Jay Lee

Mechanical & Robotics Design Portfolio

University of Michigan

BSc Mechanical Engineering

Robotics Concentration

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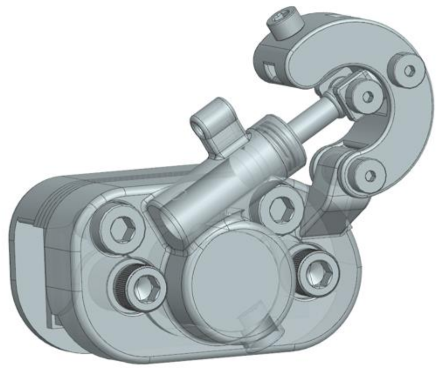
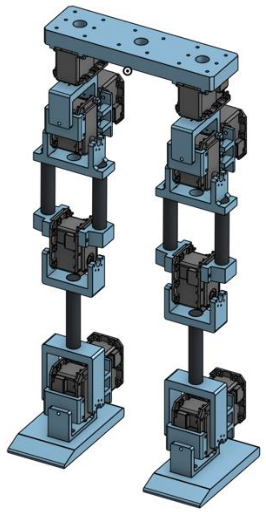
Highlights

1. Mechanical & Mechatronics Design
2. First Principle Analysis & Usage of Other Analysis Tools (FEA, ADAMS, etc.)
3. Engineering System Integration
4. Robotic Manipulation & Control System Design



Solar Car Team

- Brake Pedal & Caliper Mount
- Custom Brake Caliper
- 6-bar Linkage Canopy Hinge



WolverBot Kickers

- Leg Initial Design & Development
- System Integration
- 22 DOF Kinematics

MMINT Lab

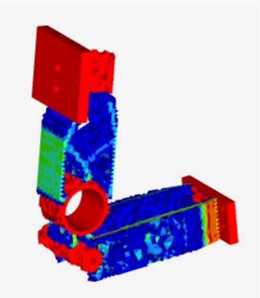
- Tactile Sponge Sensor Module
- KUKA Robot Arm Control & ROS
- 4-Finger Tactile Sensing Hand

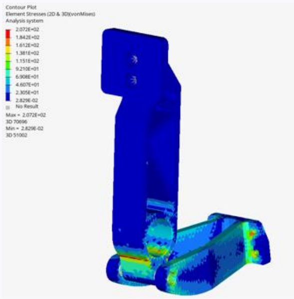
Brake Legbox Assembly

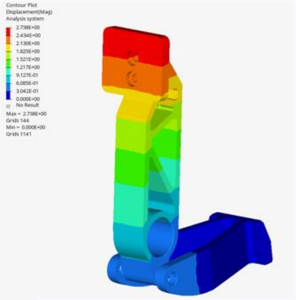
World Solar Challenge 2023, Brakes Team Co-Lead

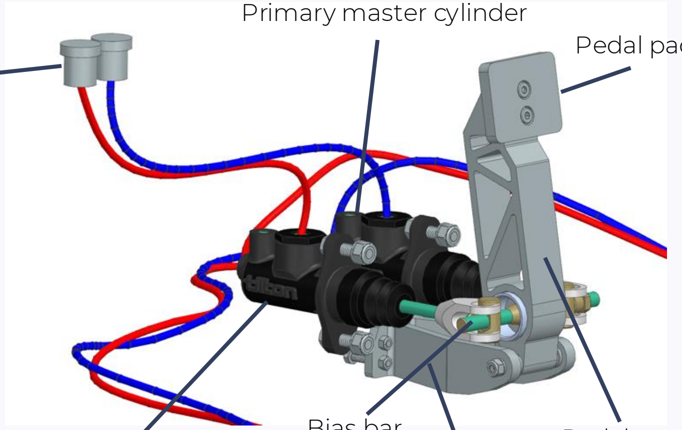
Implications: Weight reduction (race time reduction)
Higher rolling efficiency (zero brake scrub)
Driver safety

Skills	Siemens NX (CAD Design) First Principle Alanysis (Hydraulic pressure, pedal lever advantage) Hyperworks optimization & FEA analysis
Targets	Stopping distance at 22.5 m (primary), 44.5 m (secondary) without yaw Front wheels must lock up earlier than the rear wheel (WSC regulations)
Load Cases	500 N input force applied on pedal pad (RBE2 rotational connection, constrained on the end of mount-chassis)
Fabrication	3-axis CNC Machine
Assumptions	Set initial velocity 27 m/s, car mass ~240 kg Safety factor 1.1 (to yield strength)
Materials	Aluminum 6061-T6 DOT 4 brake fluid

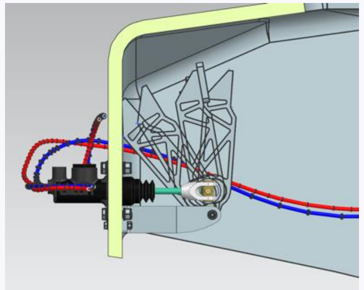

Optimization
Minimized mass

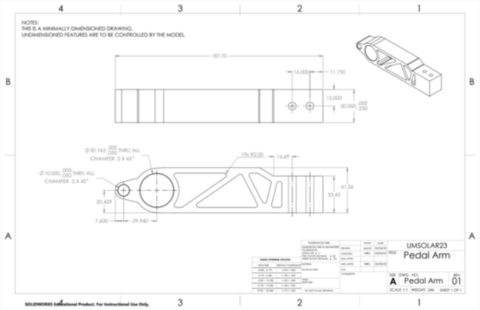

FEA Stress Analysis


FEA Deflection Analysis



Final Pedal Assembly
Off-the-shelf master cylinders & brake calipers


Pedal Stroke Range test



Engineering drawing of the pedal arm
→GD&T skills required

→ Pedal in “Astrum”
4th place in Worlds Solar Challenge 2023
1st place in American Solar Challenge 2024

Brake System Redesign

American Solar Challenge 2024, Brakes Team Lead

Skills
- Siemens NX (CAD Design)
- First Principle Alanysis (Hydraulic pressure, lever advantage)
- Hyperworks optimization & FEA analysis

Targets
- Minimum average acceleration 4.72 m/s² (ASC regulations)
- Parking brake must with stand force 10% cars weight (289 N)

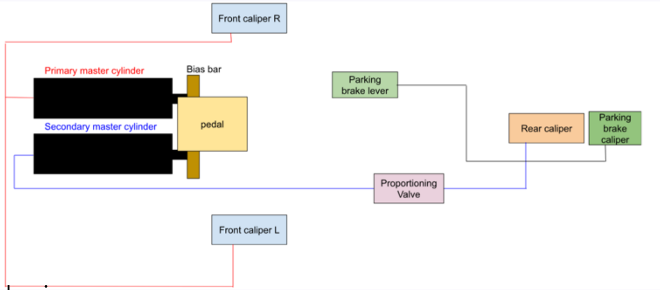
Load Cases
- 500 N input force applied on pedal pad → 718 N on the caliper mount
- 120 N input force from the lever (parking brake)

