ROBOTIC HAND: FINAL PACKAGE

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ENGR3260: Design for Manufacturing

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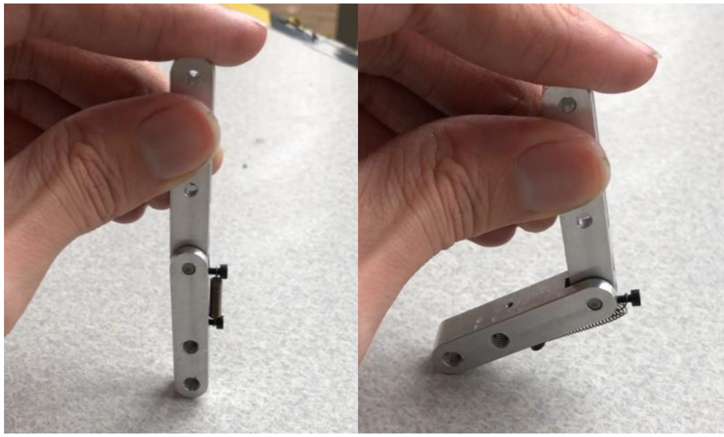
Executive Summary:

We designed a compact, low-cost robotic hand for small-batch manufacturing. Compliant links prevent damage in the event of a collision, and modular fingertips allow customization for specific applications. The hand is designed with users in mind, featuring easy access to both the electronics and the attachment point to the robotic arm. Sleek aesthetics and a consistent color scheme further strengthen the product's brand image.

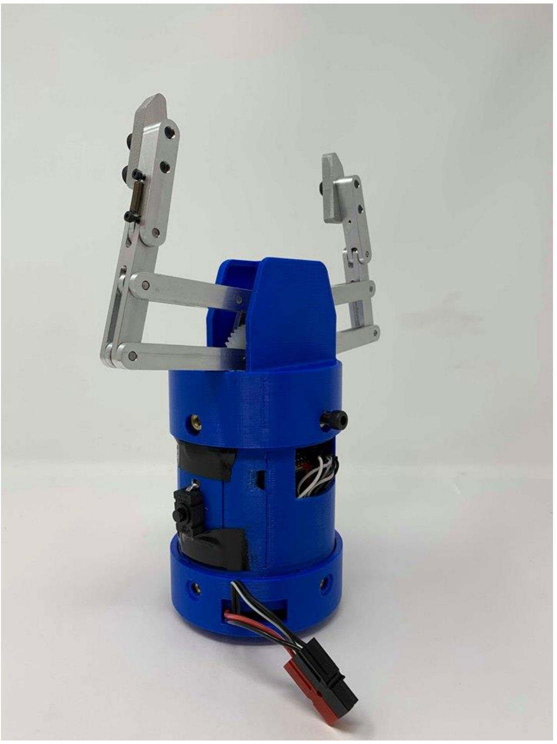
A variety of manufacturing techniques were used to reduce cost without compromising strength, including CNC milling, water-jetting, 3D printing, and investment casting. Additionally, at larger production volumes injection molding offers an opportunity to further reduce the cost of certain parts. Overall, this hand presents a significant improvement over the initial prototype in quality, cost, and brand.

Detailed Design:

The distinguishing feature of the initial hand prototype was compliance – if the hand collided with a table, the fingers would harmlessly fold out of the way. However, the four-bar mechanism added significant cost and complexity, leading us to move towards a simpler design, using a single finger joint held open by a tension spring. The fingers also feature modular tips, allowing them to be swapped out for different applications (e.g. greater compliance or finer control).



