

Engineering Portfolio

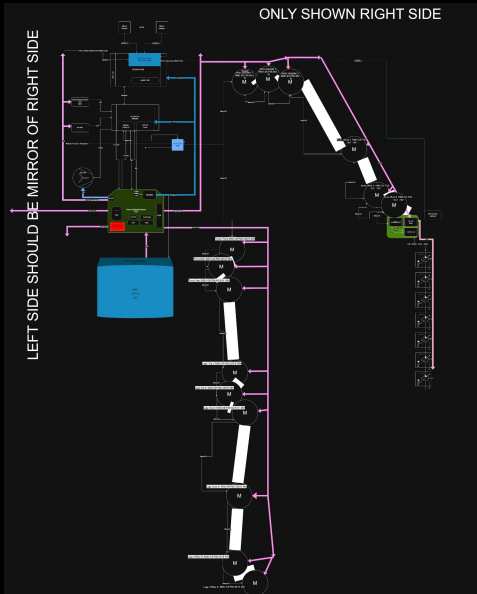
Grant Gao

2022-2026

31 DOF Humanoid (WIP Spring 2027)

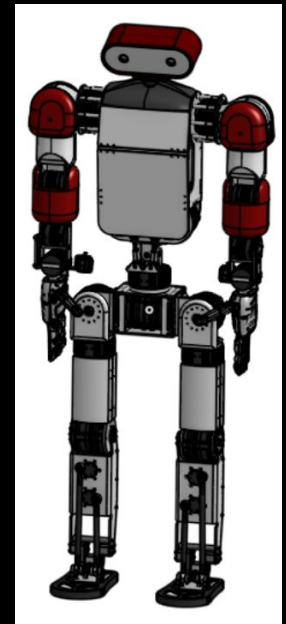
Electronics System Architecture:

- **Compute:** Jetson Thor + Rockchip
Rockchip RK 3588
- **Sensors:** 6 DOF IMU + 1x Zed X Head
Cameras + 2x Zed X Nano wrist
cameras (Synchronized Trigger)
- **Power:** Custom PDB/BMS/Battery



Mechanical Design Specifications:

Total System Mass (Target)	35 Kg +- 5Kg
Height (Target):	1.28 m
Leg DOF (per limb)	6
Arm DOF (per limb)	7
Torso DOF:	3



Current Work:

- **Overall:** Led overall mechanical, electrical, and software architecture, and worked across CAD, simulation, teleoperation, data collection, and fabrication.
- **Arm:** Revised the mechanical design of a 14-DOF bimanual test rig, converted its CAD model to MJCF, and ported an inverse kinematics solver for VR teleoperation in MuJoCo.
- **Backpropagating from first principles:** Conducted studies for kinematics layout. Derived the required torque and velocity specifications for the actuator selection by working backward from specific subgoals per mechanism.

Designing Robots for the Data

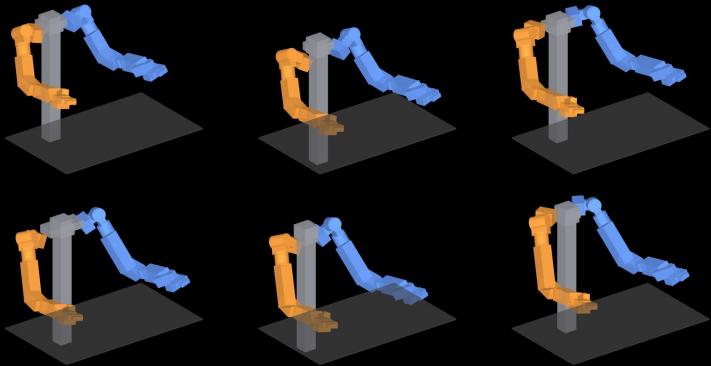
Motivation

Robot arms are usually sized by intuition. Here the task data picks the geometry of a 14-DOF bimanual arm.

Method

Each candidate is built in MuJoCo and replays two-hand teleoperation demos (YUBI, six task families) with one shared IK and PD controller. The CMA-ES search tried 5,040 designs.

