:



3. FINAL TEST RESULTS

As of now (Aril 3, 2024), the final test cases have not been releases yet. The final test results will be supplemented in the next submission.

4. DISCUSSION

- Force is always applied to the center of mass no matter where the contact point is. On the other hand, torque depends on the position of contacts.
- Although gravity is not considered in this project, through the in-class discussion, we learned that gravity is merely pure force (i.e., without torque) exerted on the object. In other words, the wrench generated by gravity is [0, 0, 9.8, 0, 0, 0].
- In real-world scenarios, it's common to use soft finger contact (e.g., adding a rubber pad on the fingertips) to increase the friction, which enlarges the volume friction cone (range admissible force).
- In practice, we use 8 facets to approximate a friction cone. Friction cones having less than 8 facets are not sufficient to determine force closure. On the other hand, having more than 8 facets brings benefits in edge cases only but causes lots more computation effort.
- Nonmarginal v.s. marginal equilibrium: Marginal equilibrium means that the object is balanced, but its center of mass is located on the boundary of grasp wench convex hull. Nonmarginal equilibrium refers to a better balance status in which the grasp has room to resist external forces.