Fabrication
- 3-axis CNC Machine

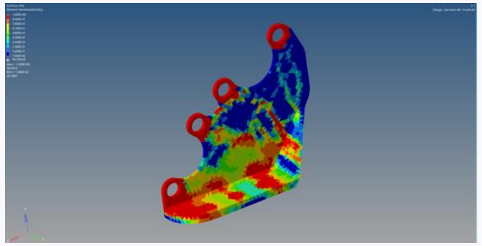
Assumptions
- Initial velocity 50 km/h
- Vehicle is tested on the wet pavement (friction coefficient 0.4)
- Safety factor 1.1 (for stresses, used yield strength)

Materials
- Aluminum 6061-T6
- PLA 3D printed material
- DOT 4 brake fluid

ASC brakes system schematics



Rear caliper mount design

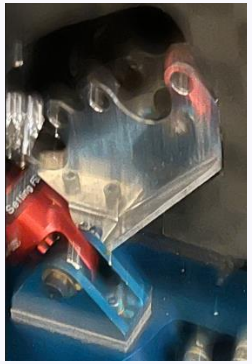


Optimization

Minimized mass

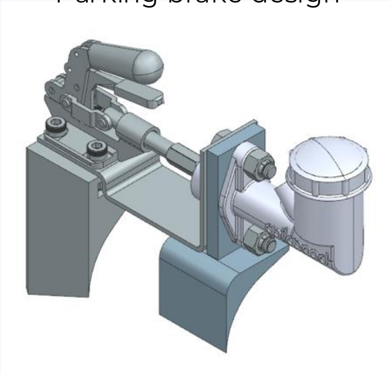
FEA Deflection Analysis

Less than 0.5 mm



1st place in American Solar Challenge 2024

Parking brake design



Custom Caliper Desgin

World Solar Challenge 2025, Brakes Team Lead

Skills	Siemens NX (CAD Design) First Principle Alanysis
Targets	With 500 N input force, 2,000 N output caliper to rotor Brake pad MAX travel, minimum leaking points
Load Cases	Hydraulic pressure 20 MPa Bending stress on all bolts < 804.17 MPa (s.f. 1.2 to yield)
Fabrication	3-axis CNC Machine
Assumptions	Initial velocity 50 km/h Vehicle is tested on the wet pavement (friction coefficient 0.4) Safety factor 1.1 (for stresses, used yield strength)
Materials	Stainless Steel DOT 4 brake fluid

Background

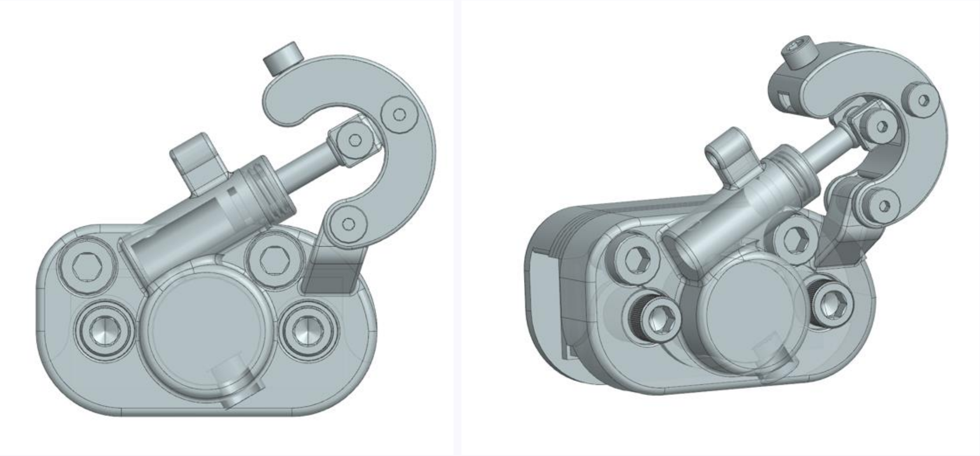
Brake scrub from the past WSC and ASC

→ fixed by testing 4 different springs inside to increase retraction force

→ 22, 35, 36, 46 lbs/in springs tested

→ each test is held during a single drive day

Implications: Weight reduction (race time reduction)
Improved performance & safety (customization)
Heat management



Custom caliper design

Design Description

- Actuated by the cable which is fixed by the set screw on the lever
- 2 middle bolts are connected to the caliper mount
- 2-stage linkage pump on the integrated cylinder
- 1” bore diameter

Prototype is in progress

Canopy Hinge & Upper-Canopy Interface Design

American Solar Challenge 2024, Race Mechanical Engineer

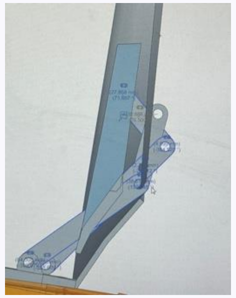
Skills	Siemens NX (CAD Design) First Principle Alanysis – 4-bar linkage analysis
Targets	Rigidly connected to the upper and the canopy, no sideways movement Must be able to push opened by the driver, minimum travel 100° (hinge) Adhesive must withstand wind load, shear stress of 441.19 kPa (shelve)
Load Cases	210.9 N in all directions in the middle of the canopy
Fabrication	3D printer
Assumptions	Maximum Wind speed 70 km/h Safety factor 1.1 (for stresses, used yield strength)
Materials	Aluminum 6061-T6 SLS 3D Printed Material (hinge) SLA 3D printing material (shelve) DP 420NS Black

→ upper pattern was printed and placed before the parts were placed
→ sanded thoroughly for aerodynamic purposes (up to grid 800)

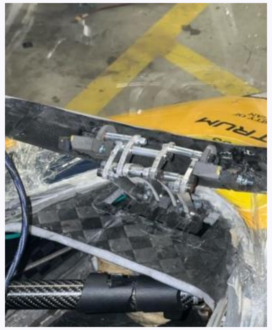
1st place in American Solar Challenge 2024

Implications: Vibration reduction & structural integrity
Driver ergonomic & user interface

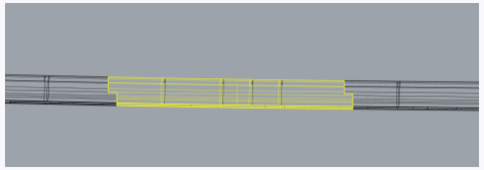
Canopy Hinge

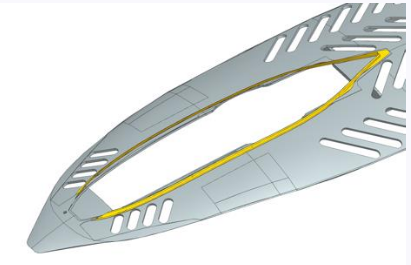
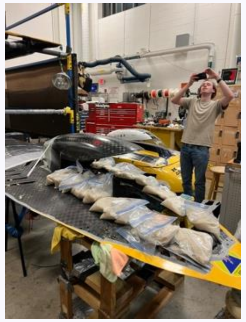
6-Bar Watt-2 Linkage design
→ since the canopy must not penetrate the upper
→ canopy travel of 119° achieved
→ opened by driver with a single push from inside