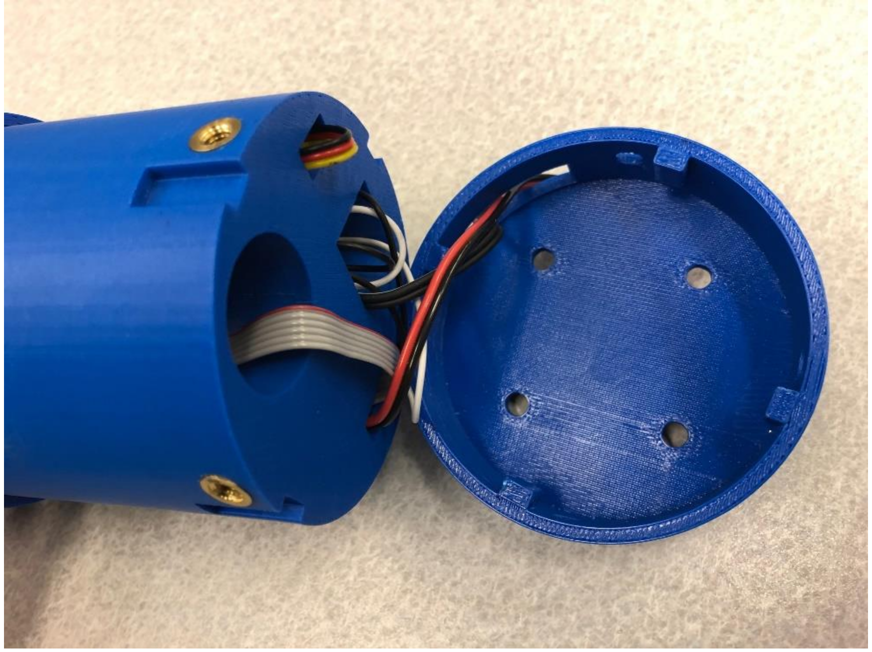
The fingers are mounted on a four-bar linkage, which provides a large range of motion without greatly increasing the size of the hand in the way that a rack and pinion or leadscrew would. A single motor drives both linkages, with spur gears transmitting power between them. Using a single motor reduces component cost, space usage, and overall system complexity.



The body itself is 3D printed, which allows highly detailed features like snap-fits and internal wire routing without increasing the manufacturing complexity. While plastic is sufficiently strong for the body itself, water-jet aluminum plates are used to more securely join the four-bar linkages to the body. An infrared rangefinder on the top face provides distance measurements between the hand and the object it is attempting to grasp. At larger production volumes the hand would likely be cast instead of printed for greater economy of scale.

A 3D printed casing covers the top of the body to protect users from the moving gears. Investment casting was also used to produce an aluminum casing as a demonstration of the production technique that would be used at higher volume.

The electronics are contained within the body behind removable panels, allowing easy access while providing protection and maintaining a sleek appearance. An Arduino Nano was chosen as the onboard computer due to its small size and low price. The one motor has a built-in encoder, allowing the Arduino to accurately control the position of the linkage. Wires are routed through channels in the body itself to a cavity at the base of the hand from which they can run to wherever they are needed. The arm attachment has all the necessary mounting features for the UR-5 robot arm, while easily accessible external bolts connect the part to the body. This allows unobstructed access to the fasteners holding the hand in place for rapid swapping.



Team Contribution:

I (Paul) primarily worked on the four-bar linkage and the compliant fingers, both during the design phase and during manufacturing. I also took point on implementing the software on the Arduino and the motor shield.

Anika was in charge of the hand body, including the design of electronics mounting and the UR-5 interface as well as fabricating the 3D printed parts, wiring up the electronics, and machining half of the linkage parts.

Niyi worked on many different aspects of the project, including the design of the fingertips and cable strain relief, as well as the manufacturing of the molded and water-jet components.

Remy contributed to the early-stage design of the linkages, and also designed the casing for the body. During fabrication she put a lot of work into investment casting, creating and powder-coating an aluminum version of the casing.

Time Distribution

These times estimates are approximate, but roughly represent the net cost of our work to a company given an $85/hour rate.

Category	Hours Each	Hours Total	Cost
Design	25	100	$8,500
Manufacturing	10	40	$3,400
Assembly/Testing	10	40	$3,400
Total	**45**	**180**	**$15,300**

Personal Reflection:

Overall, I found this project a very useful experience. The end results were mixed: our final robot hand design was really neat, but due to time constraints the fabricated version was a lot less polished than we had hoped, and the last-minute failure of a motor meant we could not demonstrate it during the final event (although we had fortunately already taken a video). However, it was still a valuable learning process. This was the greatest amount of machining experience I have had in a project, and I now feel a lot more comfortable and confident operating the machines. I also have a much better sense of which operations are easy or challenging, and I hope that this will allow me to improve my mechanical design abilities by making modifications that do not significantly affect functionality but do make fabrication much easier.