Example designs, first CMA-ES generation



Design space

Half-spacing	180–260 mm
Shoulder height	380–560 mm
Shoulder setback	75–225 mm
Upward cant	0–30°
Forward cant	–10–30°
Total link length	580–700 mm
Upper-arm share	45–55 %
Elbow offset	0–30 mm
J1–J2 separation	0–30 mm

Scoring objectives

Primary: tracking error, lower is better

Frame loss = $\min[100, (\text{pos}' / 10 \text{ mm})^2 + (\text{ori}' / 5^\circ)^2]$
 pos', ori' = hand error minus a 3 mm / 1.5° deadband

Per clip	$\frac{1}{2}$ mean + $\frac{1}{2}$ P95 per hand, hands averaged, relative pose $\frac{1}{3}$, capped at 10
Tasks	six families $\times \frac{1}{6}$, clips frame-weighted $\rightarrow$ J_capped
Accepted	P95 ≤ 10 mm and 5° per hand, relative ≤ 15 mm and 5°

Hard Limits

No hard contact between links, arms or torso
2 kg hold $\leq 1.4\times$ rated torque on executed poses
 $\leq 0.6\times$ peak torque over the whole joint range

Secondary terms and weights

Joint speed	20	Smoothness	20
Limit margin	2	Conditioning	2
Clearance	1.5	Hold headroom	1.5
RMS load	1	Deflection	0.6
Distal inertia	0.3	Fwd sensitivity	0.15
Search fitness = J_capped + $\sum \text{weight} \times \text{term}$			

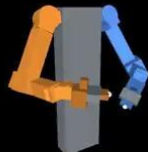
Designing Robots for the Data

Optimized (ours)
chain score 0.03 reach 66%



Validation chain 157 (F4 insert and feed), real time $t = 0.0 \text{ s} / 13.3 \text{ s}$

Almond Axol
chain score 0.31 reach 84%



i2rt YAM
chain score 37.94 (as 10) reach 75%



reach = farthest target / arm reach

Current arm
chain score 3.43 reach 109%



white = hand target blue = left, orange = right dashed = deadband, acceptance

Enactic OpenArm
chain score 3.96 reach 98%



Primary Secondary terms measured for every arm, weight $\times$ term

Arm	J	Speed	Smooth	Limit	Cond.	Clear.	RMS	Inert.	Sens.	Σ	Total	Pass	$\times$ Axol	$\div$ peak
Build design	0.52	0.03	0.03	0.03	0.02	0.02	0	0.82	0.16	1.11	1.62	85%	0.78	0.53
Almond Axol	2.35	0.13	0.20	0.01	0.17	0.03	0	0.98	0.17	1.70	4.05	67%	0.81	0.31
i2rt YAM	5.28	0.21	0.20	0.11	0.38	0.12	0.13	0.73	0.14	2.04	7.32*	8%	0.90	1.10†
Current arm	8.00	0.07	0.12	0.07	0.62	0.04	0	0.30	0.14	1.36	9.36	13%	0.63	0.45
Enactic OpenArm	9.28	0.20	0.32	0.11	0.15	0.12	0	0.38	0.14	1.42	10.70*	<1%	0.61	0.57

Speed $\times 20$ mean over frames, joints of $(\text{speed} / \text{rated speed})^2$

Smooth $\times 20$ mean of $(\text{acceleration} / (\text{rated speed per } 0.1 \text{ s}))^2$

Limit $\times 2$ mean $(1 - \text{distance to joint stop} / 10^\circ)^2$, 0 past 10°

