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MITERS JOURNAL

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What is MITERS?

To answer this question, let us look into the past to the very first issue of the MITERS Journal where they attempted to answer this very question.

"What is MITERS? MITERS is the MIT Electronic Research Society, a non-profit, student-run laboratory for MIT's EE hackers. The Society provides work space, tools, low-cost parts and information to any number of the MIT community. We have a few good 'scopes, various and sundry pieces of test equipment, a b'zillion power supplies, and Bertha, our beloved PDP-7 computer. (No snickers from the peanut gallery, please. Bertha is very sensitive.) We also have the most incredible plunder-trove on campus" - **1976 Journal 1 Number 1**

From its humble beginning in building 20 (20-B-119) back in the 1970's, MITERS has grown, changed, and adapted to the ever-evolving technological world. But when you take a hard look at the core of what MITERS is, the spirit and culture are still rooted in the ideology of the original hackers that founded it.

Since those early days MITERS has gone through various evolutions, from migrating out of Building 20 to a shop space in Building N52, to acquiring new and interesting tools, cruft, and various heavy duty equipment. In its current state, MITERS is a member-run project space and machine shop where we provide the MIT community with access to tools, knowledge, and space needed to make their projects come to life. We are both a shop and a vibrant community of students, staff, and alumni who are happy to answer questions, teach new members, or just hangout and chat.

Though we have somehow become a respected shop around campus, we still are the finders and keepers of the great MIT Cruft. We still find time to plunder Reuse posts, lab clean-outs, and tech. dumps on the loading docks for recycled electronics and hardware.

What is the MITERS Journal?

Originally the MITERS journal was intended to serve as a means for intra-society communication as well as contain the following:

- An Editorial; An asbestos soap-box upon which Society Members may flame about a topic
- Intermittents; A column of notes and announcements
- Gizmo-of-the-Month
- Minutes and Notices

Going foward, the plan is to roughly follow the original intent of the journal as a guide. The journal will be used as a way to inform both our undergraduate members about the going-on's of MITERS as well as share updates and projects with the greater MITERS alumni network. To this end, we will generally plan to write an issue once a semester and publish them as a PDF onto the MITERS webpage. The journal will take the place of the MITERS Blog as the societys way of bringing attention to projects.

<u>General Layout:</u>

(1) Promote MITERS member projects
(2) Inform everyone about the Going-on's in and related to MITERS
- New Tools / Equipment
- Organization
- News Stories

(3) Important Upcoming Dates
- Swapfest
- MakerFaire (or whatever the tech. faires evolve into)

(4) Asbestos Soap-box
- Incase there are interesting topics, stories, or things members would like to write up (Editorial)

(5) Gizmo-of-the-Month
- If a member finds something interesting that they want to document and share. This will generally be dependant on member submissions.

So, this is the starting point of a new generation of the MITERS journal experiment and we shall see how it evolves from here.

Enjoy!

A Look inside MITERS

MITERS is not just a shop space, but a living and breathing hacker space. This is evident in the constantly changing landscape that is the shop space. From mounted winches on the ceilings to hold various electric vehicles up and out of the way when they are not being worked on, to the ever changing state of cleaniness of the work benches and floors through-out the space. But as you can see in the pictures, no space is left un-used for long, be it a new machine/equipment or simply a harebrained scheme to build a crazy contraption in the course of a night. If you are apart of the MIT community and you are wondering when we are open, check out the door twitter: https://twitter.com/MITERS_DOOR

The Rubik's Contraption

Over IAP 2018, MITERS members Ben Katz and Jared Di Carlo built the world's fastest Rubik's Cube solving robot.

The machine is called the Rubik's Contraption, and was built at MITERS and funded by MIT ProjX. When we started the project, the current world record was 0.637 seconds, set by Infineon, a German semiconductor manufacturer. Unlike the human solving rules, robots are not given any time to inspect the cube before solving, so we must include the time it takes to detect the colors on the cube, compute a solution, and execute it.

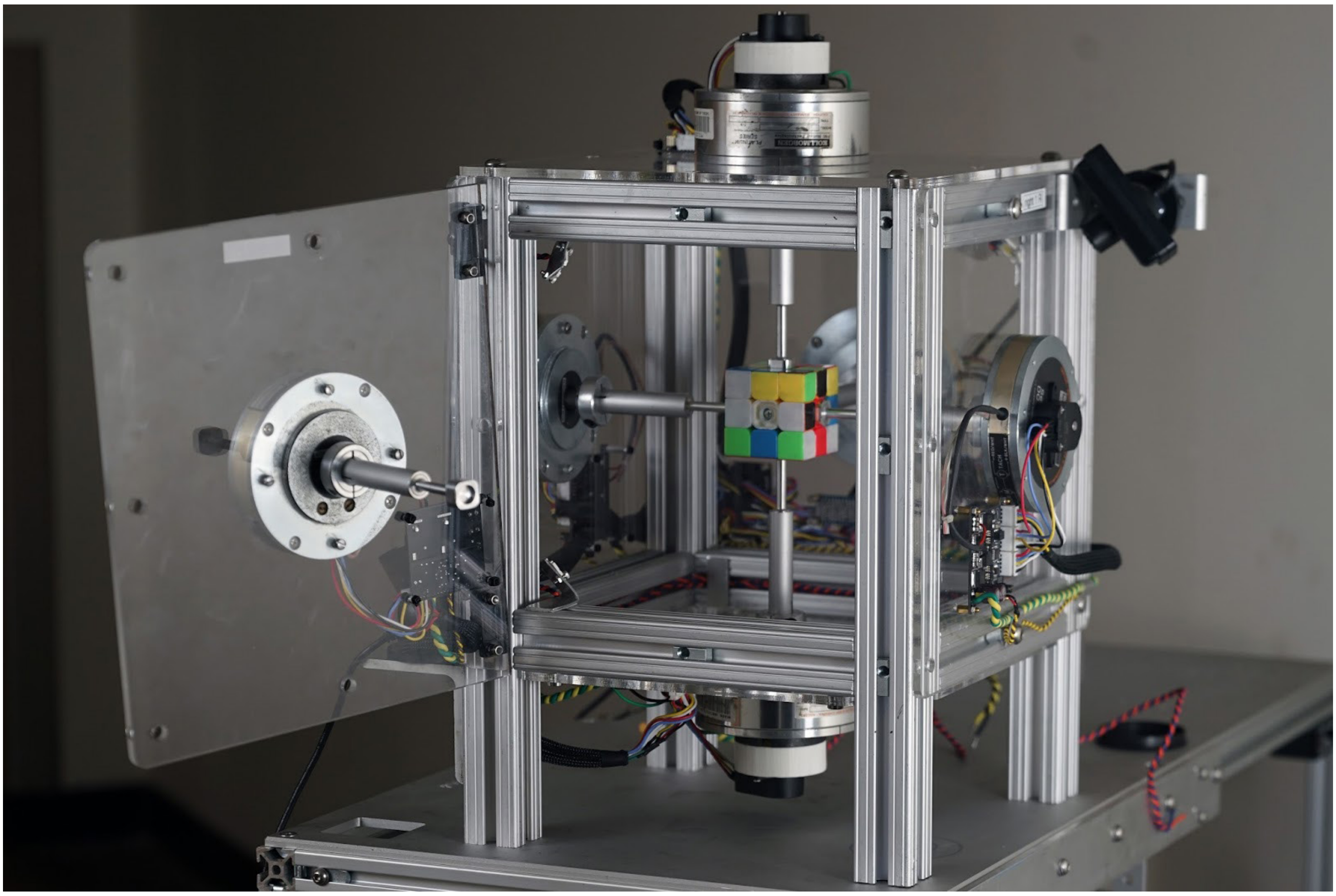
The first step of the solve is to detect colors. We used two "Playstation 3 Eye Cameras" from Amazon, because they are fast (~150 fps) and cheap ($7), and wrote an OpenCV program to detect the colors. The two cameras face opposite corners and together can see every single face.

