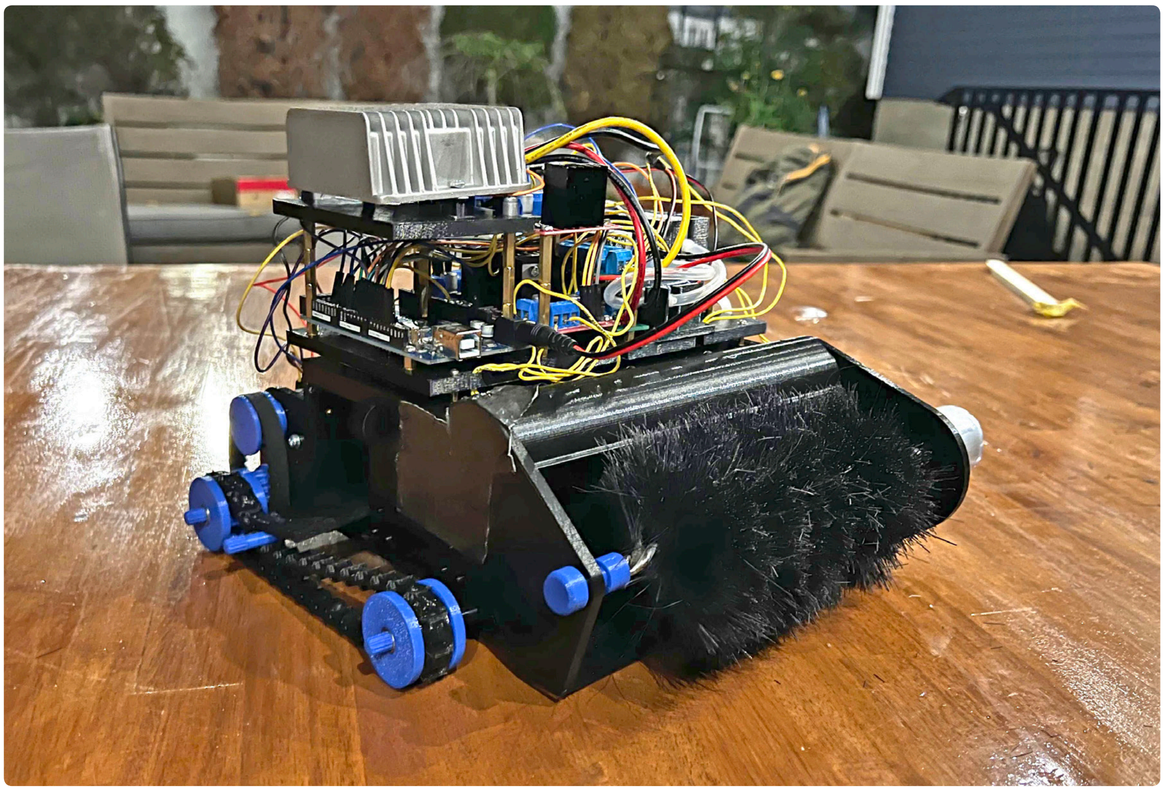
LigerBots
FIRST® Robotics Team 2877
Newton North and South High Schools

140 Brandeis Road, Newton Centre, MA 02459
info@ligerbots.org ▪ www.ligerbots.org
#FRC2877 ▪ The LigerBots
@ligerbots ▪ @ligerbots_frc2877

Cleanup Bot 9000



By Jake Freed, Eddie So, Charlotte Storey,
Yonatan Tevet-Markelevich, and Greer Swiston

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Abstract

As the weather warmed up at the end of last year, we noticed a large amount of trash that could have easily been picked up. Taking care of our environment is crucial but also a task most people find dull, dirty, and repetitive, making it the perfect application for an automated robot. We invited members of our FIRST Robotics Competition (FRC) team to take the skills they had learned on the team and use them to design, prototype, and build a robot with practical applications.

With this robot, we hoped to make a proof of concept for automating our community's trash cleanup and, hopefully, one day, build a full-scale model that could be mass produced. The robot is also modular, so different systems can easily be switched out for the current trash-collecting robot by undoing a few screws, whether you want it to be able to clean up leaves or even snow.

Our current model can pick up cut-up pieces of cardboard and plastic to simulate miniature versions of items the full-scale model would be picking up, traverse various kinds of terrain, using 3D printed treads, compact trash using a pneumatic origami accordion made of waterproof paper, and deposit trash.

Similarly to an FRC robot build season, our group performed rapid prototyping via Onshape and we 3D printed parts and created dozens of iterations to perfect mechanisms. FIRST does a great job of laying the foundation for future engineers, and after participating in multiple build seasons, the next logical step was for us to venture into creating a solution for a real-world problem. Instead of having a predefined problem and constrained solution, as we do in FRC, everything was much more open-ended, making the challenge that much more difficult, but also fun and rewarding. We had to venture out of our comfort zones and, in doing so, were able to experiment with new materials and ways of manufacturing, and research parts and vendors. Through the experience we gained by working on this project, we are more prepared for our future careers. And, by documenting the experience on YouTube and this white paper, we hope to share the design experience with as many people as possible.