Upper-Canopy Shelve



Divided into 25 pieces – tolerance stack up considered

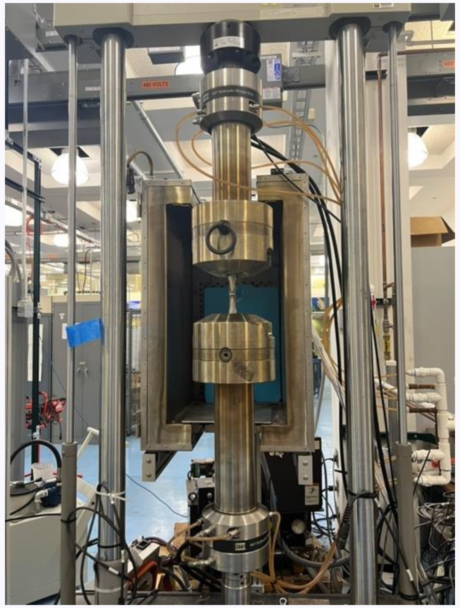
Roll Cage Weld Tensile Testing

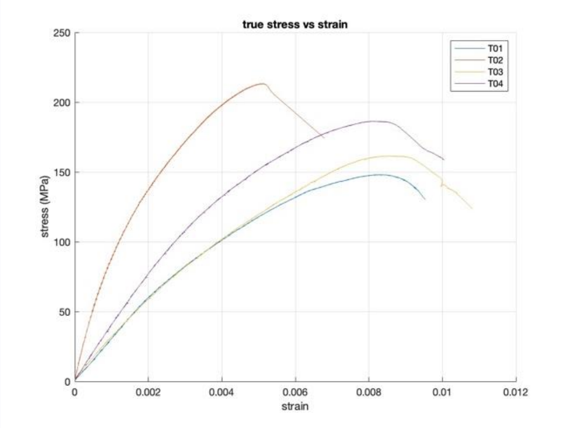
American Solar Challenge 2024, Race Mechanical Engineer

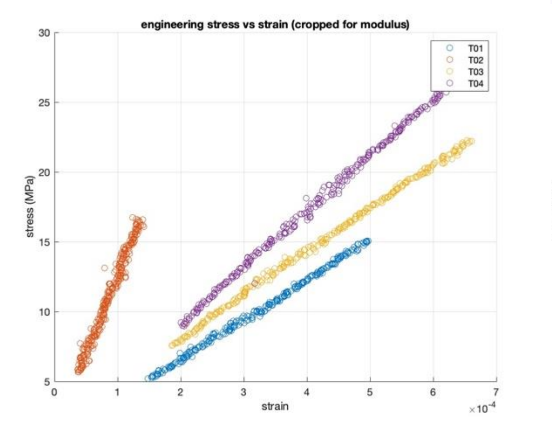
Implications: Validating structural integrity

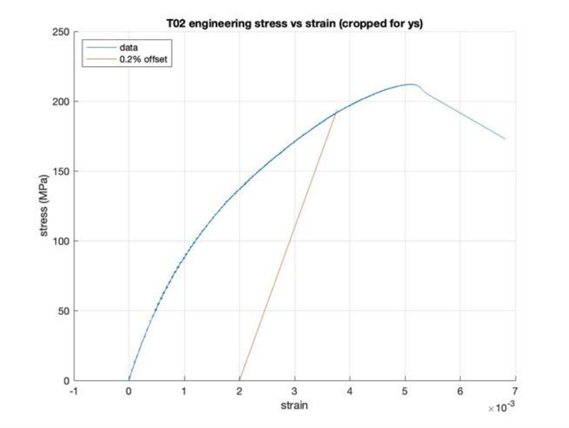
Optimizing welding techniques & material selection

Skills	Matlab graph analysis
Targets	Weld structure must withstand 435 MPa (Titanium 4130 yield strength)
Load Cases	MAX 10 kN applied by the machine until break
Fabrication	Titanium tube welded by sponsor
Assumptions	Dogbone titanium will replicate the roll cage weld
Materials	Titanium Grade 9 (tubes) Titanium Unknown Grade (welds)









- 4 tests for same samples in total
- MAX Yield strength measured amongst the sample was 194 MPa
- Result of the testing, we found that the weld grade was **Grade 2 instead of 5**
- Ended up changing the material to steel

Robot Leg Initial Design

RoboCup 2026 Humanoid League, Vice President

Implications: Stability & balance in motion, controls integration
Mechatronics system design

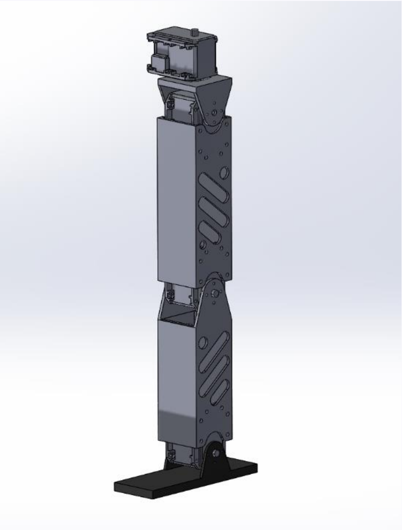
Skills	SOLIDWORKS, OnShape (CAD Design) Gazebo simulation First Principle Alanysis – Kinematics, Motor Analysis
Targets	At least ±90° movement on each joint Withstand the robot's weight (estimated 3 kg) ~80 N kicking
Load Cases	29.4 N for robot's weight
Fabrication	3-axis CNC Machine
Assumptions	All Motors (Dynamixel MX 28-T) are driven by 12 V operating voltage
Materials	SLA 3D printing material Al 6065-T6 plates Wooden dowels

Next prototype developed with dowels – to test variable leg lengths

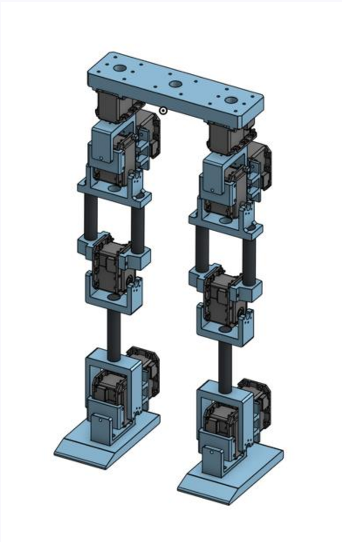
20 N of kicking force achieved from initial simulation

