Project 2: The Swinging Gripper

24-370 Engineering Design I, Spring 2011
Assigned 16 February, First prototype due 21 March, Second prototype and report due 4 April

Overview:

In this project, your team will design, fabricate, and test a robotic gripper comprised of custom and catalog components. Your team's gripper must hold a spherical object, contacting it only in specific regions. The gripper will be attached to a robot arm (provided) which will move rapidly through a circular arc. Near the attachment point on the arm, a motor-driven shaft (provided) will produce an open-loop torque when switched on. You must use this drive shaft to close your gripper on the object and hold it securely during arm motions. Don't drop the ball!

Your team must provide two fully-functional revisions of your gripper prototype for testing on the dates listed above. Both versions count! Both prototypes must meet all design and performance criteria. The only exception is dynamic performance; just one of your prototypes must successfully hold the object during rapid arm motions for full credit.

During the design process, you must use a combination of sketching and simple models, including free body diagrams and analyses in symbolic form; computer-aided design tools, including for modeling, static stress analysis and kinematic analysis of your assembly; catalog selection processes; material selection processes; and prototype manufacturing methods. You will have a small budget for purchasing catalog components. You will be required to use certain materials and manufacturing methods for some of your parts. Your team will need to fabricate and assemble your gripper on your own, unless you use funds from your budget to have parts made (within time limits). Documentation of all these steps will be required in your final report.

Diverse teams have been assigned so as to maximize the learning experience for all members. Your team will evenly divide project tasks, such that members participate in all parts of the design process evenly. Your final report will include documentation of the division of efforts. Your team will also provide anonymous self and peer evaluations.

In addition to your report and required gripper performance criteria, there are two optional challenges! The team with the lightest functional gripper assembly, including all parts, will win bonus points and a prize! Additionally, the team with the lowest-cost gripper assembly, including all costs other than team labor, will win bonus points and a prize! Teams that come close to the winning benchmarks will also win pro-rated bonus points. Prizes will be awarded based on the best of all entries from both revisions.

Please read each project description in full as they come out, so that you are not surprised by deliverables at the last moment. Please use the course email address, TA office hours, and/or Q&A sessions at the beginning of class if you have any questions about the project.

Sketched-in specifications and constraints:

This "sketch description" is intended to give you a qualitative understanding of the design challenge, without the distracting details of quantitative data. Use this opportunity to generate conceptual sketches and perform symbolic analyses related to the design.

Gripping geometry and kinematics:

Your team's gripper will need to start in an open position, then close in on the spherical object and hold it firmly. The sphere will be of medium diameter compared to the useful design envelope. The sphere will be of medium to low density compared to other materials used in your design. The exterior of the sphere will have a medium coefficient of friction. The gripper attachment point will be above the sphere. Attachment may occur only in two places: at a bolt pattern in the horizontal plane on the bottom of the robot "wrist", and on the drive shaft. The sphere cannot be supported from below by your gripper, as there is an impermissible region extending downwards from just below the hemisphere line. The gripper must also not interfere with an initial impermissible region to one side of the sphere prior to closure. The gripper must use the drive shaft to close on and hold the sphere. The drive shaft will provide an open-loop motor-driven torque of medium-low magnitude when turned on. Finally, the gripper must not extend beyond the assembly envelope (permissible region) when closed. These ideas are qualitatively shown in Figure 1.
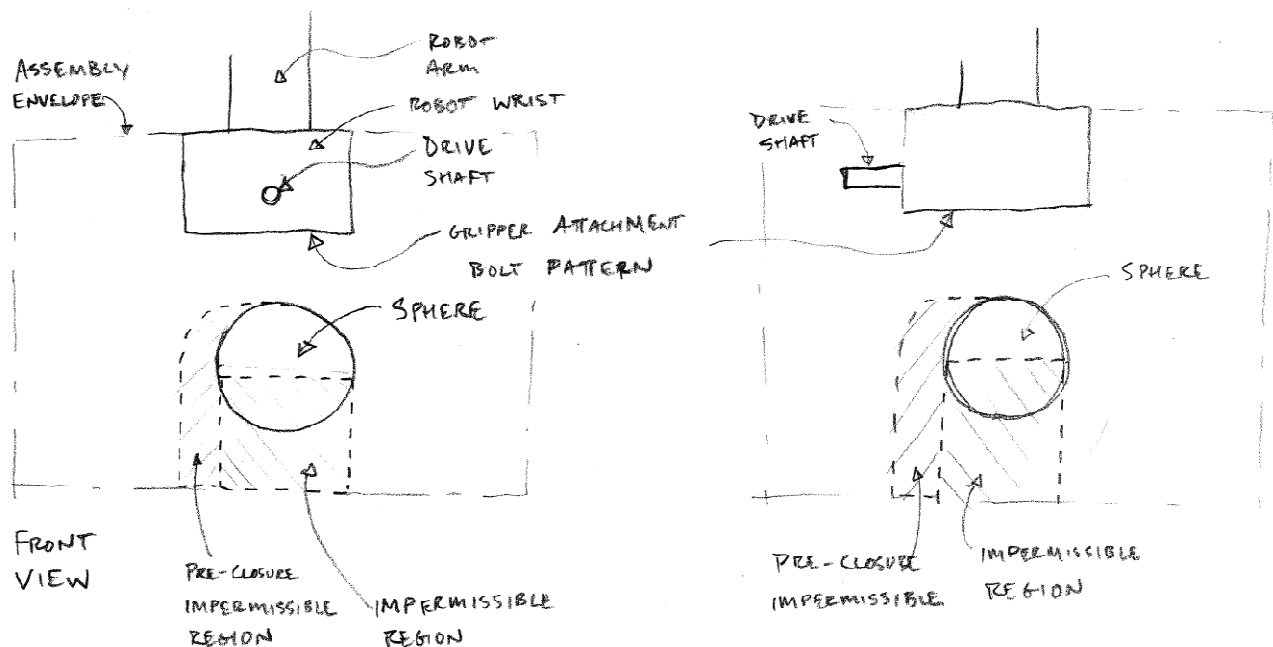

Figure 1. Gripping geometry, including possible attachment points, interference regions, and part envelope.

Dynamic arm motions:

The gripper will be mounted to the end of a robotic arm that will swing rapidly while the sphere is held. The robot arm will be relatively long compared to the size of the gripper envelope and sphere. The robotic "shoulder" joint will be a free-rotating one-degree-of-freedom pin hinge. This joint will allow rotation within the front plane, which is the same rotational direction as the drive shaft. The robot arm will hang loosely in gravity during gripper closure. After the sphere has been gripped, the robot arm will be manually rotated to a horizontal position, and then released. This will cause dynamic accelerations to be experienced by the gripper and sphere, as long as they are moving with the arm :D These ideas are qualitatively diagrammed in Figure 2.
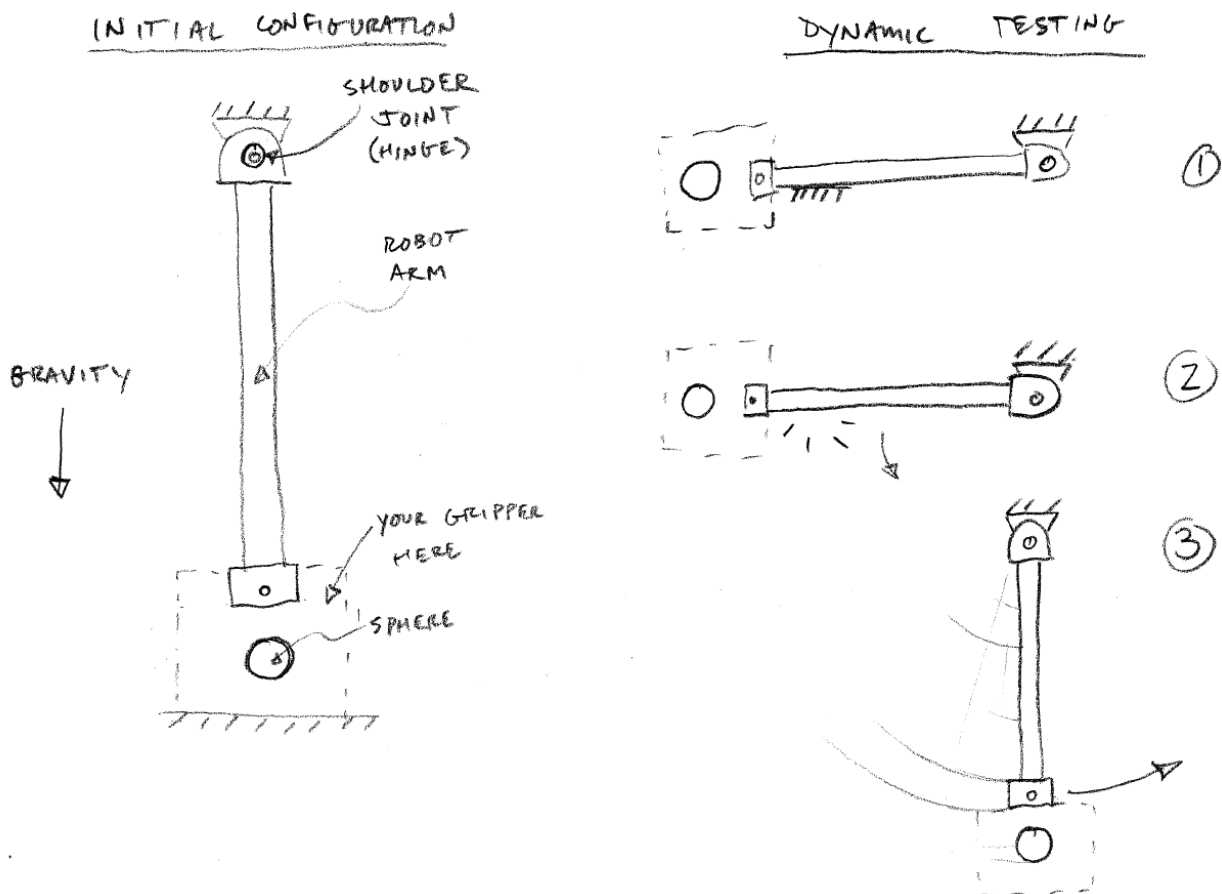