Mechanisms

3D Printed Body

There are several benefits to 3D printed parts. Although 3D printed parts are generally structurally weak, they allow us to make complicated, custom, parts easily. The finished prototype of the Cleanup Bot is small enough that 3D printing parts make a negligible difference in its performance. (However, we did consider what materials would be needed for a full-scale version.)

Because multiple team members have 3D printers, the ease of manufacturing and cost efficiency allowed the project to run smoothly. While most of the 3D printed parts are made out of PLA filament, we had some specialty parts that needed either PETG filament for heat resistance and toughness, or TPU filament for malleability. This ensured that all printed parts on the prototype were customized to fit the specific needs of each mechanism.

Intake

The intake is designed around a wire brush mechanism and a scoop. The material and structure of the brush make the intake compliant enough to intake trash of varying sizes, while providing enough force to bring the trash into the robot.

The metal rod at the center of the brush is capped on the left side by an unthreaded PETG bolt that goes through the frame, and an endcap that secures it to the frame. On the right side of the brush, there is another, unthreaded PETG bolt that slots directly onto the motor.

At the bottom of the intake is a scoop made out of Ninjatek TPU 3D printing filament, allowing it to make maximum contact with the ground as the robot moves forward. The wire brush captures the trash into the intake, and then scrapes along an angled edge made of PLA filament, to remove the trash from the brush. The trash rolls down a slight incline, which is vibrated as the intake motor spins, and the trash falls onto the conveyor.

Conveyor

A conveyor was a simple solution to transport the trash from the intake to the storage bin. The conveyor's main assembly is made of stainless-steel rods, steel bearings and shaft collars, and a sheet of neoprene stretched over the bearings and glued to itself. The end rods are then screwed into slots so that they can tension the conveyor belt. A high torque, 200 RPM motor mounted above the conveyor belt drives the conveyor via a thin neoprene belt. Forty-five-degree walls protrude from the robot's frame to keep the trash centered on the conveyor, creating space for the driving conveyor motor, and for the door-opening motor on the frame.

Storage and Compactor

After the conveyor, the trash is deposited into a bin at the back of the robot, where it is stored until being compacted and/or removed. Rather than using a pneumatic piston to compact the trash, we saved space and weight by creating an origami accordion made of waterproof paper. We found that a 12V pump with a one- to two-PSI capacity was enough to compact the trash against the trash removal door. The door is powered by a 15 RPM high-torque motor.

Drive Train

While wheels provide faster speed compared to tank treads, we realized that speed is not the primary goal; we wanted our robot to thoroughly clean a road made of any surface, and tank treads provide this versatility.

Additionally, having a tank tread removes the need for a suspension system, which greatly speeds up the development and manufacturing process. Our 3D-printed solution was modular and easily reparable. Ninjatek Cheetah TPU filament provides durability and flexibility. We drove the wheels with two 12 V 1000 RPM DC motors and HTD5 belts with a 16- to 20-gear ratio for adequate torque, while still fitting within our size constraints.

Electronics

The Cleanup Bot's power source is a 1300 mAh, 14.8V lithium polymer (lipo) battery that sits behind the storage bin for a low and balanced center of gravity. Stackable motor controllers govern the speed of each of the motors. All the electronics run on a detachable electronic board mounted on the top of the robot for ease of use and maintenance.

Control System

The program, written in C, uses multiple functions to control the motors. The NRF24L01+, a 2.4 GHz radio module, communicates between the robot and controller made out of an RC helicopter joystick.

Cleanup Bot Objectives

- Allows potential automation of our community's trash cleanup
- Modular
- Reliable
- Durable
- Cost effective
- Designed compactly
- Easily manufacturable
- Able to pick up trash and leaves
- Adaptable to variable terrain
- Able to create compact “trash-cubes”
- Useful as off-season FRC training project
- Useful as real world experience

Lessons Learned

- Note the difference between theory and practice.
  - Neoprene is a type of rubber, so we assumed it had a high coefficient of friction, but when we ran the motors that attached to the door and conveyor via neoprene belts, the neoprene belts just slipped and neither mechanism was driven.
  - We used neoprene cement to close the ends of the belts and the conveyor, but it made a temporary bond at best.
  - Even with a little bit of wear, the neoprene belts ripped easily.
  - Takeaway: Test materials extensively before deciding to use them.
- Track dependencies.
  - We overlooked the fact that in order for the rest of the CAD to change fluidly when we edited one part, constraints needed to be added to other, interdependent parts.
  - Takeaway: Before designing, set a standard for the hierarachy of how each CAD part changes in response to changes in other parts.
- Plan the design process based on schedule, budget, and staffing constraints.
  - Early on in the design process, we recognized the importance of balancing two approaches: a top-down approach that starts with a general idea and gets more and more specific, vs. a bottom-up approach that starts with specific mechanisms and later tries to fit them together. We didn't realize we would not have time to work sequentially on the mechanisms, but would have to design, order, and manufacture them all simultaneously, with limited staff.
  - Takeaway: Spend more time during the planning process considering which constraints (schedule, budget, or staffing) will dominate the design process.