→ change motor to Dynamixel RX 64-T to increase the force (on going design change)

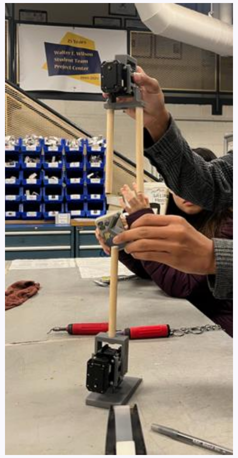
Initial Design



Updated Design



Prototype with dowels

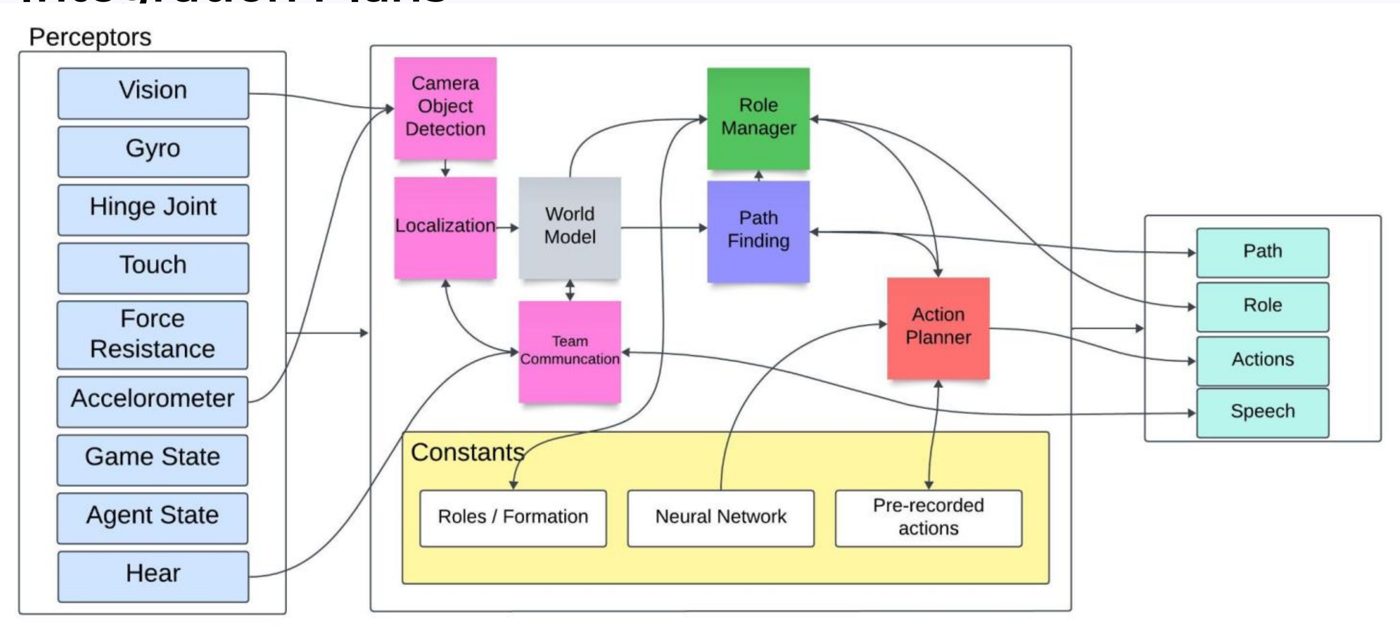


System Integration

RoboCup 2025 3D Simulation League, President

Implications: More efficient data communication
ML adaptive strategy

Integration Plans



Perceptors and effectors developed by TCP client
→ connects to the server to move the robots

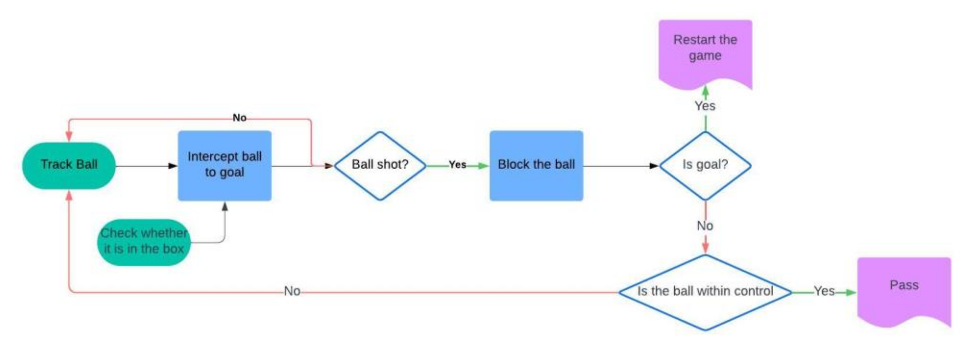
Role manager exists since role defender-midfielder role changes based on each robot's position relative to each other

Action planner run by neural network with pre-recorded motions

Modified A* for path finding

Defender voting system – changes midfileder and defender based on position
→ increased defending ability

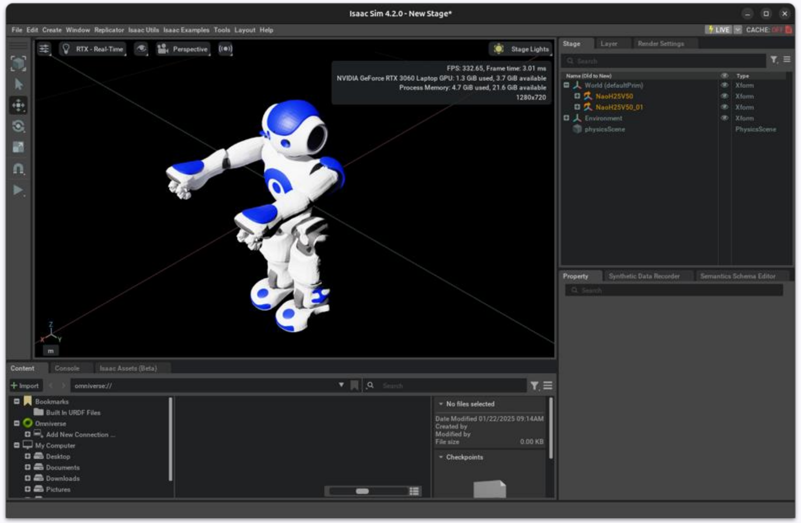
Example role schematics for goalie



Motion Kinematics

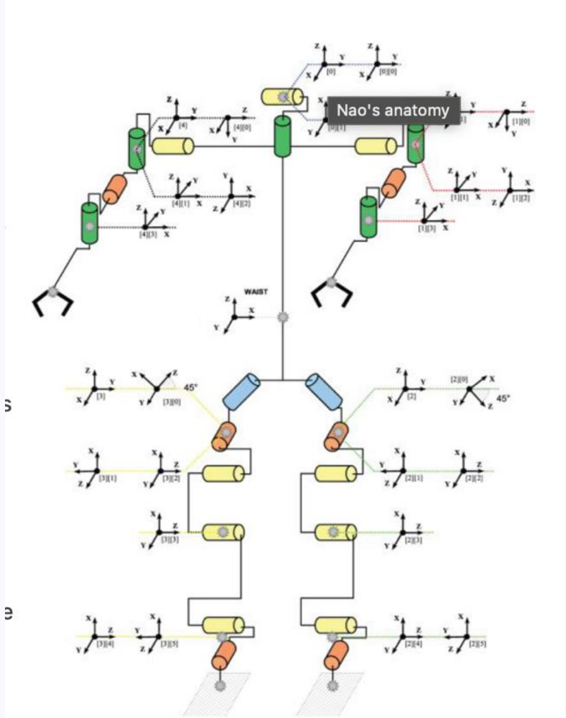
RoboCup 2025 3D Simulation League, President