Cond. $\times 2$ $1 - s / 1.5$ below 1.5; s = joint-speed headroom, P5

Clear. $\times 1.5$ per chain $(1 - \text{closest gap} / 10 \text{ mm})^2$, mean

RMS $\times 1$ RMS torque / rated – 0.8 per joint, 0 below 0.8

Inert. $\times 0.3$ peak shoulder-pitch inertia / the current arm's

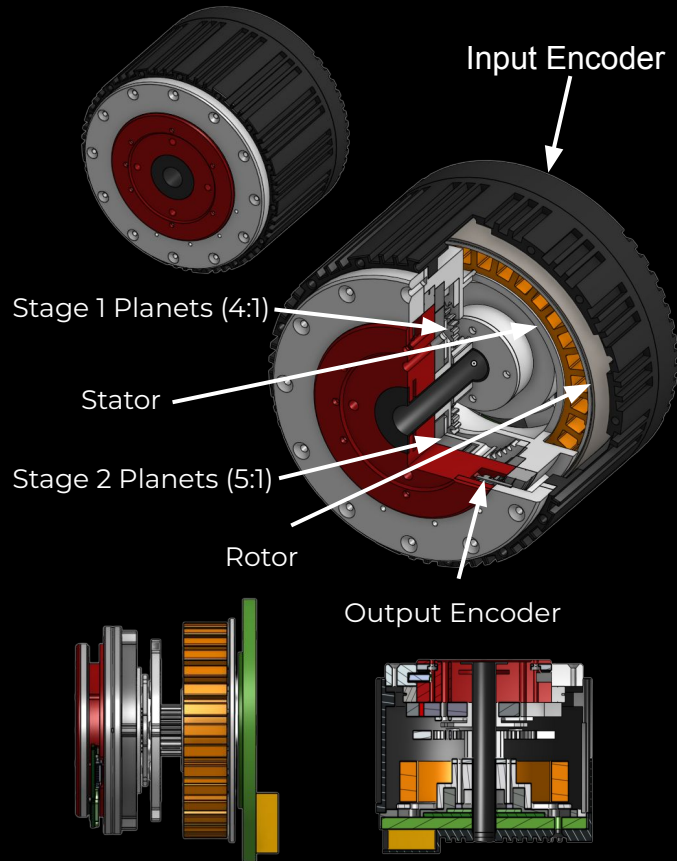
Sens. $\times 0.15$ P95 hand error from joint backlash, offset / 10 mm

$\times$ Axol hold with Axol's motors (mass and rating); $\leq 1 \rightarrow$ term 0

$\div$ peak hold torque $\div$ own motor's peak, worst pose; > 1 = cannot

Total = primary + Σ . * hard contact, ranked below every clean design. † YAM's own shoulder motor needs 1.10 $\times$ its peak for 2 kg at full reach.

Custom Dual-Encoder QDD Actuator Mock Up



Spec Sheet

Stator:	CubeMars RO100 Stator
Ratio:	20:1 (2-stage Planetary)
Sensors:	Dual Absolute Ring Encoders
Peak Torque:	60 NM [EST.]
Mass:	~2KG [EST.]

Key Engineering Challenges:

Compact 20:1 QDD actuator combining a two-stage planetary transmission with dual encoders for closed-loop joint control.

- **Packaging + Thermals:** Maximized the 12.6 mm hollow bore for EtherCAT and power routing; added radial cooling fins to manage heat from the enclosed motor.
- **Control:** Used input and output encoders in a joint-level position loop to compensate for backlash and elasticity.
- **Transmission:** Nested a two-stage 20:1 planetary gearbox inside the stator to minimize actuator length.

G1 Actuator Teardown



[UnitreeActuatorTeardownLink \(CLICK ON ME\)](#)

Unitree G1 Knee Joint Actuator

Table 0-1. Summary specification & derived quantities.

Parameter	Value	Source / notes
Overall		
Mass	1085.1 g with Wire, ~1000g without	Measured, bench scale (\$1)
Envelope	80 mm OD × 64 mm thick	Disc-shaped integrated joint module
Peak torque (claimed)	120 N·m	Manufacturer spec; not independently verified
Peak Torque density	~120 N·m/kg	120 N·m ~ ~1kg (derived)
Motor (18-slot / 16-pole PMSM, SPM rotor)		
Slot / pole count	18s / 16p (8 pole pairs)	Direct count (\$2)
Rotor OD / stator ID	50.6 / 51.8 mm	Calipers (\$2.2)
Air gap (single-sided)	0.6 mm	Calipers (\$2.2)
Active stack length	22 mm	Calipers (\$2.2)
Magnet dimensions	2 mm thick × 20 mm axial × 16 segments	Calipers + count (\$2.3)
Air-gap flux density	~0.9–1.0 T	Analytical, $B_r = 1.20\text{--}1.32\text{ T}$ (\$2.3)
Winding factor k_w	≈ 0.945	Textbook for 18s/16p; not measured
Cogging periods / rev	144	$\text{LCM}(Q, 2p) = \text{LCM}(18, 16)$
Rotor inertia J_{rotor}	~6.6 × 10 ⁻⁴ kg·m ²	Analytical estimate (\$2.4)
Gearbox (2-stage planetary)		
Total reduction	22.5:1 (4.5 × 5.0)	Tooth count (\$3)
Stage 1 teeth (s/p/r)	16 / 20 / 56	Direct count (\$3.1)
Stage 2 teeth (s/p/r)	12 / 18 / 48	Direct count (\$3.2)
Gear modules m_1, m_2	$m_1 \approx 0.65\text{ mm}, m_2 \approx 1.21\text{ mm}$	Measured via tip OD; could also be standard $m = 0.7 / 1.25$ with profile shift, see §3.5
Output bearing	IKO CRBT505A (50 × 61 × 5 mm)	Marked on outer race (\$3.3)
Output bearing C / C _e	2.28 kN / 3.20 kN	Per IKO catalog (\$3.3)
Output bearing M _e (est.)	~44 N·m	$M_e \approx C_e \cdot d_{pw} / 4$ (Rough Estimate)
Electronics & sensing		
Inverter topology	B6 bridge, 6 N-ch MOSFETs	Visual inspection (\$5.1)
Current sensing	2 × R003 low-side shunts	Two-shunt reconstruction (\$5.5)
DC-bus decoupling	~29 MLCCs (no bulk electrolytics)	Count from PCB (\$5.4)
Encoders	Dual magnetic (rotor + output)	8-pin ICs at two target zones (\$7)
Connectivity		
Power / data connector	XT30 2+2-family (daisy chain)	Direct inspection (\$4.2)
Comm physical layer	Differential, A/B labeled	CAN-FD vs RS-485 (Depending on Version) (\$6.4)
Command rate (official)	Up to ~3 kHz (A1/GO-M8010 docs)	Unitree SDK docs (\$6.4)