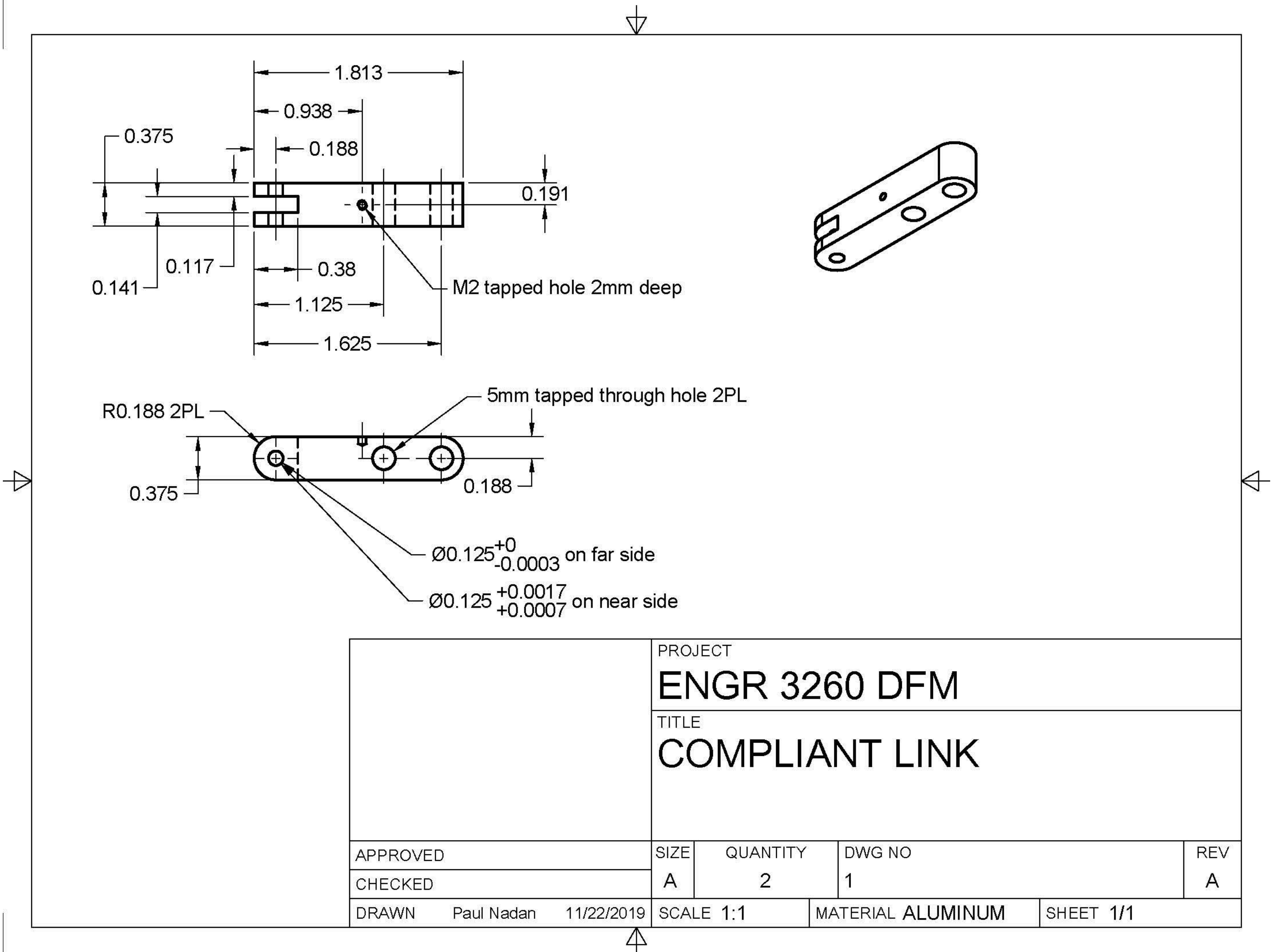
I also appreciated the opportunity to attempt to create a finished product, not just a proof-of-concept prototype. That said, our team made enough drastic design changes that it still felt a bit like a prototyping project. I definitely feel a need to take our final product and go through the DFM process again now that the overall design is more finalized. However, the initial activity of looking at a design and seeking out all the flaws and areas of opportunity was very educational, not just for applying the techniques to DFM but also learning to continually ask myself those types of questions throughout the design process. Also, just learning about all the different fabrication methods out there expanded my horizons significantly, so even if I'm not yet an expert in every technique I will at least know if it's something worth looking into during a project.