Skills	Isaac Sim, Pybullet environment Reinforcement Learning Algorithm ROS2 (modification on urdf file, package build)
Targets	Maximum walking speed Minimum getting-up time Maximum kicking force (ball distance)
Load Cases	18.2 N (mass = 2 kg) from CG
Assumptions	All parameters given by NAO robot model



Implications: Stable motion controls
Multi-body dynamics & complex control systems
Optimizing speed of each motion

- 22 DOF total
- Created urdf file from the mesh file
- Working on ROS 2 Jazzy NAO agent package
- Allow all joint movement
- Targeting the maximum speed of x-directional movement
- Pybullet simulation work in progress to verify the movement



Behavior cloning algorithm is on research
→ learning other previous open-sourced models, targeting different motions

Work in progress at the moment

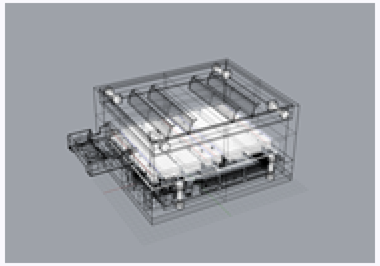
Tactile Sponge

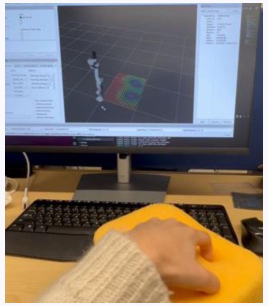
Undergraduate Research Assistant

Implications: Enhancing soft-robotics (with different materials)
Cost-effective & more accessible sensor

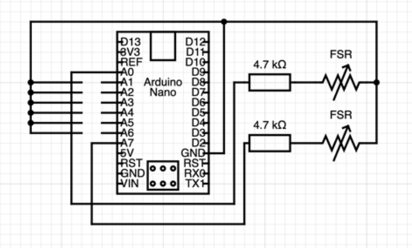
Skills	Rhino 7 (CAD Design) ROS2 Rviz, Pointcloud, TF, Arduino, pyserial Matlab & pygame for additional visualization
Targets	Stable object detection with different types of deformable material
Load Cases	80 N gripping force from the robot arm
Fabrication	3D printer
Assumptions	Sponge gripper is rigidly mounted to the KUKA Franka robot arm
Materials	SLA 3D printing material Random sponge available Force Sensitive Resistors (FSRs) → in 4 x 4 array

Initial Model

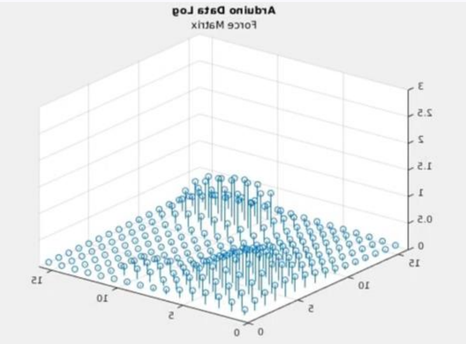




Pointcloud & TF integration
Circuit diagram



Tested 2 different objects on the robot arm
→ the other side of the arm is the flat plate
→ image processing after collecting data