Conclusion

At the end of June, 2022 we saw an opportunity to create a solution to a problem in our community and the world as a whole. Everyone wants a cleaner environment, but no one likes to have to pick up dirty trash from the ground with their hands, or even with tools. We wanted to make a scale-model prototype as a proof of concept for our idea, while also gaining valuable experience for our younger team members.

We took what we learned from researching, designing, and prototyping a robot that could win an FRC game, and applied the same process to a real-world problem.

Even though some mechanisms, like the conveyor and door, didn't function on the prototype as planned, and the treads rubbed against each other, we believe that higher quality materials and building to full scale might have solved most of these issues.

Our functional proof of concept brings us closer to a future that includes a trash-retrieving robot that runs without human involvement. This project also enabled my teammates and me to prepare for our futures while serving our community. By documenting the experience via YouTube and this white paper, we hope to share the experience with as many people as possible.

Video CAD GitHub

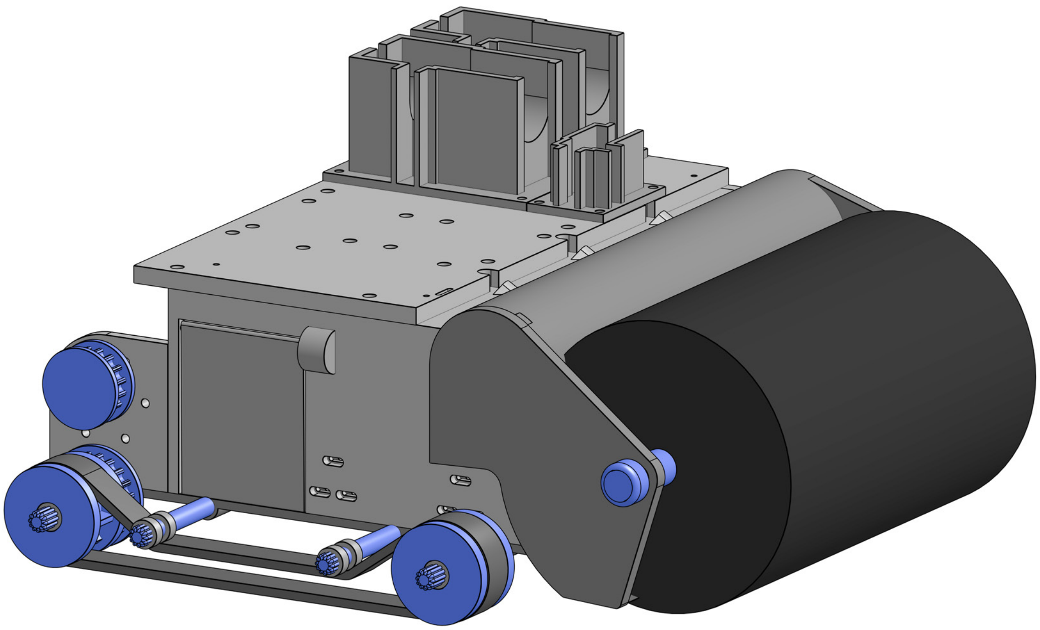
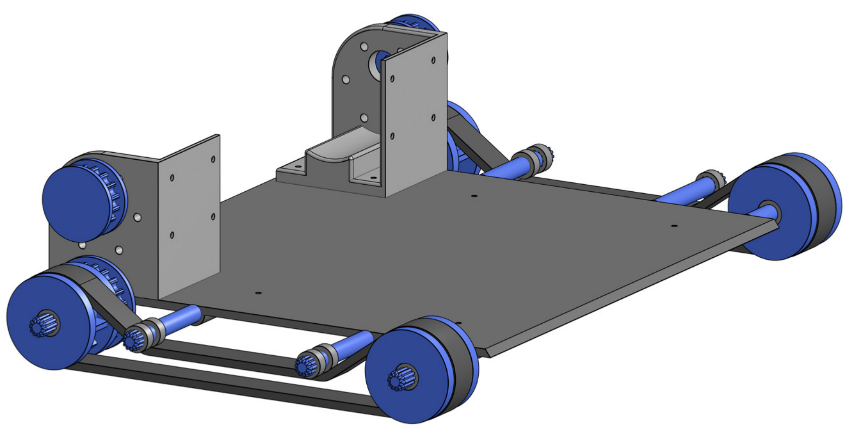
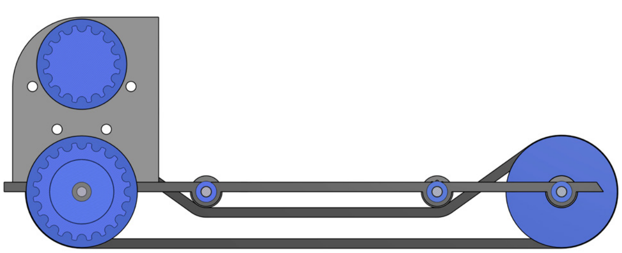