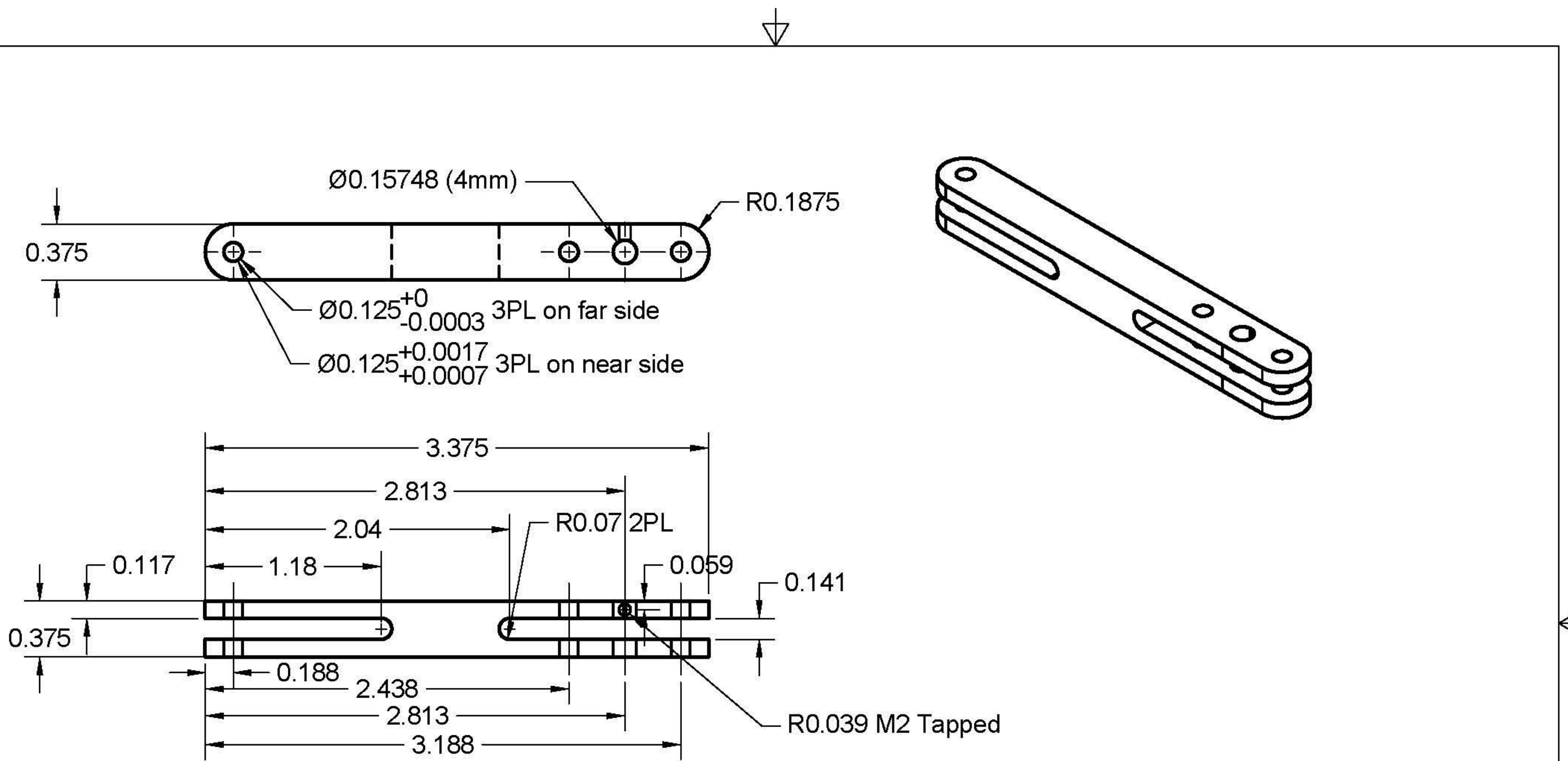
Our team definitely went through a few rough patches. We were down a member from almost the beginning, and we had some issues with dividing up tasks and keeping everyone on the same page about design changes and deadlines. In the future, using a more rigorous task tracking system would probably be useful (the white boards in class were a nice idea, but our team met enough outside of class that they never stayed up to date). We also made major design pivots fairly late into the project, and while I do not regret the changes we made, we should have taken the time to hammer out the design earlier in our timeline. At the same time, we did a lot of things very well. The initial design phase was really productive with everyone staying engaged and sharing ideas, and at the end of the semester everyone stepped up and put in extra effort to get the hand finished in time.

Conclusion:

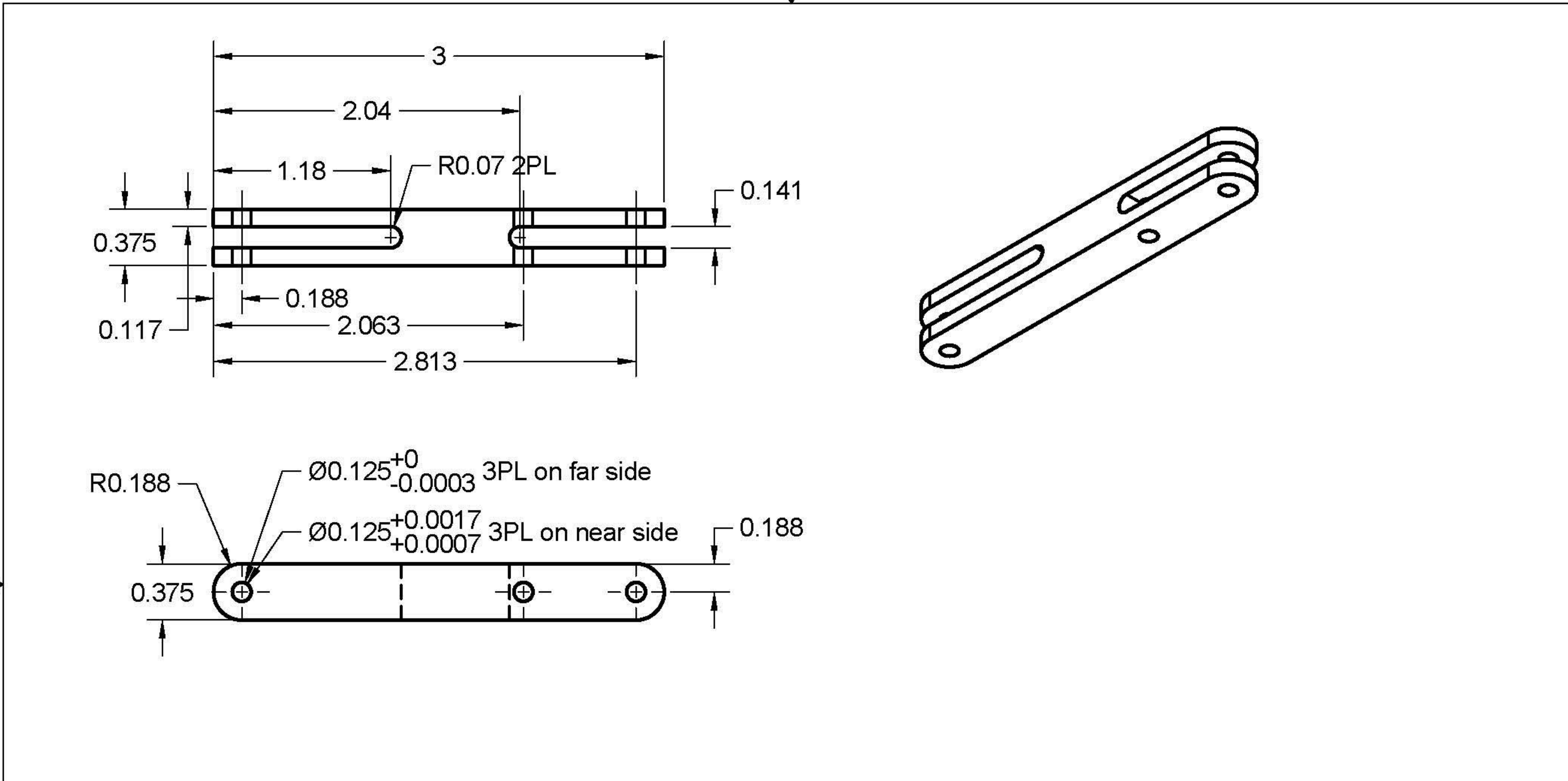
We successfully designed a robotic hand that met all our design criteria, improving on the original in key metrics: cost, quality, and brand. We redesigned almost all aspects of the original hand, finding ways to reduce complexity, increase user-friendliness, and use more cost-effective manufacturing techniques. Although the one instance we fabricated lacks much of the polish in our theoretical design, at larger scales the small issues with machining or assembly errors will go away as we get used to the process. Our first prototype is rough, but it is a proof-of-concept that the cheap, effective, eye-catching design we came up with is in fact realizable, as well as a way to discover all of the flaws remaining in our design to eliminate during the next pass.