Next, we use the "min2phase" algorithm to come up with a sequence of moves. Although it's theoretically possible to solve any cube in 20 or fewer moves, we found that finding this sequence sometimes took several seconds. Instead, we looked for 20-25 move solutions, which could always be found in under 10 milliseconds.

To move the cube, we attached a motor to each of the cube's 6 faces. To make sure the cameras can see the cube, the motors must be mounted several inches away from the cube. The motors, cameras, and lights are all mounted to a transparent box, which keeps everything aligned.

We used Kollmorgen SERVODISC motors, which can accelerate extremely quickly, combined with a custom motor controller. With a nonlinear sliding mode controller, we were able to do 90 degree moves in around 10 milliseconds. After the computer has found the solution, it sends it to all six of the motor controllers. Together, the motor controllers step through the list of moves. As they finish their moves, they synchronize with the other controllers by sending a "finished" signal to the AND BOARD. This setup makes sure that no two motors are moving at the same time, unless they are moving opposite faces of the cube.

As we began increasing our movement speed, we found that the default tightness of our $3 knockoff Amazon Rubik's cube wasn't enough. The cubes would slip or fly into pieces, and we had to wait several milliseconds after each move for all the cublets to settle. *(Cont. on next page)*



To fix this, we tightened all the faces. This made the cube much stiffer, and harder to solve by hand, but it ended up being better for the machine. To increase the lifetime of the cubes, we added some grease to the screws. Even then, they still occasionally exploded.

In the end, our fastest solve was 0.38 seconds and required 20 moves, which beat the previous record of 0.637 seconds. We think that we could go significantly faster with more tuning, which we will revisit if anybody ever beats our record.

Check out the video on YouTube

And the blog post

Jared Di Carlo
blog.cactus.zone
&
Ben Katz
build-its.blogspot.com

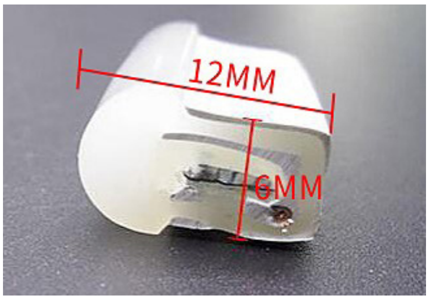
An Improvement on LED Strips

A new LED strip is on the market and it is a step above the rest. I am not sure who came up with the design but personally I think it is quite clever. I am going to mix it up and share a bit about a project of mine but focus on the product I used to make it.

I have been biking in the greater boston area for the better part of 7 years. I bike year round and tend to find myself biking home late at night after working at MITERS. Most people tend to have an LED headlight and a small array of red led's flashing on the back of their bikes. I personally found them to be inadequate, but I also had them stolen off my bike multiple times. So I eventually built my own bike battery and lights using cheap LED strips designed for underglow and lithium batteries to power them. That was 3 years ago.

Recently I decided I needed to rebuild my setup since it has been deteriorating over the years and wasn't entirely waterproof. This project had been on the back burner until I came across this LED strip on the internet and became enamored with it. So I bought 5 meters of it from ebay and waited for the boat to arrive from china.

At the heart of this LED strip is the standard SMD2835 LED which is bright and efficent, it touts 120 LEDs per meter, and is IP67 waterproof.



So why is it a clever design? There are two main points that I see as clever,

(1) It uses a diffuse silicone to encapsulate the LED strip

(2) The LED strip is mounted on the side wall

The first allows for the light to be more uniform giving the illusion of a single bar of light while also giving the strip a wider viewing angle. The default viewing angle for LED's is 120 degrees, but below you can see that the lights on the back of my bike are outputing light 180°<

The second allows for the assembly to bend at sharp angles. This increased bendability is not new to LED strips, but making the strips bending on the horizontal axis allows for more interesting shapes. *(See last page of the Journal for a sign made with these LED strips that shows off the bending radius).*

As for the waterproofing, it's as simple as the LED strip being encased in silicone, and wherever you cut the strip be sure to use hotglue to seal off the ends.

The LED strips are currently sold on EBay by someone in china for ~$25 per 5M in a handful of colors:

Flexible 12V Silicone LED's on EBay

So what are you waiting for? Go build something with these awesome LEDs, be it a Neon-esc Sign or lighting for an Electric Vehicle!