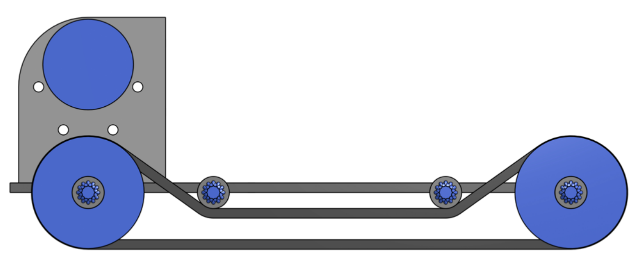
Fig 1. CAD render of the main assembly, isometric view



Isometric view

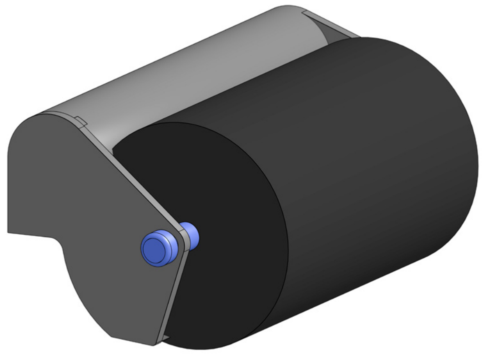


Side section view

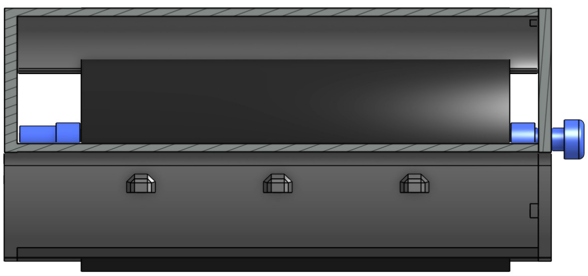


Side view

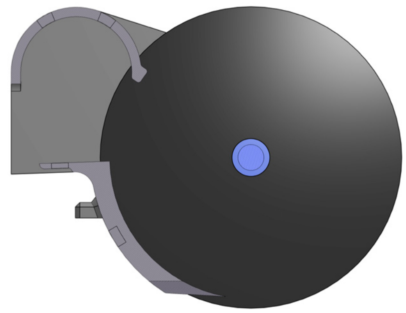
Fig 2. CAD renders of the chassis



Isometric view

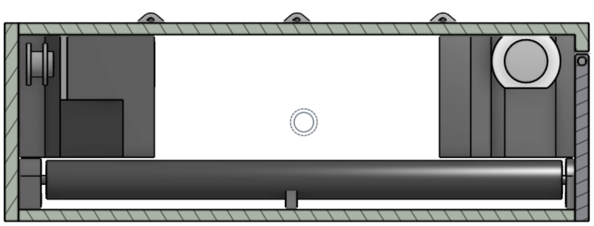


Back section view

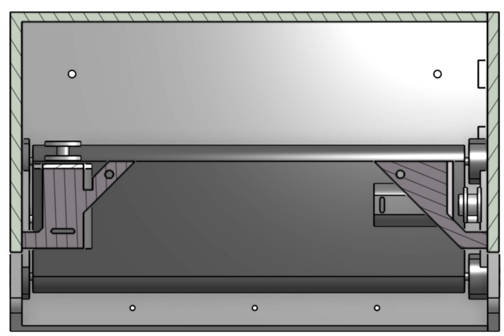


