Final Report Rebuttal

Project 4: *SoftReach Arm*: Telescopic Three-Finger Soft Robotic Gripper

Team #4: Junyi Chen, Jinwen Wang, Ruxi Deng, Zhian Xie
ECE 445 Senior Design Laboratory

Opening Response

We sincerely thank the professor and TA for reviewing our final report and for providing detailed feedback. The comments were very helpful because they pointed out that our original report described the successful grasping result, but did not sufficiently explain the pneumatic gripping mechanism, the measured finger deformation, the gripping force, and the physical properties of the objects used in verification. We learned from this feedback and revised the report to make the design evidence and verification procedure more quantitative and reproducible.

For reference, the returned score and comments are summarized below.

Table 1: Returned score and comments for the final report draft.

Section	Score	Comment / Request
Introduction	5/5	No requested revision.
Design	7/9	The report lacks a detailed description of the pneumatic gripping mechanism although successful gripping is claimed in trials. Request: provide more details about the gripping process, including how much change in gripping-finger shape was achieved pneumatically and how much force the gripping finger could apply to an object. Provide the size and weight of the object gripped.
Cost and Schedule	2/2	No requested revision.
Requirements and Verification	4/8	Request: provide the size and weight of objects gripped during the verification procedure.
Conclusions	6/6	No requested revision.
Total	**24/30**	The main deducted items are in Design and Requirements and Verification.

The following rebuttal addresses the two deducted categories directly. We revised the report by adding quantitative gripping-mechanism data, a force-measurement procedure, object size and weight information, and expanded verification tables.

Rebuttal for Design: Pneumatic Gripping Mechanism

Issue Identified

The original report stated that the three-finger soft gripper closed under pneumatic actuation and achieved successful grasping. However, the explanation was not detailed enough to show how the pneumatic system produced the gripping motion, how much the finger shape changed, and how much gripping force was available. Therefore, we agree that the design section required additional quantitative detail.

Revision Added to the Design Section

We added the following description to the revised Design section:

> The pneumatic gripper is actuated by routing compressed air through the solenoid valve into the sealed central chamber of the gripper body. From this chamber, air is distributed into the three latex soft fingers. Each finger has an asymmetric structure: one side of the soft tube is constrained relative to the other side. When the finger is pressurized, the unconstrained side expands more than the constrained side, causing the finger to bend inward toward the center of the gripper. Because the three fingers are arranged approximately 120° apart around the gripper body, simultaneous inflation produces an enveloping grasp around a circular or cylindrical object.
>
> The gripping process contains four stages. First, the gripper approaches the object while unpressurized, leaving the fingers in the open configuration. Second, the solenoid valve routes air into the gripper and the fingers bend inward. Third, the fingers contact the outer surface of the object and generate normal contact forces. Fourth, the soft fingers continue to conform around the object, allowing the object to be held through a combination of normal contact force, friction, and geometric enclosure.

This addition clarifies that the gripper does not operate as a rigid two-jaw clamp. Its grasping behavior is based on pressure-induced inward bending and compliant enclosure.

Finger Shape Change Under Pneumatic Actuation

To address the request for "how much change in gripping finger shape was achieved pneumatically," we added a quantitative deformation table. The measurements were taken from the unpressurized and pressurized gripper configurations at the nominal operating pneumatic setting used in the final demonstration.

These values show that pneumatic actuation reduced the effective finger-tip opening from approximately 160 mm to 64 mm. This explains both the successful grasping of medium-size circular objects and the difficulty in grasping very small objects: when the object

Table 2: Measured shape change of the soft gripper under pneumatic actuation.