Figure 2. Dynamic robot arm motions with the gripper holding the sphere.

Detailed Specifications and Constraints

Spherical Payload: The outer diameter of the sphere is 3.000 ± 0.125 inches and the mass is 145 ± 5 g. The dry, static, steel-contacted coefficient of friction, μ, is about 0.2. The Shore A durometer is about 70. The sphere is nonferrous and otherwise non-magnetic, with a rough semi-porous surface.

Driving Torque: The maximum output (stall) torque of the drive shaft is 1.25 ± 0.25 N m, and the maximum (no load) speed is 560 rad s^{-1}, when the motor is switched on. Consider both the minimum and maximum possible torque when designing your gripper. You should include a factor of safety both for part strength and for holding the ball, and these might require different conservative estimates of drive torque. The torque is in a clockwise direction when looking at the shaft.

Dynamic Arm Motions: The arm will be released from a horizontal position. The distance between the shoulder hinge and the center of the spherical payload is approximately 28 inches, but this distance should negligibly affect your calculations.

Gripping Geometry and Kinematics:

The details of the robotic wrist are shown in Figure 3, and details of the overall geometry are shown in Figure 4. Note that you may choose one of two possible pre-gripped non-interference regions.
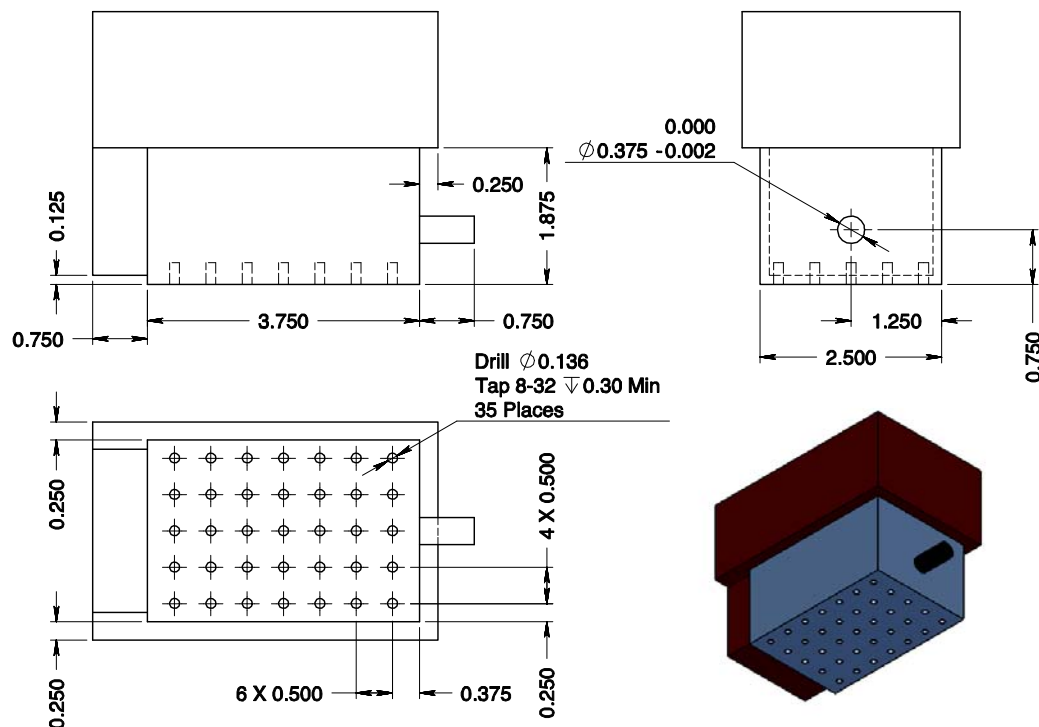

Figure 3. Detailed robotic wrist diagram. The gripper is driven by the drive shaft (black), which will provide a torque in the clockwise direction as viewed when looking at the shaft (i.e. in the right view). The gripper attaches to the wrist using the tapped hole pattern on the bottom of the aluminum block (gray). The gripper may not interfere with the regions marked in red. The drive shaft is 0.750 inches long.
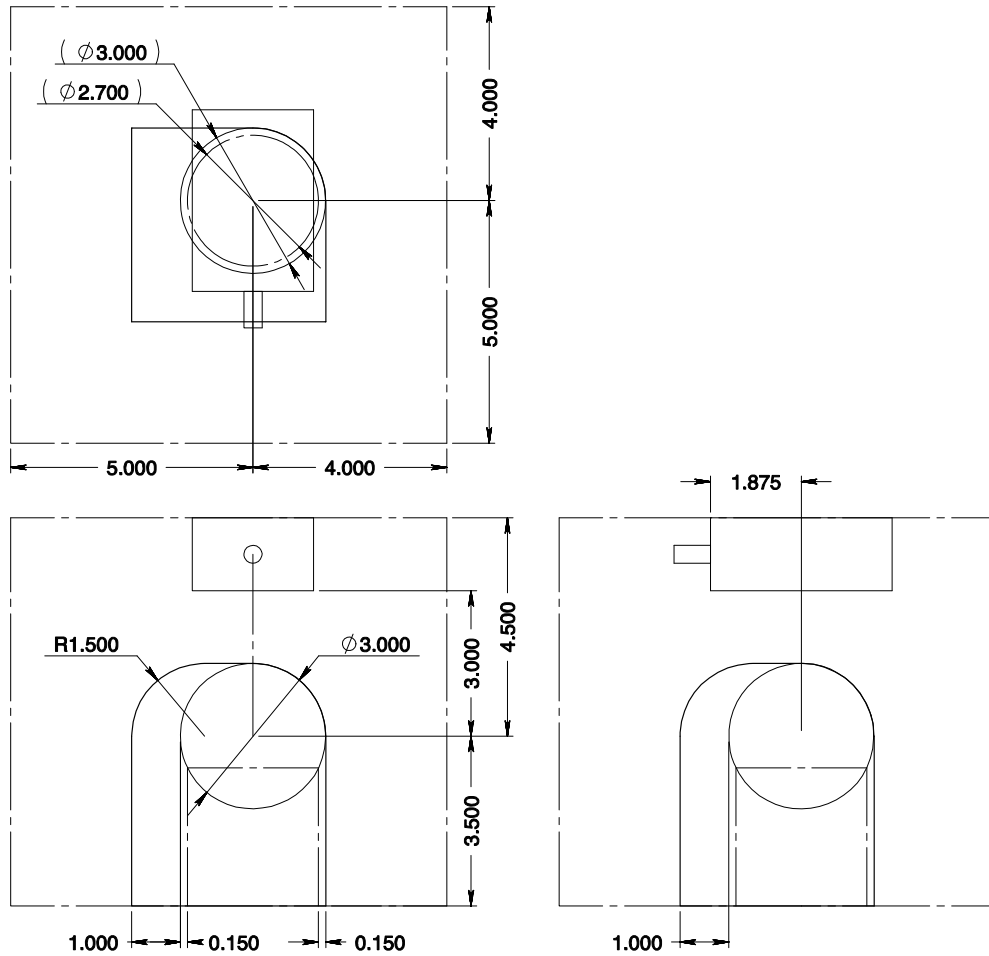
Figure 4. Overall geometry diagram. The spherical payload (solid circle) is centered below the gripper, with a pre-gripped non-interference region to two orthogonal sides (solid outline) and a post-gripped non-interference region below (dash-dot lines). The pre-gripped non-interference orientation may be chosen by your team to be as pictured relative to the drive shaft, or may be rotated 180° in the top view. The overall gripper envelope (dash-dot lines) creates a near cube, nearly centered on the sphere.