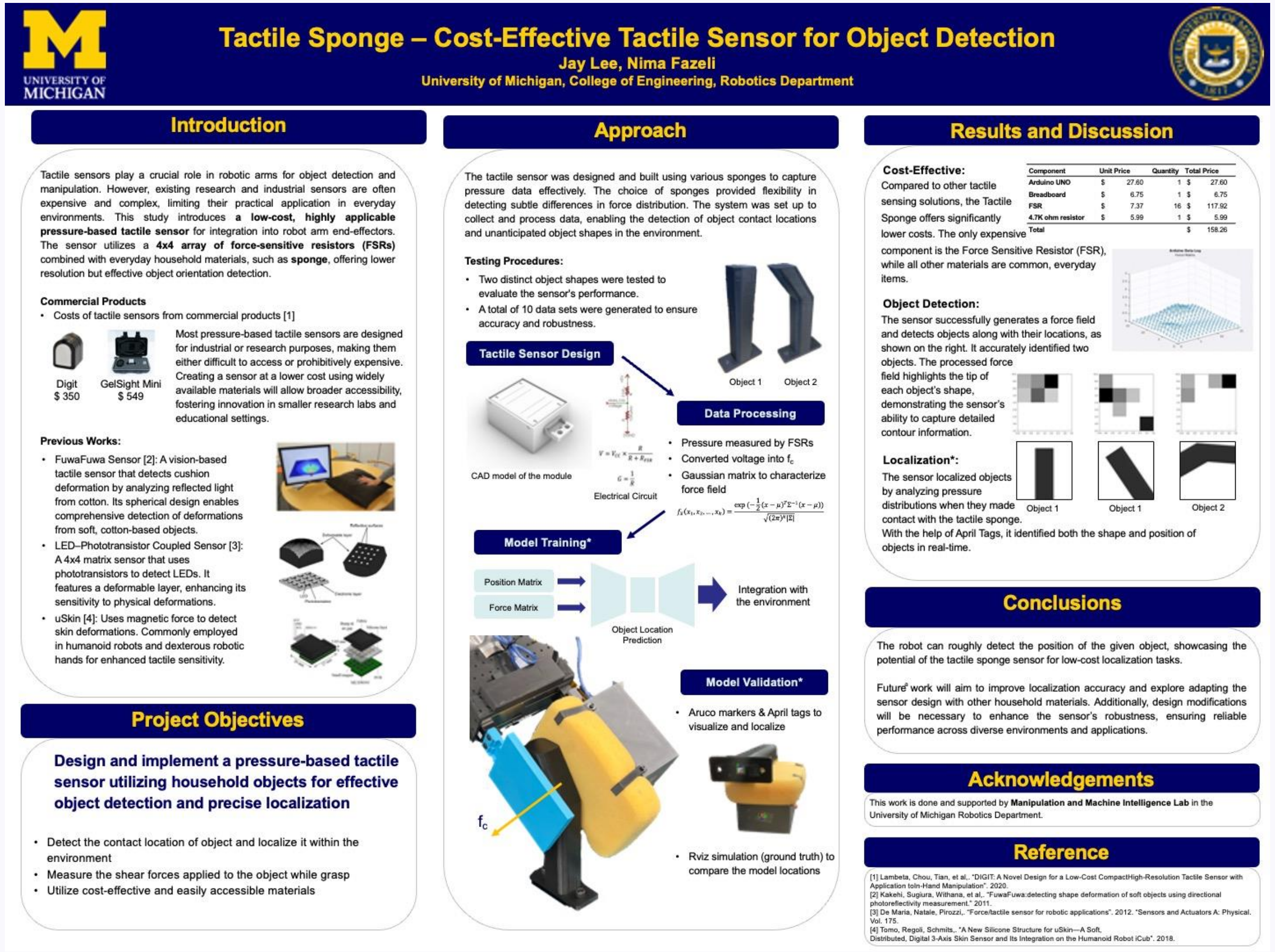


Used April Tags to approximate relative object position
→ mapped with the sensor result
→ less accurate since large human error

Tactile Sponge

Undergraduate Research Assistant

Robotics Undergraduate Research Symposium



Tactile Sponge – Cost-Effective Tactile Sensor for Object Detection

Jay Lee, Nima Fazeli
University of Michigan, College of Engineering, Robotics Department

Introduction

Tactile sensors play a crucial role in robotic arms for object detection and manipulation. However, existing research and industrial sensors are often expensive and complex, limiting their practical application in everyday environments. This study introduces **a low-cost, highly applicable pressure-based tactile sensor** for integration into robot arm end-effectors. The sensor utilizes a **4x4 array of force-sensitive resistors (FSRs)** combined with everyday household materials, such as **sponge**, offering lower resolution but effective object orientation detection.

Commercial Products

- Costs of tactile sensors from commercial products [1]

Digit $ 350

GelSight Mini $ 549

Most pressure-based tactile sensors are designed for industrial or research purposes, making them either difficult to access or prohibitively expensive. Creating a sensor at a lower cost using widely available materials will allow broader accessibility, fostering innovation in smaller research labs and educational settings.

Previous Works:

- FuwaFuwa Sensor [2]: A vision-based tactile sensor that detects cushion deformation by analyzing reflected light from cotton. Its spherical design enables comprehensive detection of deformations from soft, cotton-based objects.
- LED–Phototransistor Coupled Sensor [3]: A 4x4 matrix sensor that uses phototransistors to detect LEDs. It features a deformable layer, enhancing its sensitivity to physical deformations.
- uSkin [4]: Uses magnetic force to detect skin deformations. Commonly employed in humanoid robots and dexterous robotic hands for enhanced tactile sensitivity.

Project Objectives

Design and implement a pressure-based tactile sensor utilizing household objects for effective object detection and precise localization

- Detect the contact location of object and localize it within the environment
- Measure the shear forces applied to the object while grasp
- Utilize cost-effective and easily accessible materials

Approach

The tactile sensor was designed and built using various sponges to capture pressure data effectively. The choice of sponges provided flexibility in detecting subtle differences in force distribution. The system was set up to collect and process data, enabling the detection of object contact locations and unanticipated object shapes in the environment.

Testing Procedures:

- Two distinct object shapes were tested to evaluate the sensor's performance.
- A total of 10 data sets were generated to ensure accuracy and robustness.

Object 1 Object 2

Tactile Sensor Design

CAD model of the module

$V = V_{cc} \times \frac{R}{R + R_{FSR}}$

$G = \frac{1}{R}$

Electrical Circuit

Data Processing

- Pressure measured by FSRs
- Converted voltage into f_c
- Gaussian matrix to characterize force field

$$f_X(x_1, x_2, \ldots, x_k) = \frac{\exp\left(-\frac{1}{2}(x-\mu)^T \Sigma^{-1} (x-\mu)\right)}{\sqrt{(2\pi)^k |\Sigma|}}$$

Model Training*

Position Matrix

Force Matrix

Object Location Prediction

Integration with the environment

f_c

Model Validation*

- Aruco markers & April tags to visualize and localize
- Rviz simulation (ground truth) to compare the model locations

Results and Discussion

Cost-Effective:

Compared to other tactile sensing solutions, the Tactile Sponge offers significantly lower costs. The only expensive component is the Force Sensitive Resistor (FSR), while all other materials are common, everyday items.

Component	Unit Price	Quantity	Total Price
Arduino UNO	$ 27.60	1	$ 27.60
Breadboard	$ 6.75	1	$ 6.75
FSR	$ 7.37	16	$ 117.92
4.7K ohm resistor	$ 5.99	1	$ 5.99
Total			$ 158.26

Object Detection:

The sensor successfully generates a force field and detects objects along with their locations, as shown on the right. It accurately identified two objects. The processed force field highlights the tip of each object's shape, demonstrating the sensor's ability to capture detailed contour information.

Localization*:

The sensor localized objects by analyzing pressure distributions when they made contact with the tactile sponge.

Object 1 Object 1 Object 2

With the help of April Tags, it identified both the shape and position of objects in real-time.

Conclusions

The robot can roughly detect the position of the given object, showcasing the potential of the tactile sponge sensor for low-cost localization tasks.

Future work will aim to improve localization accuracy and explore adapting the sensor design with other household materials. Additionally, design modifications will be necessary to enhance the sensor's robustness, ensuring reliable performance across diverse environments and applications.

Acknowledgements

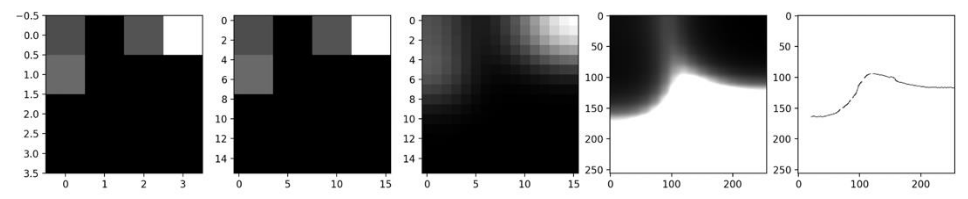
This work is done and supported by **Manipulation and Machine Intelligence Lab** in the University of Michigan Robotics Department.