Appendix

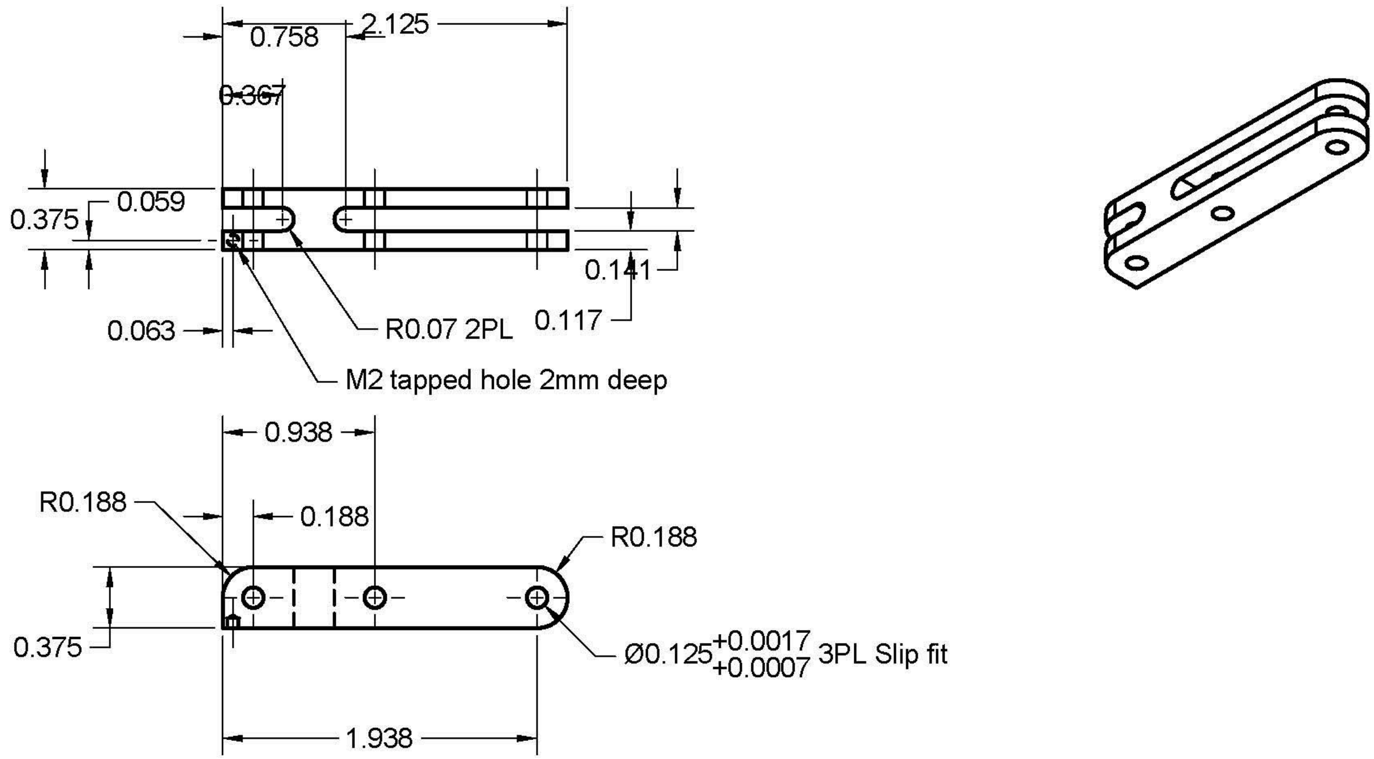

1.813
0.938
0.375
0.188
0.191
0.117
0.141
0.38
1.125
1.625
M2 tapped hole 2mm deep
R0.188 2PL
5mm tapped through hole 2PL
0.375
0.188
Ø0.125 +0 -0.0003 on far side
Ø0.125 +0.0017 +0.0007 on near side
PROJECT
ENGR 3260 DFM
TITLE
COMPLIANT LINK
APPROVED
CHECKED
DRAWN Paul Nadan 11/22/2019
SIZE A
QUANTITY 2
DWG NO 1
REV A
SCALE 1:1
MATERIAL ALUMINUM
SHEET 1/1



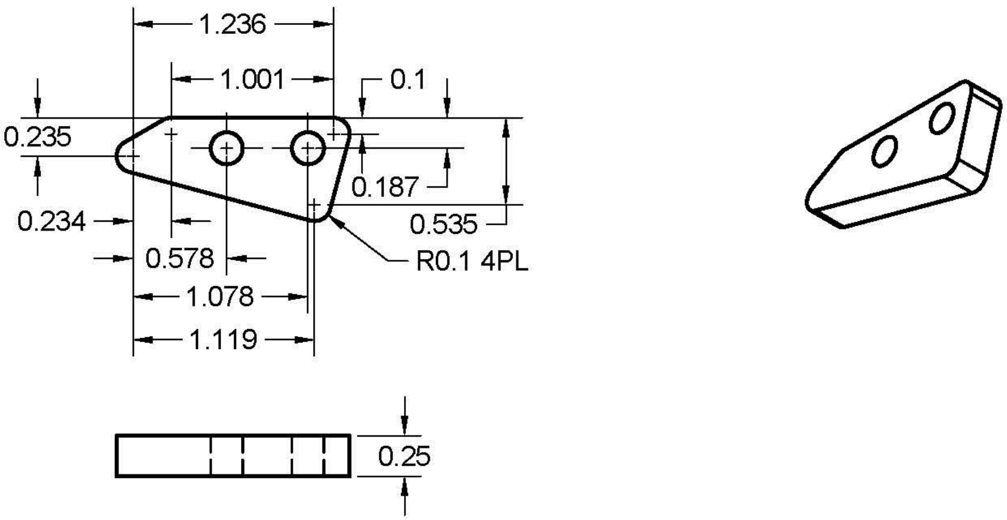
	PROJECT: ENGR 3260 DFM				
	TITLE: LONG HORIZONTAL LINK				
APPROVED	SIZE	QUANTITY	DWG NO		REV
CHECKED	A	2	2		A
DRAWN Paul Nadan 11/22/2019	SCALE 1:1		MATERIAL ALUMINUM	SHEET 1/1	