Performance-based Grading

Both gripper prototypes must function in order to receive the maximum grade on your project, and at least one must hold the ball during dynamic motions of the arm. Assemblies that do not meet the geometric criteria or do not nominally function, e.g. close on the ball, will result in a loss of 5% credit at either or both stages. If neither assembly holds the ball during dynamic motions, 10% credit will be lost.

For the team whose gripper meets all requirements and successfully holds the ball during dynamic motions while comprising the lowest mass, an additional 10% bonus will be awarded. Designs that are within 33% of this winning mass will also receive a pro-rated bonus. For example, if the lowest mass were 60 g and your team's gripper weighed 70 g, your team would receive a bonus of 5%! Similarly, the team with the lowest cost functional gripper will receive a 5% bonus, with pro-rated bonuses for teams within 20% of this cost. A total of two awards will be given, based on best mass of either gripper and lowest total cost.

Final Report

You will submit a final report presenting your final design, as well as the conceptualization, simple modeling, detailed modeling and analysis, and manufacturing that went into its creation. The report should be divided into the following sections:

1. Cover page: Please include the following on one side of one page:
    a. Your group number, team member names, the project name, and the date
    b. An isometric screen shot of your assembly at the top of the page
    c. other details to be announced.
2. Conceptual Design Sketches
    a. Please include all your notes and sketches from your idea generation sessions. These will be evaluated on the basis of both apparent volume and apparent quality of design ideas. A typical set of sketches and notes might occupy 3 pages, front and back, with a medium density, for each component in your assembly.
    b. Your notes must include free-body diagrams, using force and moment balance to obtain reaction forces, with symbolic parameters. This will allow you to understand the implications of different design choices on the function of your components and assembly.
3. Simple Modeling of Candidate Designs
    a. Please evaluate at least 2 candidate designs for each component using simple analytical modeling approaches
    b. Include hand-drawn sketches of the simple models that allow analytical analyses of interest. Include the analysis you performed by hand. For example, you might model one aspect of the part as a beam in bending, and then relate peak stress, beam height, and part mass in a single function. You will probably need more than one simple model to analyze different aspects of each candidate model.
    c. Although "conceptual design sketches" and "simple modeling of candidate designs" are listed as separate items in this list, ideally these are intermingled in a logical way throughout your design sketches. There is a continuum between a crayon stick figure on the back of a napkin and a Matlab parameter sweep, which you may find yourself flowing along during your designing.
4. Materials Selection
    a. details to be announced
5. Component Selection
    a. details to be announced
6. Detailed Model and Analysis of Final Design
    a. Please include a model description section for each of your custom-designed components, which will consist of the following elements:
        i. An isometric screen shot of the component
            1. On this screen shot, call out each feature and give a brief (~5 words) description of its function (this may be done by hand on the print-out).
        ii. A screen shot of a static stress analysis for the component, with visible units in psi.
    b. other details to be announced

7. Manufacturing Report
   a. Please include a fully dimensioned engineering drawing for each custom component
   b. other details to be announced