Reference

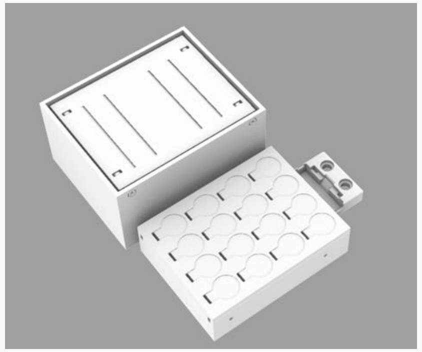
[1] Lambeta, Chou, Tian, et al,. "DIGIT: A Novel Design for a Low-Cost CompactHigh-Resolution Tactile Sensor with Application toIn-Hand Manipulation". 2020.
[2] Kakehi, Sugiura, Withana, et al,. "FuwaFuwa:detecting shape deformation of soft objects using directional photoreflectivity measurement." 2011.
[3] De Maria, Natale, Pirozzi,. "Force/tactile sensor for robotic applications". 2012. "Sensors and Actuators A: Physical. Vol. 175.
[4] Tomo, Regoli, Schmits,. "A New Silicone Structure for uSkin—A Soft, Distributed, Digital 3-Axis Skin Sensor and Its Integration on the Humanoid Robot iCub". 2018.

Participated 2024 Research Symposium and demonstrated the sensor

Data processing
→ extract contour from sensor data



Next iteration design idea
→ smaller & lighter module (~60% volume reduced, ~40% mass reduced)
→ mounted as a single pusher on the arm



* Work in Progress

Anthropomorphic Robotic Hand Module

Undergraduate Research Team Member

Implications: Improve dexterity & anthropomorphic motion

Automation advances, future behavior cloning learning

Skills
- SOLIDWORKS (CAD Design)
- ROS2 Rviz, Pointcloud, TF, Arduino, pyserial for data control
- Python & Matlab for dynamics calculation

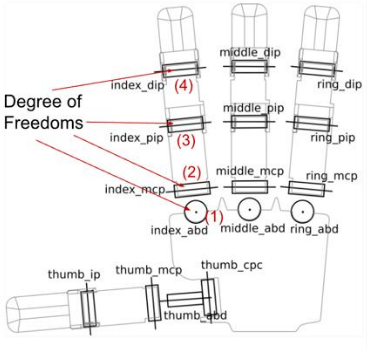
Targets
- 50 N grasp force
- ROS data communication
- No overheating, continuous usage (more than 4 hours)
- Interface with KUKA robot arms
- GelSlim 4.0 interface on the fingertips (requires camera module)
- Total cost < $1,000

Load Cases
- 50 N gripping force to the object

Fabrication
- 3D printer

Materials
- SLA 3D printing material (or CF material)
- DYNAMIXEL XL330 motors
- Silicon (GelSlim materials)

Adapted from Tilburg Hand



4-finger (3 fingers & 1 thumb) configuration → 16 DOF

4 cameras (one on each finger) for GelSlim sensor

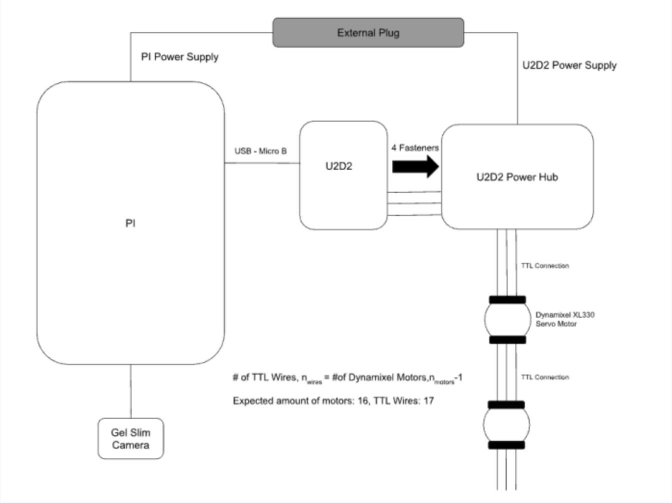
Motor controller & Raspberry Pi inside the palm

Table 3. Benchmarking analysis. ** Note that the technical information on the Allegro and PSYONIC Hand are closed source. Hence, the overheating threshold of their motors cannot be determined

Requirements	Our Design	Allegro Hand	Tilburg Hand	PSYONIC Hand
Grasp Force	≥ 50 N	25 N	17.33 N	14 N
Dexterity	Intermediate	High	Low	High
Acquisition Cost	< $1000	$15,000	$4623.15	$20,000
Assemblability	Can be assembled	Pre-assembled	Pre-assembled	Pre-assembled
Software Versatility	Available	Available	Not available	Available
Data Acquisition	Yes	No	No	No
Hand Profile	Intermediate	Intermediate	Intermediate	Low
Mass/Weight	< 2 kg	1.004 kg	< 1kg	0.490 kg
Finger Motion	< 20 seconds	2 seconds	2 seconds	1 second
Structural Strength	Intermediate	Intermediate	Intermediate	Intermediate
Packaging	Built-in	Built-in	Exposed	Built-in
**** No Overheating**	65 ºC	Not Available	65° C	Not Available

Initial electrical circuit design

CAD design in progress



CK-30 Urine Analizer

Project Manager & Mechanical Designer

Implications: Human interface design
Integration with different engineering systems

Skills	Rhino 7 (CAD Design, visualizer)
Targets	Design a housing for the urine analyzer containing electronic systems Locking mechanism for the urine test strip
Fabrication	3D printer for prototype Mass manufacturing by injection molding
Assumptions	All electronics are given All components can be rigidly fastened by fasteners
Materials	ABS or other Plastic Materials for mass manufacturing

Used gripping style push lock mechanism for the strip plate
Strip of LED module, camera sensing, PCB, and LCD screen (for one type) are packaged inside
→ load case not considered

Overseen Bluetooth module programming process during project management

In the process of commercializing this project in Korea

Electronic Prosthetic Hand Parts Design

Mechanical Engineering Intern

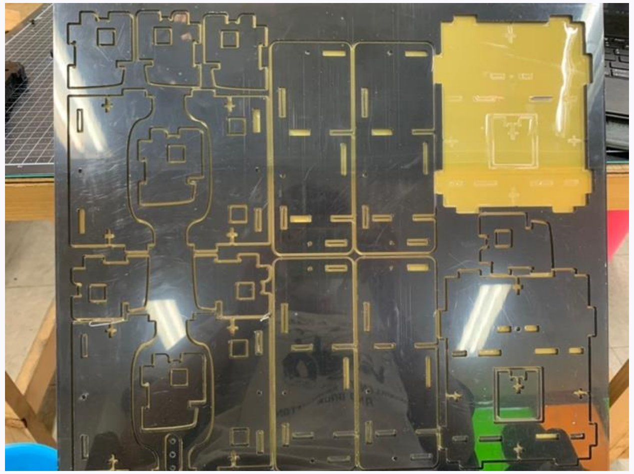
Implications: Seamless Human interface design
Accessibility & user comport

Sensor Housing Design

Electrode sensors are used to sense the movement of the muscles
→ sending sensor values to PCB and move fingers according to their patter
→ designed electrode sensor housing which goes on the wrist
→ used Rhino 5