Side section view

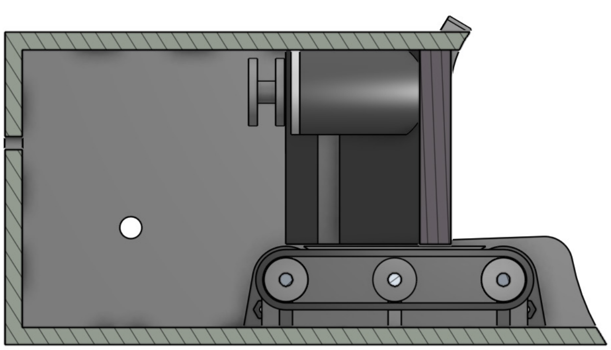
Fig 3. CAD renders of the intake



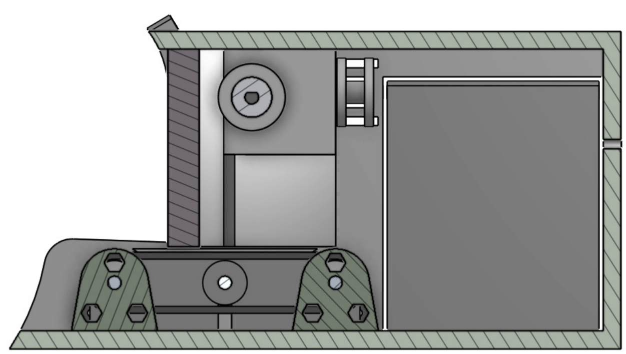
Back section view



Top section view



Left section view



Right section view

Fig 4. CAD renders of the storage

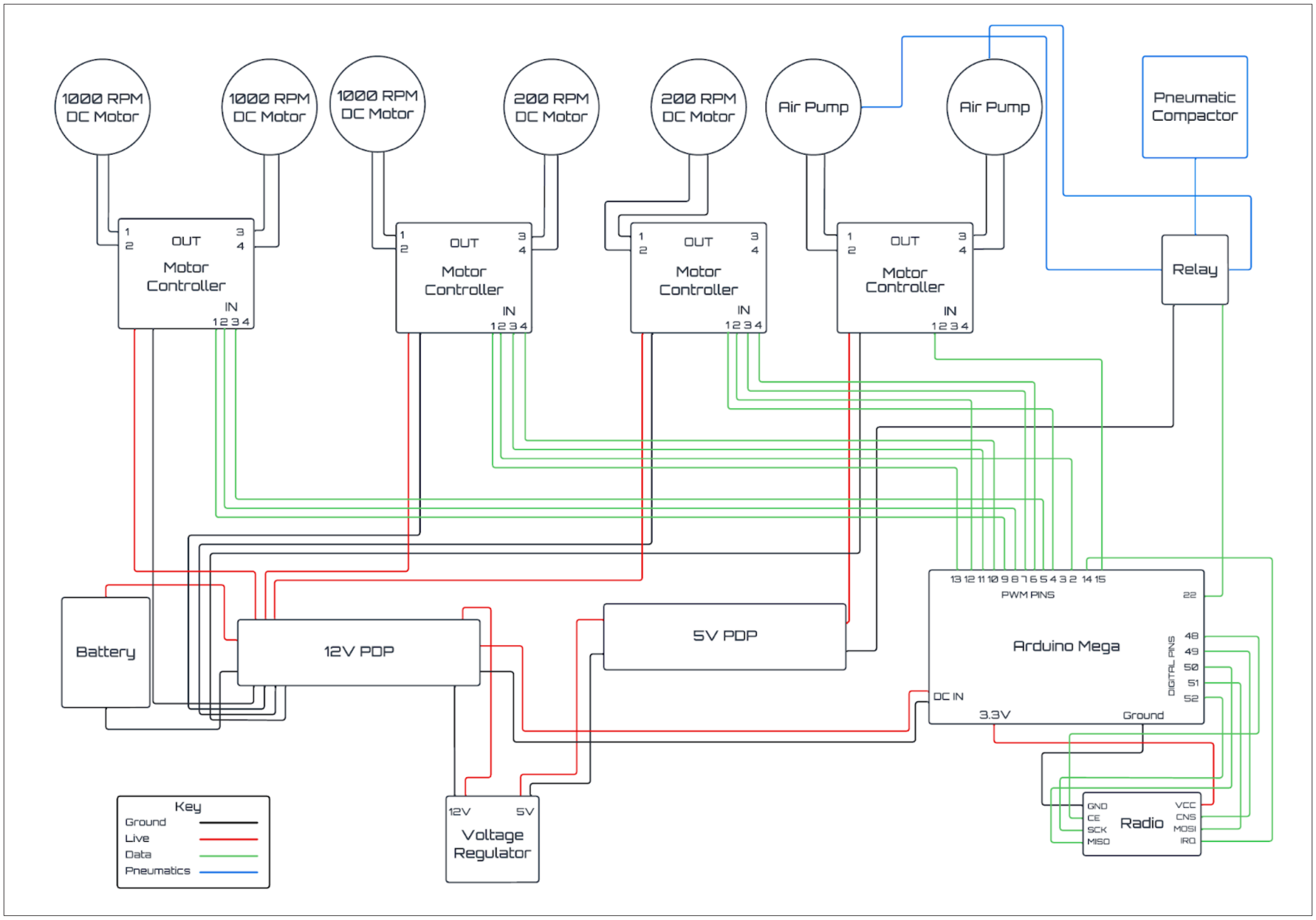


Fig 5. Wiring diagram for the Cleanup Bot 9000

Tools Needed for Manufacturing and Assembly

All of the tools below are common tools.