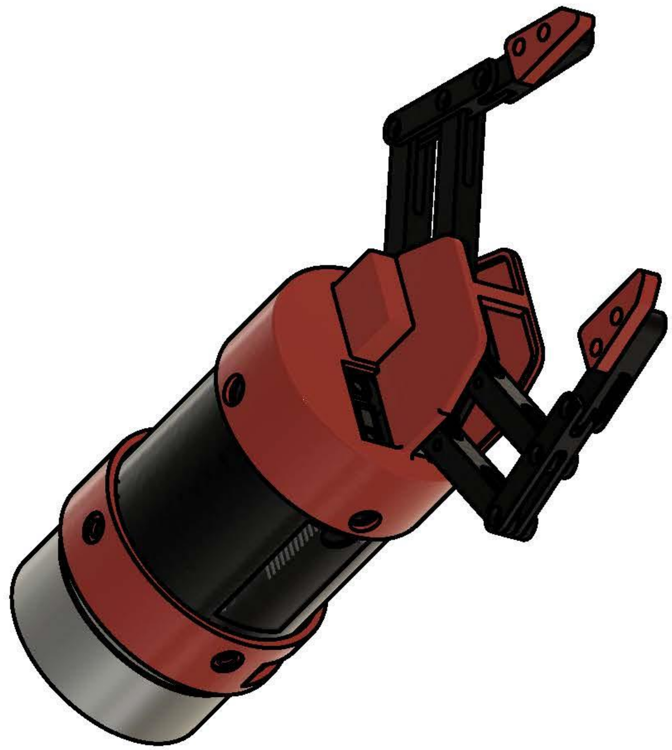
	PROJECT ENGR 3260 DFM				
	TITLE SHORT HORIZONTAL LINK				
APPROVED	SIZE	QUANTITY	DWG NO		REV
CHECKED	A	2	3		A
DRAWN Paul Nadan 11/22/2019	SCALE 1:1		MATERIAL ALUMINUM	SHEET 1/1	



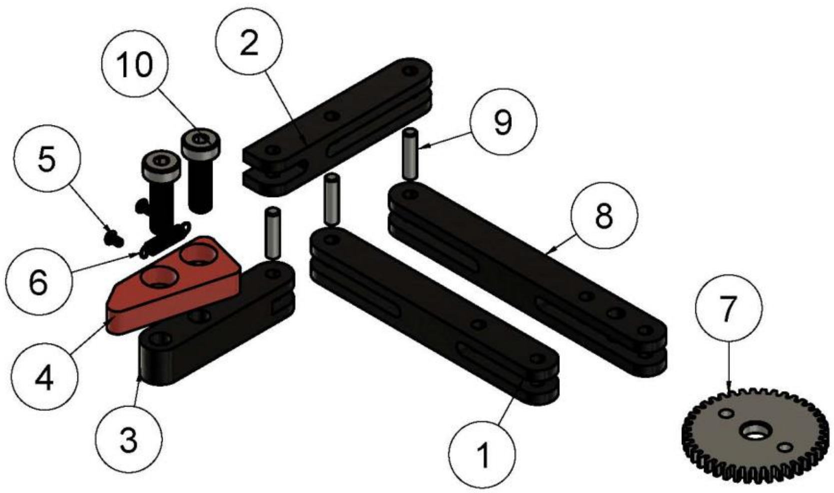
	PROJECT: ENGR 3260 DFM			
	TITLE: VERTICAL LINK			
APPROVED	SIZE: A	QUANTITY: 2	DWG NO: 4	REV: A
CHECKED				
DRAWN: Paul Nadan 11/22/2019	SCALE 1:1	MATERIAL ALUMINUM	SHEET 1/1	



PROJECT	ENGR 3260 DFM			
TITLE	FINGERTIP			
APPROVED	SIZE: A	QUANTITY: 2	DWG NO: 5	REV: A
CHECKED				
DRAWN: Paul Nadan, 11/22/2019	SCALE 1:1	MATERIAL ALUMINUM	SHEET 1/1	