Andrew Birkel
AndrewBirkel.com

Motor Dynamometers

An Introduction

Nearly every project at MITERS these days involves an electric motor, and there is currently a particular interest in electric motor control and design. To make our vehicles faster and more efficient, and robots jump higher, we have built several electric motor dynamometers for characterizing and stress-testing our motors, inverters, and motor control algorithms.

A dynamometer is a device for measuring the mechanical power output of a motor. Our motor dynamometers measure voltage and current input to a motor, and torque and speed at the motor shaft. These four measurements allow calculation of efficiency, losses, torque ripple, and other useful motor characteristics.

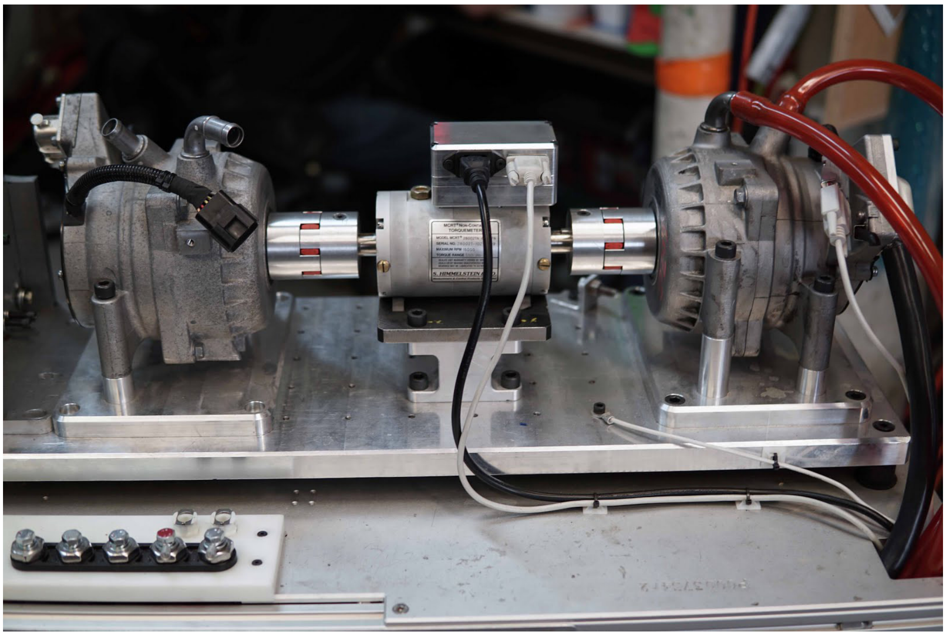


Figure 1: The dyno uses a Hyundai Sonata HSG on the right as the absorber. Here the dyno is shown with a second HSG on the left as the Device Under Test. The torque sensor is in the middle, between the two motors.

Dynamometer Architecture

The three core components of the dynamometers are a rotary torque sensor, a motor being tested (Device Under Test), and a motor permanently attached to the dyno called the "absorber". As its name implies, the absorber reacts the torque from the DUT, and converts the mechanical power from the DUT back into electrical power. The torque sensor lies between the output shaft of the DUT and the input shaft of the absorber. Typically, the absorber sinks power, operating in "regenerative braking", but it can also output power in order to test regen on the DUT.

Both the absorber and the DUT are powered by the same power supply. As the motors run, electrical power flows from the power supply, into the DUT where it is converted to mechanical power, through torque sensor to the absorber, where it is converted back to electrical power, flowing back into the power supply. With this architecture,

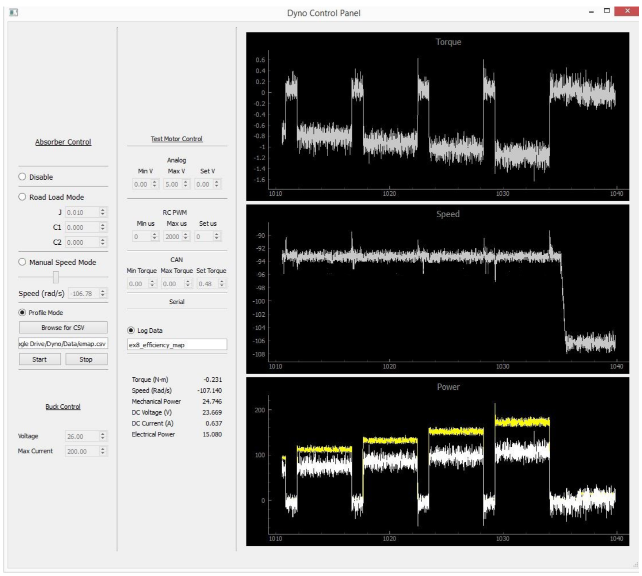


Figure 2: Dyno Software control panel mid-experiment

the power supply only needs to supply the losses in the system (motor losses and friction), rather than the whole power of the DUT, meaning a motor can be tested at 10's of kW of output power with only a few kW of load on the power supply.

The absorber controller was built from the power electronics of a 2nd Toyota Prius, with custom logic and motor control using Field Oriented Control on an STM32F4. Custom A/D boards sit directly next to each analog sensor (torque, voltage, current) to digitize their signals as close as possible to their sources. The measurements are sent over serial to the control computer. The control computer runs a Python and QT-based dyno control software which logs and live-plots sensor data, and sends commands to the absorber. Long tests are automated by generating a time series of torque and speed operating points to test.

Data Collection

By sweeping all torque and speed operating points of the motor, performance maps can be generated which describe the steady-state performance of the motor. The efficiency map, a standard in the automotive industry, is mechanical output power divided by electrical input power at each operating point. The loss map, which shows how much power is dissipated in the motor and controller, is just the difference between mechanical output and electrical input power. And the input power map shows how much power would be drawn from a battery or power supply at each operating point.