One big electrode sensor + 2 small sensors
→ connected to custom-made sensor board
→ wires need to packaged in the tight space

Charger Module "Cradle" Design



Laser cut from acrylic board + 3D printed middle board
No fasteners used
3D print part should be curved as the prosthetic arm can sit
→ bent 3D print part to fit in the acrylic board
Power module inside the charger

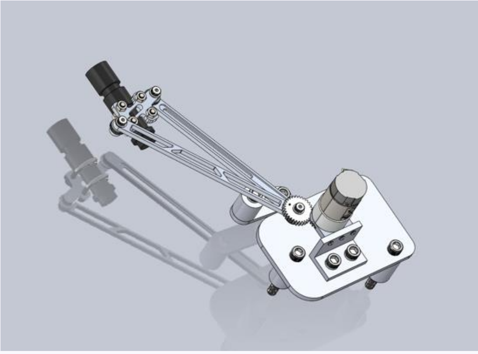
Hit the Targets! 4-Bar Linkage Design

Mechanical Engineer

Implications: Weight reduction & power efficient systems

Vibration control

Skills	SOLIDWORKS (CAD Design) First Principle Analysis - 4-bar linkages, motor power output, joint tolerance stack up calculation, gear wearing, torque transfer ADAMS linkage simulation Arduino code for sensing target → motor control, PID
Targets	Move linkage without overshooting, targeting the light sensor that has the flag on in real time Minimum deviation angle towards all sensors
Load Cases	0.598 lbs weight 67071 gcm³ moment of inertia
Fabrication	Waterjet (linkages) Mill & lathe (mounts)
Assumptions	Power output is the same as the result simulated in ADAMS
Materials	Aluminum 6061-T6

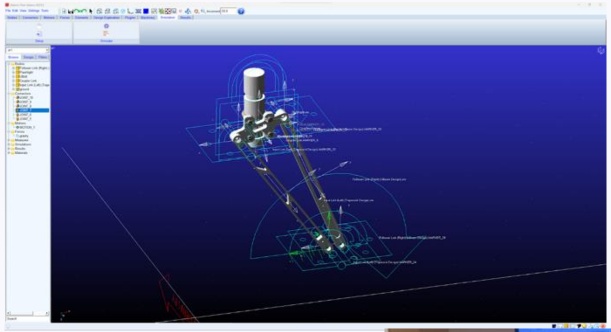


Average deviation angle: 10.10°

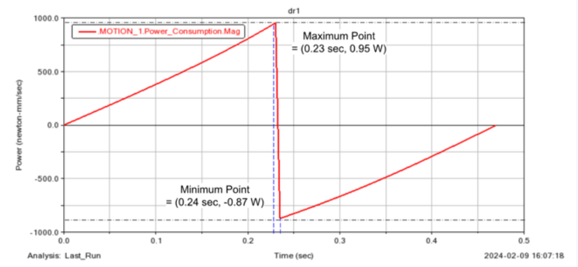
Time of motion: 0.47 s

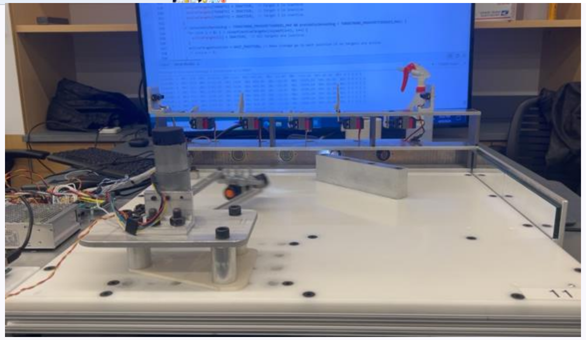
Total linkage length: 18.3 in

→ one of the lowest average deviation angle in the competition



ADAMS Simulation





Scored 30/31

→ top score in the competition

→ exhibited in the design expo as a representative

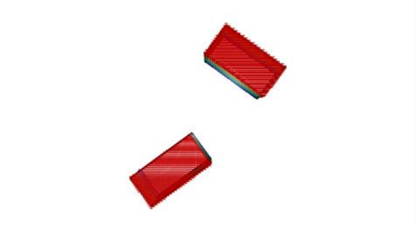
Stacking Tower with a Robot Arm Gripper

Robotics Engineer

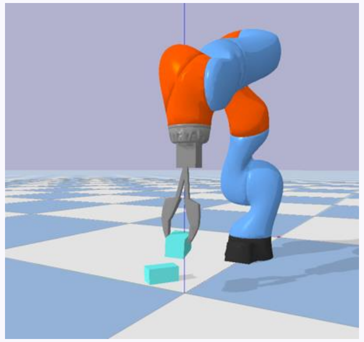
Skills	pybullet (visualizer) First Principle Analysis – contact normal, antipodal grasping
Targets	Grip the object stably → rotate the object using the obstacles → stack the objects as a tower
Assumptions	The objects are rigid

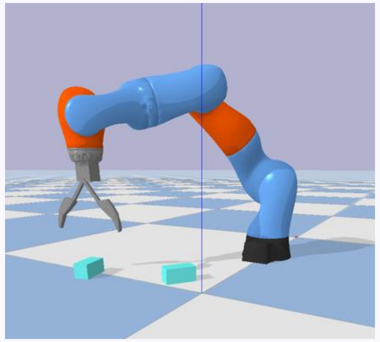
Implications: Stable grasping (contact dynamics) & manipulation
Evaluate motion planning / possibility of sim-to-real

Antipodal Grasping



Based on the Pointcloud → contact normals calculated
Find the best grasp that has parallel sides fitting the gripper
Stable grasp → providing contact normal forces within the friction conde

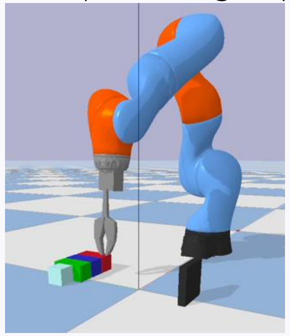


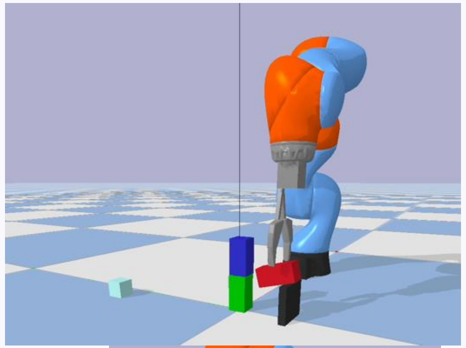


- Object locations are random
- Get parallel contact normals fitting the requirements
- Calculate for antipodal grasping
- Pick the closest point from the gripper for faster operation

Tower Stacking

Created 'push' & 'grasp' member functions





- In-hand manipulation to rotate the object from the black obstacle
- Automatically grasp the shorter side of the block when it is stacked

→ highest tower achieved