- Drill
  - ⅛ inch drill bit
- Allen wrenches
  - 0.035 inch allen wrench
  - 1.5mm Allen wrench
- Screw drivers
  - Small Phillips head
  - Small flat head
- Hack saw
- Wire strippers for 22 AWG
- Quick release clamps
- Super glue
- Five-minute epoxy
- Power supply for testing
- Dremel and/or angle grinder with cutoff wheel

Assembly

1. Print all parts with of a mix of PLA, PETG, and TPU filaments.
2. Drill out holes to make sure they are circular.
3. Use a soldering iron to insert M2 and M3 threaded inserts.
4. Assemble the drive train
   a. Attach two 1000 RPM motors to the motor brackets.
   b. Attach the motor brackets to the floor.
   c. Insert one 300mm stainless steel shaft into each of the four holes on the bottom so that they are centered.
   d. For the back wheels, use super glue to stick the pulley outer ring to the main piece.
   e. Add spacers onto the shafts according to the CAD.
   f. Press fit one bearing into each side of each wheel.
   g. Slide all wheels on, with the two wider wheels on the back.
   h. Put end caps on all shafts and super glue them in place.
   i. Put timing belts around the wheel pulley and the motor pulley.
   j. Slide the motor pulleys onto the motor shafts.
   k. Attach 38 TPU belt links together into a belt.
   l. Put one belt on each side, going on both wheels, and having both sides go under the second to last shaft.
   m. Position the intake body and main body together and use three 16mm M2 screws to attach them together through the bottom.
   n. Use another three 14mm M2 screws to attach them through the top.
   o. Place the main body and intake assembly on the floor and use four 12mm M2 screws to attach it to the floor from the top.