PROJECT	ENGR 3260 DFM				
TITLE	MAIN ASSEMBLY				
APPROVED		SIZE	QUANTITY	DWG NO	REV
CHECKED		A	1	ASSEM 1	A
DRAWN	Paul Nadan 11/22/2019	SCALE 1:2	MATERIAL	SHEET 1/1	



PARTS LIST				
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	2	SHORTHORZLINK	SHORT HORIZONTAL LINK	ALUMINUM
2	2	VERTLINK	VERTICAL LINK	ALUMINUM
3	1	COMPLIANTLINK	COMPLIANT LINK	ALUMINUM
4	2	FINGERTIP	FINGERTIP	ALUMINUM
5	2	92949A314	M2 BOLT	STEEL
6	1	9654K945	TENSION SPRING	STEEL
7	1	57655K45	SPUR GEAR	STEEL
8	1	LONGHORZLINK	LONG HORIZONTAL LINK	ALUMINUM
9	3	98381A304	DOWEL PIN	STEEL
10	2	93070A125	M5 BOLT	STEEL

	PROJECT ENGR 3260 DFM				
	TITLE LINKAGE SUBASSEMBLY				
APPROVED	SIZE B	QUANTITY 2	DWG NO ASSEM 2		REV A
CHECKED					
DRAWN Paul Nadan 11/22/2019	SCALE 1:1		MATERIAL ALUMINUM	SHEET 1/1	

Bill of Materials:

ITEM	QTY	DESCRIPTION	MATERIAL	MANUFACTURING
1	1	Arduino Nano		
2	1	Roboclaw Motor Shield		
3	1	Motor with Encoder		
4	1	Infrared Sensor		
5	15	Cables		
6	1	22 Gauge Red & Black Wire		
7	2	Linkage	Aluminum	CNC Mill
8	1	Hand Body	Onyx	3D Print
9	1	Arm Attachment	Onyx	3D Print
10	1	Fingertip stock	Aluminum	Waterjet
11	0.1	PLA Filament for 3D printing molds	PLA	3D Print
12	1	Ransom & Randolph Advantage Investment	Calcium Sulphate	Investment Cast
13	1	Onyx Liquid Cast Resin	Polyurethane	Urethane Cast
14	2	24T Bevel Gears	Hardened Brass	
15	2	Spur Gears	Steel	
16	2	Steel extension springs (Compliance)	Steel	
17	1	4mm Linear Shaft		
18	2	M3 Heat Set Inserts		
19	2	M3 Screws		
20	1	1.375" Dowel Pin (flag)	Alloy Steel	
21	0.05	Hotcoat Powder Coat Satin Black	Hotcoat Powder	Powder coat
22	4	1/8" x 3/8" Dowel Pin (gear constraint)	4037 Alloy Steel, 4140 Alloy Steel	
23	3	1/8" x 5/8" Dowel Pin (body axle)	4037 Alloy Steel, 4140 Alloy Steel	
24	6	1/8" x 1/2" Dowel Pin (linkage axle)	4037 Alloy Steel, 4140 Alloy Steel	
25	2	Steel extension springs (Strain relief)	Music-Wire Steel	
26	6	Gear Shaft	Steel	
27	4	M2 Screw	Black-Oxide Alloy Steel	

28	8	M5 Screws	Black-Oxide Alloy Steel	
29	8	M5 Heat Set Inserts	Brass	
30	8	1/16" Magnets	Neodymium	
31	1	Casting Aluminum	Aluminum Silicon Alloy	Investment Cast

Design for Assembly Analysis:

There were a number of obstacles to speedy assembly of our prototype. The first was the electronics – they are packed into a very small space, requiring a great deal of finesse from the assembly technicians. Additionally, many of the wires were only barely long enough to reach their destination. Increasing wire length and allocating more space to electronics should solve this issue.

The spur gears were meant for a larger shaft size, and so fine alignment was needed to ensure they meshed properly. However, this issue would be easily fixed by using gears of the right dimensions.

A harder to solve issue is the alignment of the bevel gears. Because the motor can’t be back-driven, the alignment of the linkage must be set perfectly before the setscrews can be tightened. This is extremely demanding of the operators’ technical abilities to operate the motor control software. This would be addressed by having a non-gear motor, such that back-driving doesn’t break it.

On the positive side, the joints of the four-bar linkages were made using press-fit dowel pins, which made their assembly extremely rapid because no fasteners were needed.

The casing can fit perfectly fine but cannot be put on while the fingertips are attached. This is not a problem as long as the assembly techs carry out operations in the correct order.

Attaching the tension springs for compliance is difficult, because the spring must be kept in tension during the process. An assembly fixture to bear the load could address this issue.

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