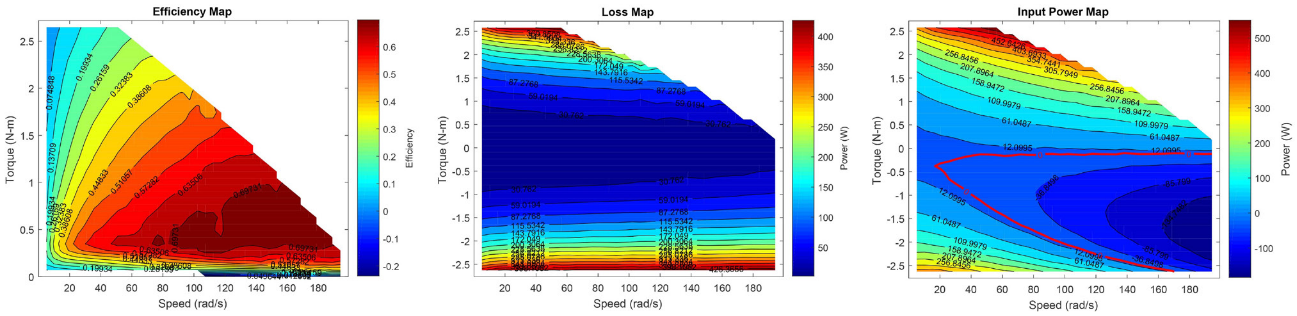


Figure 3: Left: efficiency map. Center: Loss Map. Right: Input Power Map – region enclosed by red corresponds to negative electrical power flow.

Other than measuring performance maps, the dynamometers can be used to measure torque ripple, motor saturation, gearbox losses, and other quantities of interest.

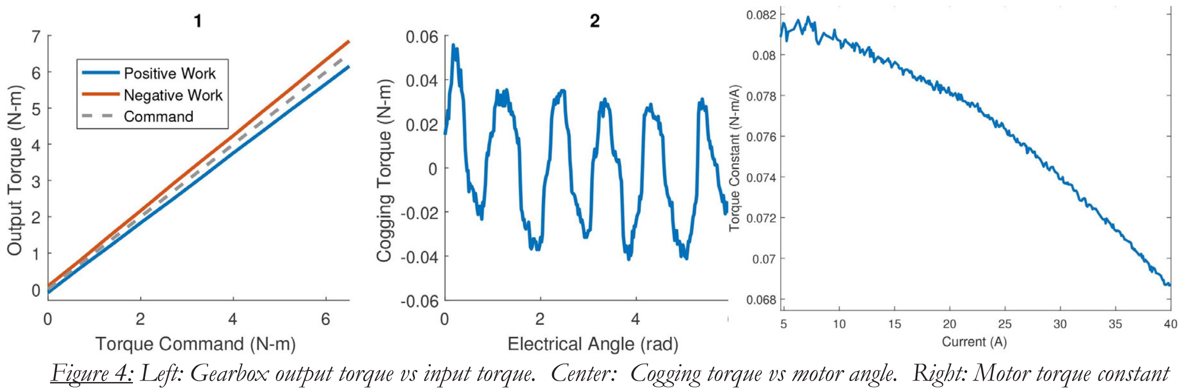


Figure 4: Left: Gearbox output torque vs input torque. Center: Cogging torque vs motor angle. Right: Motor torque constant vs current

For more information visit:

http://isopack.blogspot.com

and

http://build-its-inprogress.blogspot.com/search/label/Motor%20Dyno

Ben Katz
build-its.blogspot.com
&
Bayley Wang
Isopack.blogspot.com

Wooden Engineering Tool Case

The main stay of an engineers tools is the caliper, Whether it is taking measurements of the device or part you want to hack, modify, or mate to, usually the first thing you reach for is a pair of calipers. In this project I decided to create a dedicated tool case for my pair of calipers and a few other interesting measurement tools I enjoy using.

This box was made using a CNC-router following my own design made in Solidworks. The box is made of black walnut and finished with a few coats of teak oil. The engraving was done with a laser cutter and I designed the pattern in Adobe Illustrator. My favorite find during the design of this project were the hidden barrel hinges. This hinge is what gives the backside of the box a smooth and clean look by the nature of having the hinges completely hidden.

The tools inside

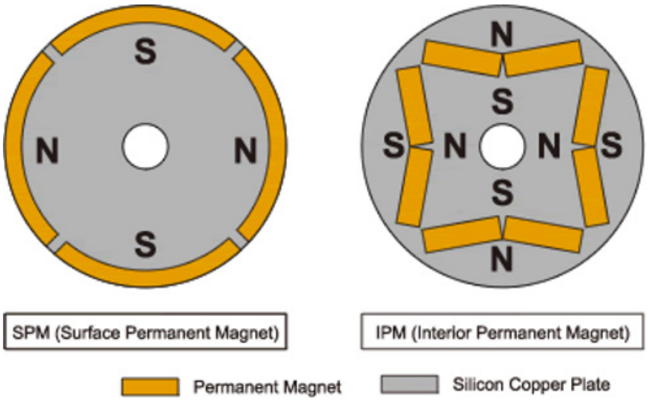
Mitutoyo 6" Digital Calipers

Starrett Tooling: *156M+ (Metric Thread Gauge set), 472+ (English Thread Gauge set - 51 Leaf), 178A+ and 178B+ (Small & Large; Fillet and Radius Gauge set)*

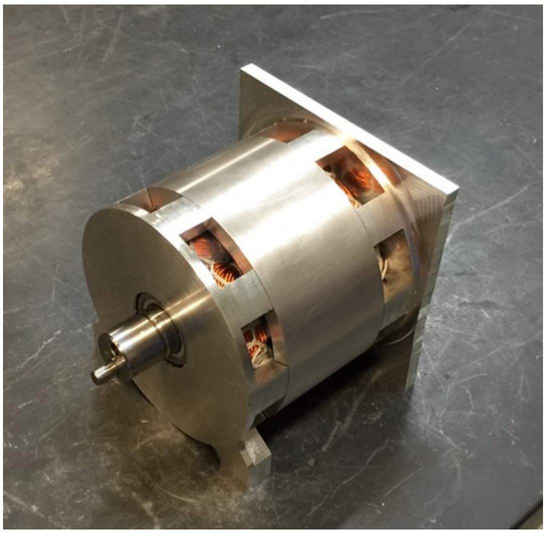
Andrew Birkel
AndrewBirkel.com

Toyota Prius Air Conditioner Motorbike

An IPM motor from Toyota Prius A/C unit rehoused to make a great 4kw E-bike.