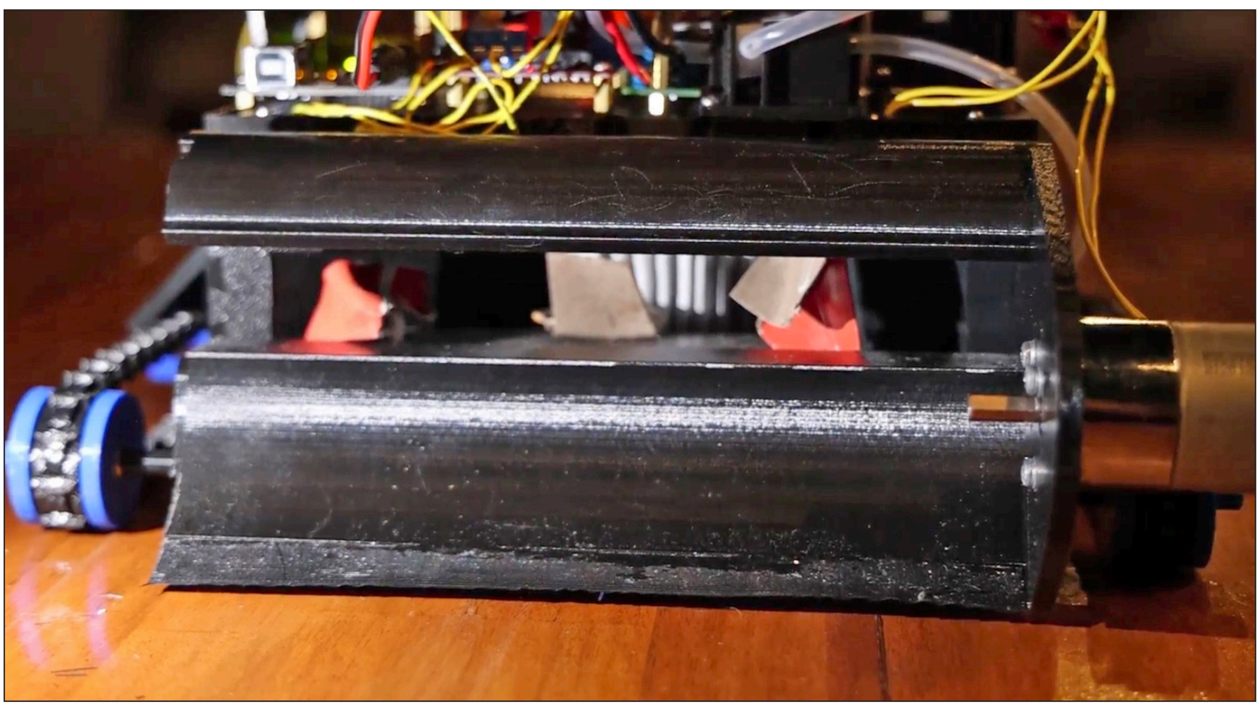


Fig 6. Cleanup Bot 9000 intake

5. Assemble the conveyor

a. Slide spacers and bearings onto 200mm stainless steel shafts according to the CAD.
b. Slide 4 TPU spacers onto a third 200mm shaft.
c. Use 0-80 screws to loosely secure the tensioners in place on each side of the main body box and superglue a nut into all 12 respective holes.
d. Cut neoprene according to the length in the CAD and glue it together.
e. Press fit a bearing into each side of the main body.
f. Slide 15RPM mini dc motor into left motor housing, ensuring that the wires go through the slot in the top.
g. Snap fit the cover into place.
h. Position left motor housing and put wires through top of main body.
i. Slide the motor housing dovetails into the slots on the body.
j. Attach the motor housing permanently by screwing a 12mm M2 screw through the top into a threaded insert in the motor housing.
k. Put all three shafts into their respective holes.
l. Slide the neoprene conveyor over the three shafts, ensuring it goes under the left motor housing.
m. Slide 200 RPM mini dc motor into the right motor housing, ensuring that the wires go through the slot in the top.
n. Snap fit the cover over.
o. Press fit pulley.
p. Position right motor housing.
q. Attach a small rubber band between the pulley and middle shaft.

6. Assemble the compactor

a. Fold an origami accordion out of water-resistant paper.
b. Super glue one end shut.
c. Cut a 6” length of PTFE tubing.
d. Super glue the other side of the accordion around the PTFE tubing.
e. Feed the PTFE tubing through the hole in the main body side wall so that the compactor is on the inside.

7. Finish the main body

a. Put your left hand through the intake to hold all three conveyor shafts in place.
b. With your right hand, take the right main body side panel, position it so it has the dovetails from the right motor housing in the dovetail slots, and snap it into place while at the same time moving the two outer conveyor shafts for clearance.
c. Once the two outer shafts are clear, you can use the viewing hole to see where the middle shaft is and align it with the bearing hole.
d. Put five 0-80 screws through the main body, into the nuts in the tensioners, tightening them slightly in all holes except the bottom frontmost hole.
e. Repeat this step on the other side.
f. Use an M2 screw to secure the right motor housing, going through the top of the main body and into a threaded insert.
g. Put your hand through the intake again and push the back roller all the way back and tighten the back 6 screws.
h. Pull the front roller towards you and tighten the front four screws.

i. Take a small rubber band and put it around the left motor pulley.
j. Position the pulley by the left motor housing and feed the other end of the rubber band through the slot in the left side of the body.
k. Hold that end of the rubber band as you slide the pulley onto the motor.
l. Use a hacksaw to cut a 6.5cm length of stainless steel shaft.
m. Position the door in place and slide the shaft through the outer hole, door, rubber band, and finally into the end stop.
n. Place the cover over the rubber band.

8. Intake

a. Cut down the wire brush with an angle grinder or Dremel so it is about 16 cm long and the brush has a radius of about 3 inches.
b. Use epoxy to attach an unthreaded bolt to each side, ensuring they stay in line with the axis of rotation.
c. Attach a 1000 RPM motor to the ride side of the intake.
d. Slide the brush assembly onto the motor shaft.
e. Put the cover over the left side, ensuring the roller shaft goes through the hole and the slots in the cover line up with the slots on the body.
f. Snap the end cap onto the shaft.
g. Take some more epoxy and glue the TPU ramp into the slots on the bottom, clamp and let dry.

9. Electrical

a. With 4 x 12 mm M2 screws, attach the electrical board to the top of the main body.
b. Attach all brackets with M3 standoffs.
c. Layout first layer of electronics and screw them down in their respective places, either with screws or more standoffs, depending on whether there will be a second layer.
d. Attach all wires to corresponding pieces according to the wiring diagram.
e. Layout second layer of electronics and screw them down.
f. Finish wiring by attaching all electronics on the second layer according to the wiring diagram.
g. Download the code from GitHub and load onto Arduino Mega.
h. Attach the battery and connect RC controller
i. Have fun cleaning!

Components

Description	Quantity	Unit Price	Total Price
Low-scratch tube brush with 4” diameter x 6-1/2”. Long brush, horsehair bristles	1	$12.70	$12.70
Qunqi L298N motor controller board	4	$6.99	$27.96
Helifouner M2 M2.5 M3 hex brass spacers standoffs	1	$22.99	$22.99
2 x 12, 24V, 10A position double-layer power distribution board	2	$11.99	$23.98
Greartisan DC 12V 200 RPM motor	1	$11.99	$11.99
Uxcell 623ZZ deep groove ball bearing, 3mm x 10mm x 4mm (pack of 10)	2	$9.49	$18.98
Gear aid aquaseal neoprene contact cement	1	$7.95	$7.95
Greartisan DC 12V 1000 RPM motor	3	$14.99	$44.97
Swpeet M2 M3 M4 M5 M6 female 3D threaded inserts	1	$17.95	$17.95
VictorsHome 3mm x 200mm stainless steel rods (pack of 10)	1	$8.99	$8.99
Rubber Sheet Warehouse .062" (1/16") thick x 12" wide x 36” neoprene rubber	1	$15.00	$15.00
Rite in the Rain weatherproof paper, 8 1/2" x 11" (pack of 50)	1	$14.95	$14.95
VictorsHome 3mm x 300mm stainless steel rods (pack of 10)	1	$9.99	$9.99
6V air valve with 2-pin JST PH connector	1	$2.95	$2.95
Air pump and vacuum DC motor - 4.5 V and 2.5 LPM	2	$7.95	$15.90
18-8 stainless steel button head hex drive screw 0-80 thread, size, 1/4” long, (pack of 50)	1	$4.31	$4.31
3D printing filament TPU NinjaTek Cheetah, midnight black, 1.75mm, 0.5kg	1	$45.00	$45.00