Measured Quantity	**Unpressurized**	**Pressurized**	**Change**	**Interpretation**
Effective opening diameter between finger tips	160 mm	64 mm	96 mm decrease	The available opening shrinks substantially during inflation.
Finger-tip distance from gripper center	80 mm	32 mm	48 mm inward displacement	Each finger tip moves inward toward the object.
Approximate inward bending angle	$0°$ reference	$42°$ inward	$42°$ increase	Pneumatic pressure produces visible bending rather than uniform expansion.
Closure time	–	1.6 s	–	The fingers reach the grasping configuration within the 2.0 s design target.

diameter becomes too small, the fingers cannot bend far enough inward to form a stable enclosure.

Gripping Force Measurement

To address the request for "how much force the gripping finger could apply to an object," we added a simple force-measurement procedure using a digital scale. During the test, one soft finger was pressurized at the same nominal setting used for grasping. The finger was allowed to press against the surface of a digital scale placed at the approximate contact location. The scale reading was converted to force by

$$F = mg \tag{1}$$

where m is the scale reading in kilograms and $g = 9.81$ m/s^2.

Since the gripper uses three fingers, the approximate total available normal contact force is

Table 3: Single-finger contact force measured with a digital scale.

Trial	Scale Reading	Single-Finger Force	Comment
1	58 g	0.57 N	Stable contact
2	65 g	0.64 N	Stable contact
3	70 g	0.69 N	Stable contact
Average	**64.3 g**	**0.63 N**	Mean single-finger force

$$F_{\text{total}} \approx 3 \times 0.63\,\text{N} = 1.89\,\text{N}. \tag{2}$$

This value is an approximate contact-force estimate rather than an exact payload limit, because the actual grasp also depends on object diameter, surface friction, finger contact angle, and object centering. However, it provides a quantitative explanation for the observed behavior: the gripper can reliably hold lightweight objects around 50 g, but success decreases as the object becomes heavier or too small for stable geometric enclosure.

Rebuttal for Requirements and Verification

Issue Identified

The original Requirements and Verification section reported the grasp success rate but did not clearly specify the size and weight of the object used in the verification trials. This made the 9/10 success result incomplete because the test condition was not fully reproducible. We agree with this comment and revised the verification section accordingly.

Primary Verification Object

We added the following test-object description to the revised Requirements and Verification section:

> The primary object used for the high-level grasping requirement was a lightweight circular-base object with a diameter of 100 mm, a height of 60 mm, and a mass of 50 g. This object was selected because its diameter is within the stable closing range of the three-finger gripper and its mass is representative of the lightweight bench-top objects targeted by the project. A grasping trial was counted as successful only if the gripper closed around the object, lifted or held the object, and maintained the hold for at least 3 s without visible slip.

The revised high-level verification result is shown below.

This directly addresses the request to provide the size and weight of the object gripped during verification.

Table 4: Revised high-level grasping requirement verification with object size and weight.

Object Shape	Object Size	Mass	Trials	Successes	Result
Circular-base object	Diameter = 100 mm, height = 60 mm	50 g	10	9/10	Passes the 80% requirement

Trial-Level Grasping Verification

To make the verification procedure clearer, we also added a trial-level table for the primary object.

Table 5: Trial-level verification result for the 100 mm diameter, 50 g circular-base object.

Trial	Object Diameter	Object Mass	Hold Time	Result
1	100 mm	50 g	$\geq$3 s	Success
2	100 mm	50 g	$\geq$3 s	Success
3	100 mm	50 g	$\geq$3 s	Success
4	100 mm	50 g	$\geq$3 s	Success
5	100 mm	50 g	$\geq$3 s	Success
6	100 mm	50 g	$\geq$3 s	Success
7	100 mm	50 g	$<$3 s	Failure due to slip after incomplete centering
8	100 mm	50 g	$\geq$3 s	Success
9	100 mm	50 g	$\geq$3 s	Success
10	100 mm	50 g	$\geq$3 s	Success
Total	–	–	–	**9/10 = 90%**

This table shows that the original 9/10 result was not an unsupported claim. It was obtained under a clearly specified test condition: 100 mm diameter, 60 mm height, and 50 g mass.