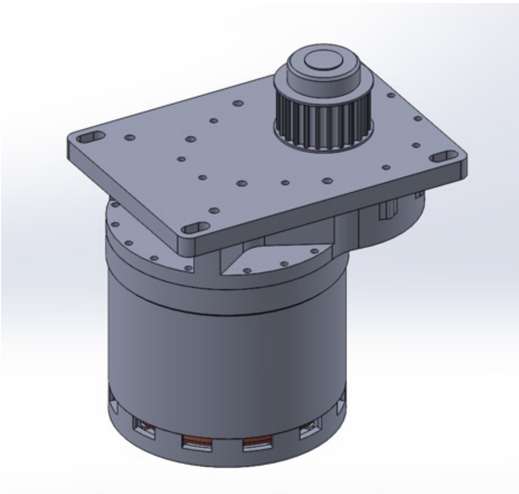


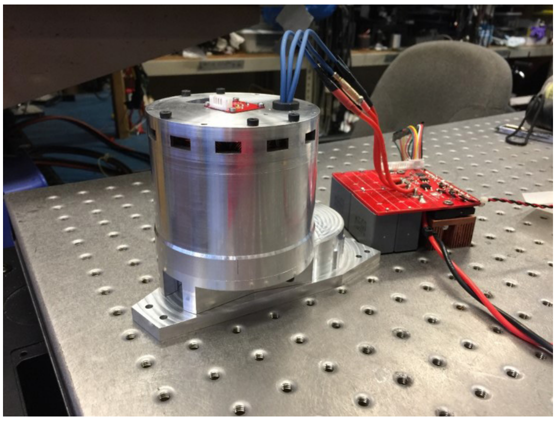
IPMs are ideal for traction applications due to broad power range and high efficiency compared to SPM motors, hence why IPMs are used in nearly every electric car on the market. Can we use one for an E-bike?



What I did:

- A/C unit rotor/stator put in custom machined housing with integrated 3.14:1 spur gearbox
- Ran dynamometer tests of this housing to find maximum torque per amp operating points
- Made custom FOC controller to run these points
- Motor/gearbox unit and controller attached to bike with 160v of power tool batteries





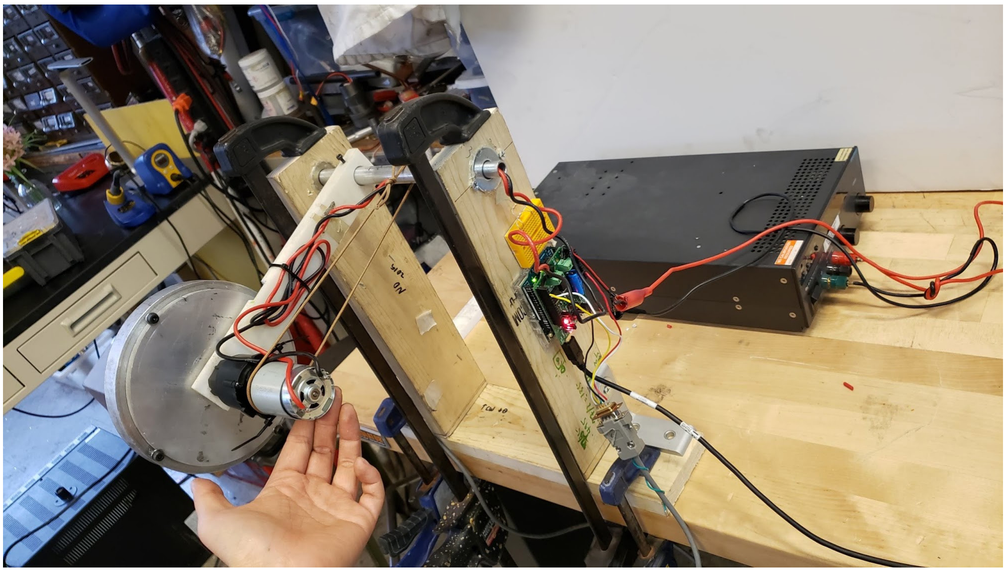
Austin Brown

Reaction Wheel Inverted Pendulum

Hullo MITERS journal! (I'm very excited about this, and happy that Andrew is taking this on).

This past semester my main project at MITERS has been a reaction wheel inverted pendulum. I took *Underactuated Robotics* this past semester, and was choosing between writing a controller for (autonomous) sailboats, or physically realizing p-set three: a reaction wheel inverted pendulum. Being bummed out about my theory struggles, I chose the latter. The inverted pendulum has a single input, a motor attached to a flywheel, and two stable points (upright and downright). The controls consisted of energy-shaping for the swing up, and then when we're close to the fixed point (in the "region of attraction" as determined numerically by Lyapunov analysis) we linearize & get a LQR (linear quadratic regulator) controller.

So, I proceeded to build a wooden frame, with ball bearings, an encoder press fit into the shaft, a motor rigidly attached to shaft via a stick, a flywheel press fit onto the motor, and everything clamped to the table + a power supply, Arduino, and motor controller to round it all off.