Description	Quantity	Unit Price	Total Price
Low-strength steel hex nut, zinc-plated, 0-80 thread size (pack of 100)	1	$5.02	$5.02
Black-oxide alloy steel socket head screw 0-80 thread size, 1/8" Long (50 pack)	1	$4.26	$4.26
Greartisan DC 12V 15 RPM motor	1	$14.99	$14.99
30t x 9mm timing belt (HTD 5mm)	1	$7.99	$15.98
200 pcs 3 x 2 mm round magnets	1	$7.99	$7.99
YXQ 10 ft silicone tube, 3mm ID, 5mm OD	1	$6.49	$6.49
Jessie premium PLA 1.75mm, black, 1kg	1	$20.00	$20.00
Jessie premium PETG 1.75mm, bold blue, 1kg	1	$22.00	$22.00
Total			**$388.35**

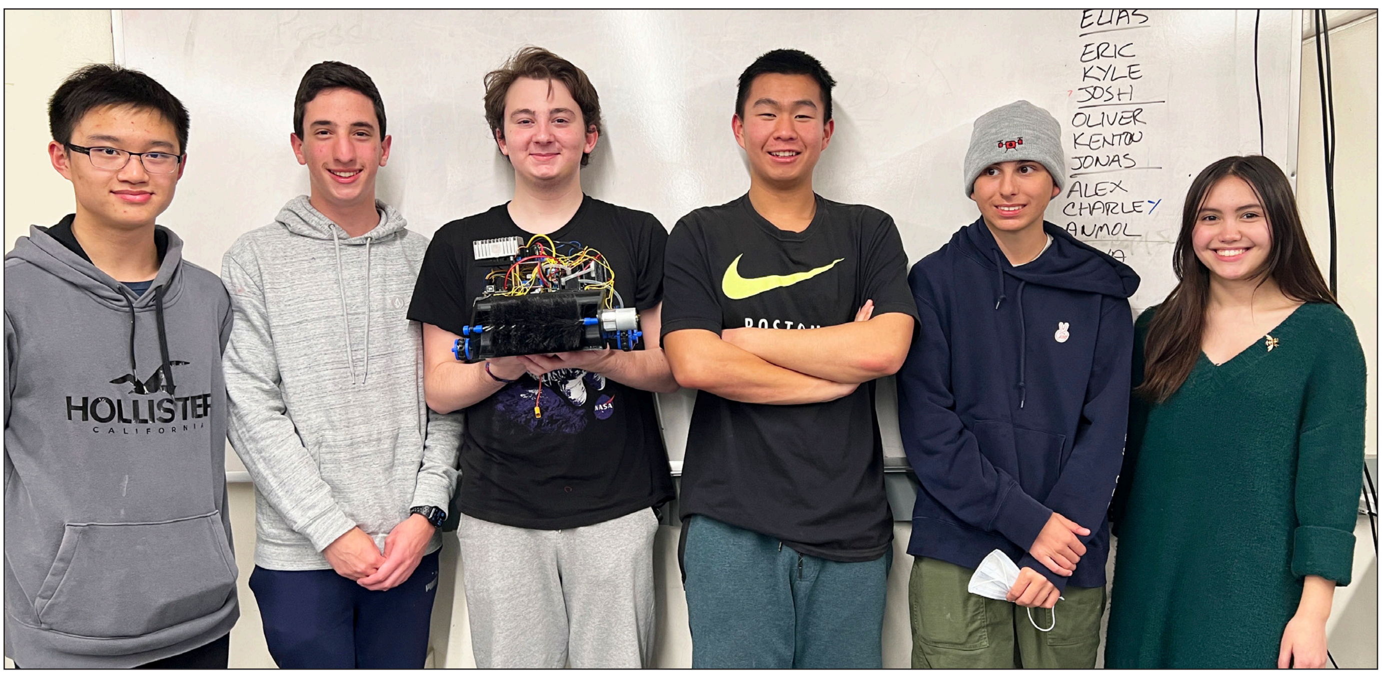


Fig 7. Cleanup Bot 9000 inventors Eddie So, Yonatan Tevet-Markelevich, Jake Freed, Kevin Yang, Diego Mobarak, and Charlotte Storey