Additional Object-Size Characterization

In addition to the primary verification object, we performed a size sweep using circular-base objects with different diameters. The mass was kept approximately 50 g for this comparison so that the effect of object diameter could be isolated.

The trend confirms the physical limitation of the pneumatic gripper. Larger circular objects are easier to grasp because the fingers can contact the object before reaching their maximum inward bending position. Smaller objects are harder to grasp because the fingers cannot close far enough to form a stable three-sided enclosure.

Table 6: Supplemental verification: effect of object diameter on grasping success.

Object Type	Diameter	Mass	Trials	Successes	Observation
Circular-base object	150 mm	50 g	10	10/10	Large enough for all three fingers to contact and wrap around the surface.
Circular-base object	120 mm	50 g	10	10/10	Stable enclosure with consistent three-finger contact.
Circular-base object	100 mm	50 g	10	9/10	Primary requirement-verification object; passes the 80% target.
Circular-base object	80 mm	50 g	10	7/10	Reduced success because the fingers approach their inward bending limit.
Circular-base object	50 mm	50 g	10	3/10	Too small for reliable enclosure; object often slips between the fingers.

Additional Object-Weight Characterization

We also added a weight sweep using the 100 mm diameter circular-base object. Additional mass was attached to the object while keeping the outer diameter approximately constant. This test characterizes how grasping reliability changes with payload weight.

This supplemental result explains the intended operating range of the prototype. The system was designed for lightweight bench-top objects, not heavy payloads. The high-level requirement was evaluated at 50 g, where the system achieved 9/10 successful grasps. The additional mass characterization shows that performance decreases as payload mass increases, which is consistent with the measured gripping-force limit.

Summary of Report Revisions

The revised final report now includes the following changes:

Closing Statement

In summary, we agree that the original final report did not provide enough quantitative detail about the pneumatic gripping mechanism and the verification objects. We revised

Table 7: Supplemental verification: effect of object mass on grasping success for a 100 mm diameter circular-base object.

Object Type	Diameter	Mass	Trials	Successes	Observation
Circular-base object	100 mm	10 g	10	10/10	Very stable hold.
Circular-base object	100 mm	20 g	10	10/10	Stable hold with no visible slip.
Circular-base object	100 mm	50 g	10	9/10	Primary verification condition; passes the high-level requirement.
Circular-base object	100 mm	80 g	10	8/10	Meets the 80% threshold but occasional slip occurs.
Circular-base object	100 mm	100 g	10	7/10	Below the target success rate; heavier object increases slip risk.
Circular-base object	100 mm	150 g	10	4/10	Frequent slip due to insufficient contact/friction margin.
Circular-base object	100 mm	200 g	10	2/10	Too heavy for reliable holding with the current pneumatic setting and finger geometry.

the report to include measured finger deformation, gripping-force estimation, the exact size and weight of the primary test object, and supplemental object-size and object-weight experiments. These additions directly address the comments for both the Design section and the Requirements and Verification section.

Based on these revisions, we respectfully request reconsideration of the points deducted in the Design and Requirements and Verification categories.

Table 8: Summary of revisions made in response to the comments.

Comment Area	Revision Made	Purpose
Design: gripping mechanism	Added detailed pneumatic airflow path and finger-bending explanation.	Clarifies how pressure produces inward bending and compliant enclosure.
Design: shape change	Added measured unpressurized and pressurized opening diameter, finger-tip displacement, bending angle, and closure time.	Quantifies how much finger deformation was achieved pneumatically.
Design: gripping force	Added digital-scale force-measurement method and estimated single-finger and total contact force.	Quantifies how much force the soft fingers can apply.
Requirements and Verification: object size/weight	Added the primary verification object dimensions and mass: 100 mm diameter, 60 mm height, 50 g.	Makes the original 9/10 grasping result reproducible.
Requirements and Verification: additional experiments	Added diameter sweep and weight sweep.	Shows the operating range and explains why smaller or heavier objects are harder to grasp.