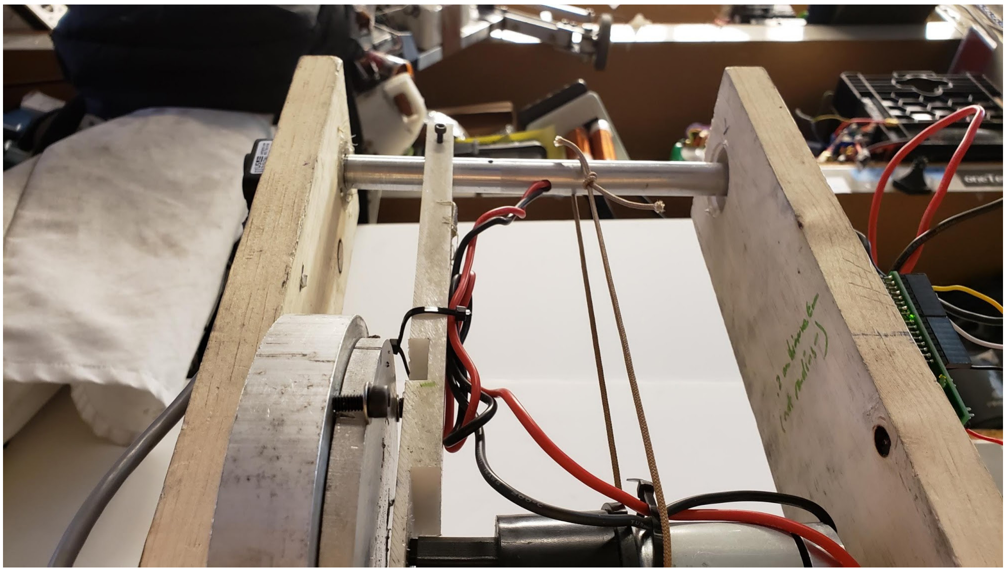


<u>What I learned:</u>
1) Drill motors are $18 of happiness
2) Press fits are the way to attach things fast to shafts
3) MITERS needs more buttons and switches
4) If your math outputs a torque controller, that's current control. By default, motor bridges are essentially running voltage control :)
5) Re-learned equations of motion. Angular velocities "add" :0 So, the inertial kinetic energy of the

flywheel = $\frac{1}{2} I_{Stick}(\theta'^2_{stick} + \theta'^2_{Wheel})$

In the end, I was only able to implement a bang-bang swing up with a PID stabilization around an experimentally-determined region of attraction. And really, the inverted pendulum is not an underactuated system, though it is nonlinear. Some people were a lil' dismissive of my enthusiasm, given I ended up "just" doing PID, but I'm pretty happy about it all :) And it appears to have impressed my Prof. so much he typo'd my grade ?? so I'm still in grad school, hurrah's all around!

I think next time I will build a much lighter system, possibly 3d printed, and then I will be able to do proper LQR. Or maybe I'll build a more underactuated system – perhaps a hopper? :)



A fun closeup shot of the neat trick for attaching the inertial rim to the wheel, and how barely the new motor + flywheel fit in between the wooden posts.

Video @ https://www.youtube.com/watch?v=bWbEt6hoUvY
Blogpost @ https://www.orangenarwhals.com/2019/08/diy-flywheel-inverted-pendulum/

Nancy Ouyang
OrangeNarwhals.com

Square Yo!

As a professional yo-yoer, I got tired of my high performance aluminum yo-yos rolling off tables and so I decided I needed an upgrade. My competition yo-yo that I compete with is called *the Boost*, so now I'd like to present the *Boost Squared*. An aluminum bearing-ized, fully functional yo-yo.

Later versions of this yo-yo were made on the Area 51's Haas VF-2. They were designed with different weights, materials, sand blasting patterns, etc. I also was able to sneak them into the FSAE anodizing batch.

For the weight rings seen below, I primarily used brass and machined pieces of brass and super glued them into place.

The First Protoype was made on MITERS CNC mill and manual Bridgeport

After sending these designs to my yo-yo sponsor, they were concerned about safety, so I also designed and made this safety square yo-yo which sports injection molded covers to make the yo-yo appear round from the outside, thus preventing bruised fingers. And for added fun, I also made a display stand to show off my yo-yos. Featuring my design that my sponsor already produces.

Custom Glow-in-the-dark finger protector

Display stand for my previous design that is already in production

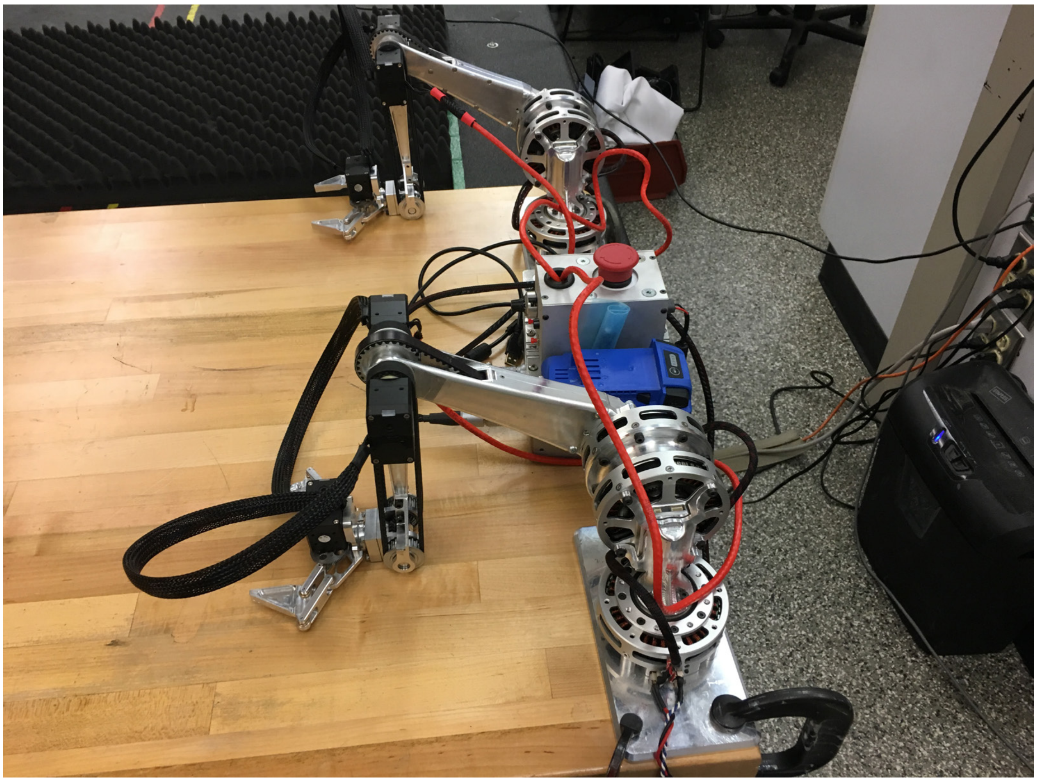
Video of a Test YO @ https://www.youtube.com/watch?v=2a4LQrjymk8