Exoskeleton Data Glove



Spec Sheet (Per Hand)

Degrees of Freedom	16
Encoders per DOF:	RDC506018A
State Estimation:	iPhone SLAM
Size	185mm (Wide) x 230mm (Long)
Mass:	~800g [EST.]

Key Engineering Challenges:

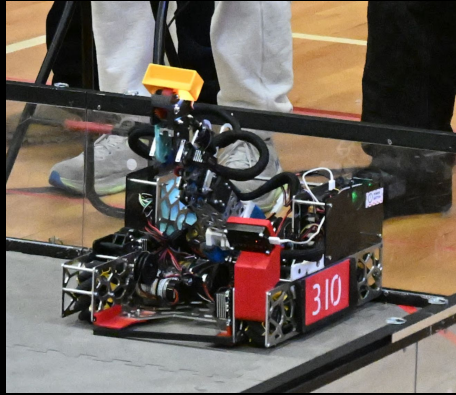
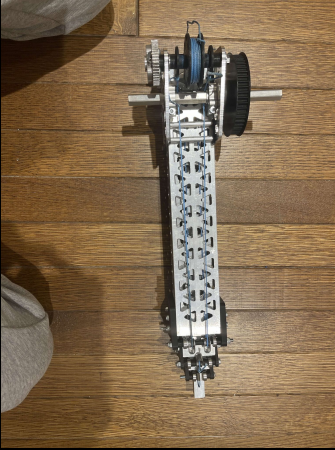
- **Human Interfacing:** Iteratively optimized linkage geometry to align mechanical pivots with biological joint centers (MCP, PIP, DIP) preserving natural dexterity during teleoperation.
- **Joint Tracking:** 1:1 kinematic mapping to the Orca hand with RDC506018A Encoders at each DOF to capture joint angles for imitation learning.
- **State Estimation:** Integrates an iPhone to do SLAM to leverage commercial VIO (iPhone/ARKit) for future 6-DOF end-effector tracking, reducing the need for expensive external motion capture systems.

V2 Pivot:

V1 Issues: Rigid linkages constrained Thumb CMC dexterity. Reliable OTS Hand Does not exist.

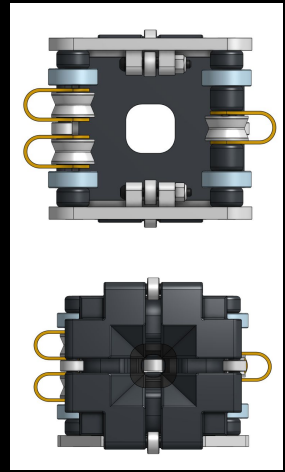
V2(WIP):
Handheld UMI

Pivoting Telescoping Arm 24' - 25'



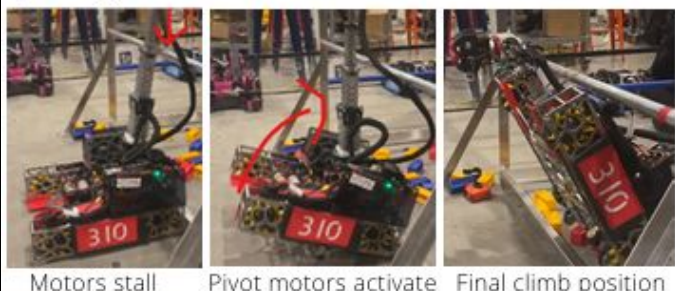
Spec Sheet

Telescoping Speed:	2.6 m/s
Peak Pivot Torque:	12.7 Nm
Moving Stages:	3



Key Engineering Challenges:

- **Manufacturing:** Used a custom box-tube jig for multi-sided CNC operations (Fusion 360 CAM) to maintain hole-pattern tolerances across four telescoping stages. This precision was critical to ensuring a sliding fit with minimal binding under high-speeds.
- **Rigidity:** Developed a dual-plane, 8-point bearing constraint system (4 top, 4 bottom) per stage to manage cantilevered loads. This configuration limited tip deflection to <0.5 inches at maximum extension, preserving extension efficiency under combined axial and torsional loading.
- **Speed:** Conducted a time-matching analysis between drivetrain traverse speed and arm extension (2.6m/s) to ensure the mechanism reached scoring height mid-transit, minimizing mechanism idle time and optimized the intake-to-outtake scoring cycle.



Motors stall Pivot motors activate Final climb position

Current Research: Robot Learning(In Development)

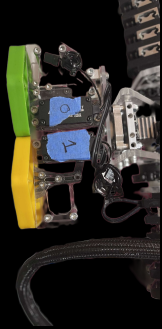
Research Question: How does the composition of multimodal demonstration data collected with a unified tool interface influence the robustness and execution quality of learned manipulation policies in contact-rich Tasks?



Key Engineering Challenges:

- **Hardware Interface:** Iterated upon the VDI architecture (originally developed by Prof. Hagenow) to optimize it for the UR7e and include an integrated wrist camera specifically for Natural Demonstration mode. This isolates the tool from the hand in the visual frame, preventing out-of-distribution (OOD) failures during autonomous rollouts where the hand is no longer present.
- **State Estimation:** Working on a real-time optimization algorithm that drives the robot to actively follow the handheld tool during Natural Demonstrations. This minimizes marker occlusion and keeps the tool centered in the camera frame, extending the effective workspace beyond the static camera's field of view.
- **Data Logging:** Architecting a synchronized logging framework to align asynchronous sensor streams (robot proprioception vs. external tool tracking) into a unified observation space. This alignment is critical for training Visuomotor Diffusion Policies that generalize across heterogeneous data sources.

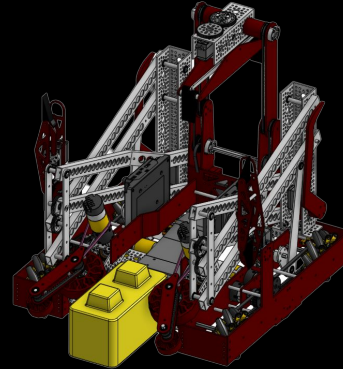
Archive (22'-26')



Over-center linkage based claw for zero power object retention.



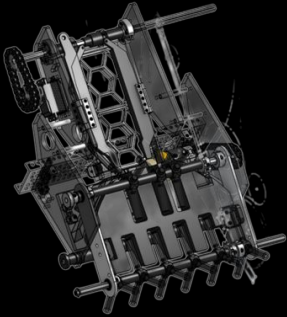
Finger Test Bed: Validated Nitinol wire flexible properties for tendon driven approach. Mediapipe for joint angle detection.



Double Reverse Virtual four Bar Lift with integrated compliant intake and linkage gripper.



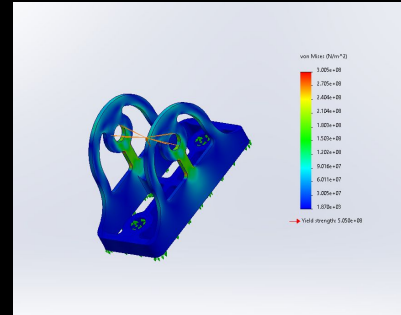
2024 Robot: Designed, self fabricated and built the drivetrain, lift, intake, outtake subsystems.



Flip Up Intake to allow for faster, lighter end effector.



Open Source Lightweight 3DP Parallel Jaw Gripper for SO-101



Weight optimization for FSAE clevis(7075 T6 Alum) under 700 lbf with a safety factor of 1.5



Calhacks 2025: Integrated SmoIVLA to map human gestures to robot actuation commands.