Alex Hattori
AlexHattori.wordpress.com

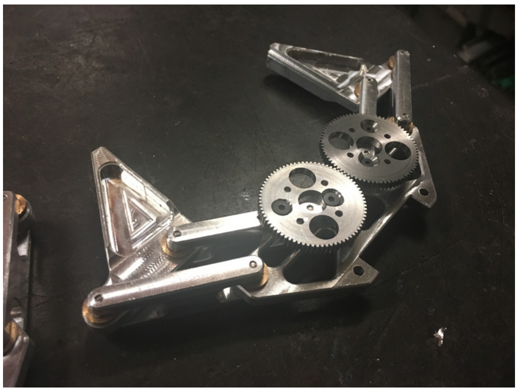
A Gripping Senior Thesis

My senior thesis consisted of adding 2 more degrees of freedom and a gripper to a set of bilateral teleoperated arms that Ben Katz made for our lab. I thought I could let the pictures do the talking, if you would like more information please see my thesis.

Video @ https://www.youtube.com/watch?v=YSrqIPfSt7E



The Forearm assemblies attached to Ben's 3-DOF arms



Gripper machined assembly

These are the completed forearm assemblies.

Alex Hattori
AlexHattori.wordpress.com

Uppercut 2019 - 250lbs BattleBot

This year, MITERS and the Combat Robtics Team (MIT-CRC) decided to give the TV show Battlebots another shot. The show consists of 250lbs fighting robots, destroying each other in a large polycarbonate arena. The rules are simple: destroy the opponent and make it look good for viewers. Thus Uppercut was born.

Uppercut sports a 50lb vertically spinning fist shaped blade. The fist spins at around 3000 rpm, giving us an effective tip speed of around 200mph. It's made of AR500 (abrasion resistant steel) and packs quite a punch.

Uppercut was a team composed of 16 MIT undergrads. Alex Hattori focused his efforts on the rear design of the robot. He CNC milled the "butt" out of aluminum, which housed critical components such as batteries, drive motors, motor controllers, and the drive wheels. Meanwhile Mason Massie designed and welded the front of the robot from steel. This part held weapon motors and the weapon while allowing modular forks and wedges to be attached.

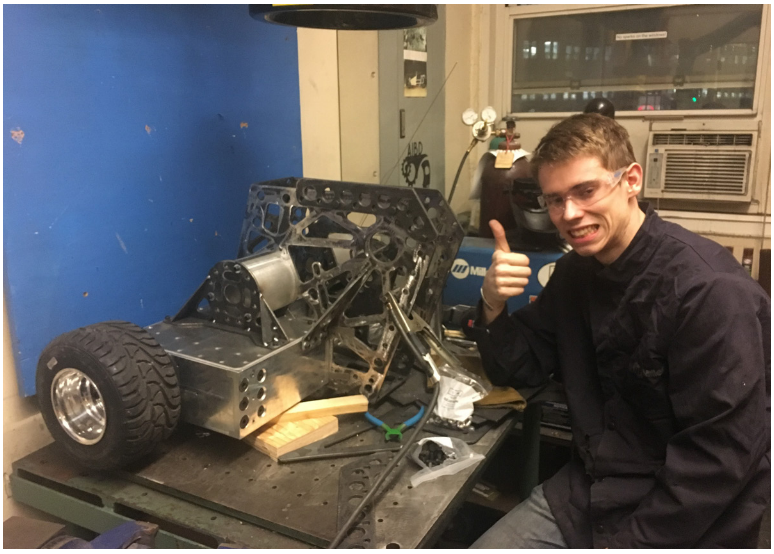
Inspiration for Uppercut came from Alex Hattori's combat robots built in lighter weight classes. Much redesign and testing occurred in the smaller weight classes to inform the design of the 250lb robot. The team extensively used CAD to model the robot before manufacture.

A sub-set of the overall team, the filimg process took two weeks!!! (So not everyone was there for the promo-photos)

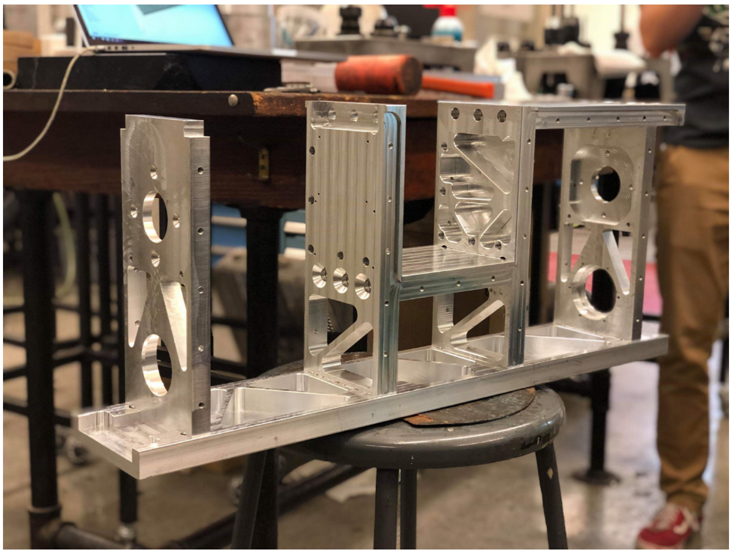
For Video's, Visit: https://www.youtube.com/channel/UC0Da03iAGRyuENLBJUB-71WQ/featured

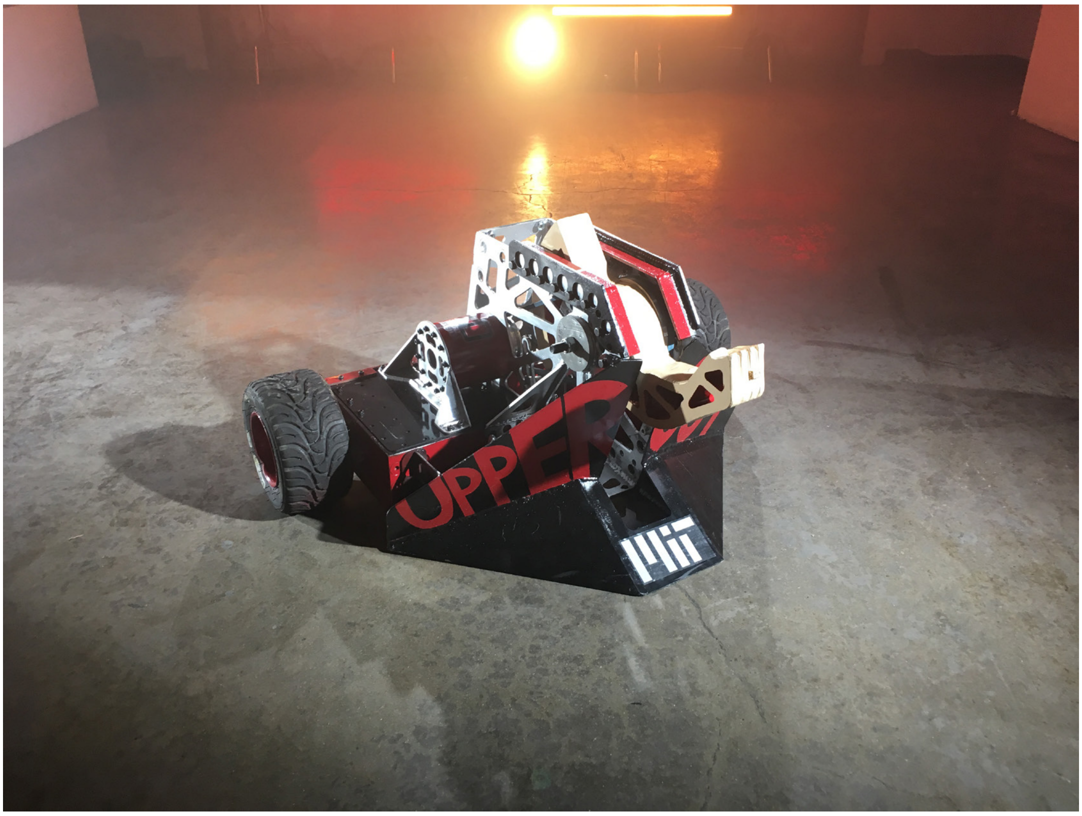
The Team: https://battlebots.com/robot/uppercut-2019/

Facebook Group: https://www.facebook.com/UppercutBattlebot/



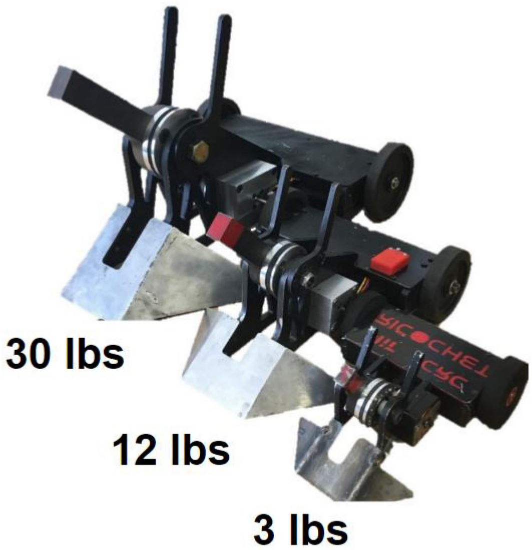

UPPER
CUT




UPPER

Various members of MITERS and the Combat Robotics Club built many robots for the 3lb weight class.

Notable ones includes:
Ricochet by Alex Hattori
Son of Wasabi V1 and V2 by Mason Massie
Yeet V1 by Sofia Leon
Yeet V2 by Mason and Sofia
Byte by Chetan Sharma
One Tire Fire by Jackson Gray
So Ratchet by Sarah Pohorecky



Ricochet

Byte

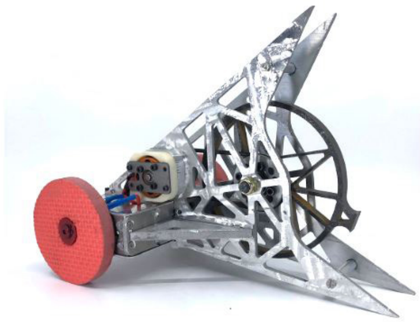
Son of Wasabi

Son of Wasabi V2

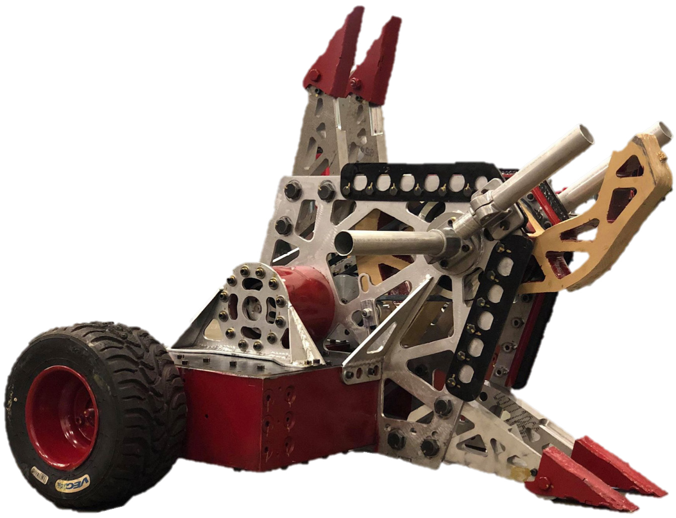
One Tire Fire

So Ratchet

Yeet V1



Yeet V2



Big Yeet

Sofia Something
ACoolWebsite.com
&
Mason OrOther
ACoolerWebsite.com
&
Alex Hattori
AlexHattori.wordpress.com

A MITERS publication:

Edited by *Andrew Birkel*