Rapid Lightweight Firmware Architecture of the Mobile Metamaterial Internal Co-Integrator Robot

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PRESENTATION OUTLINE

- The MMIC-I robot
- Avionics
- Firmware Architecture
- Controller
- Motion Generation
- Operating Modes and Autonomous Fault Detection
- Reliability Data
- Conclusion and future work

BACKGROUND: ARMADAS

Ames Research Center

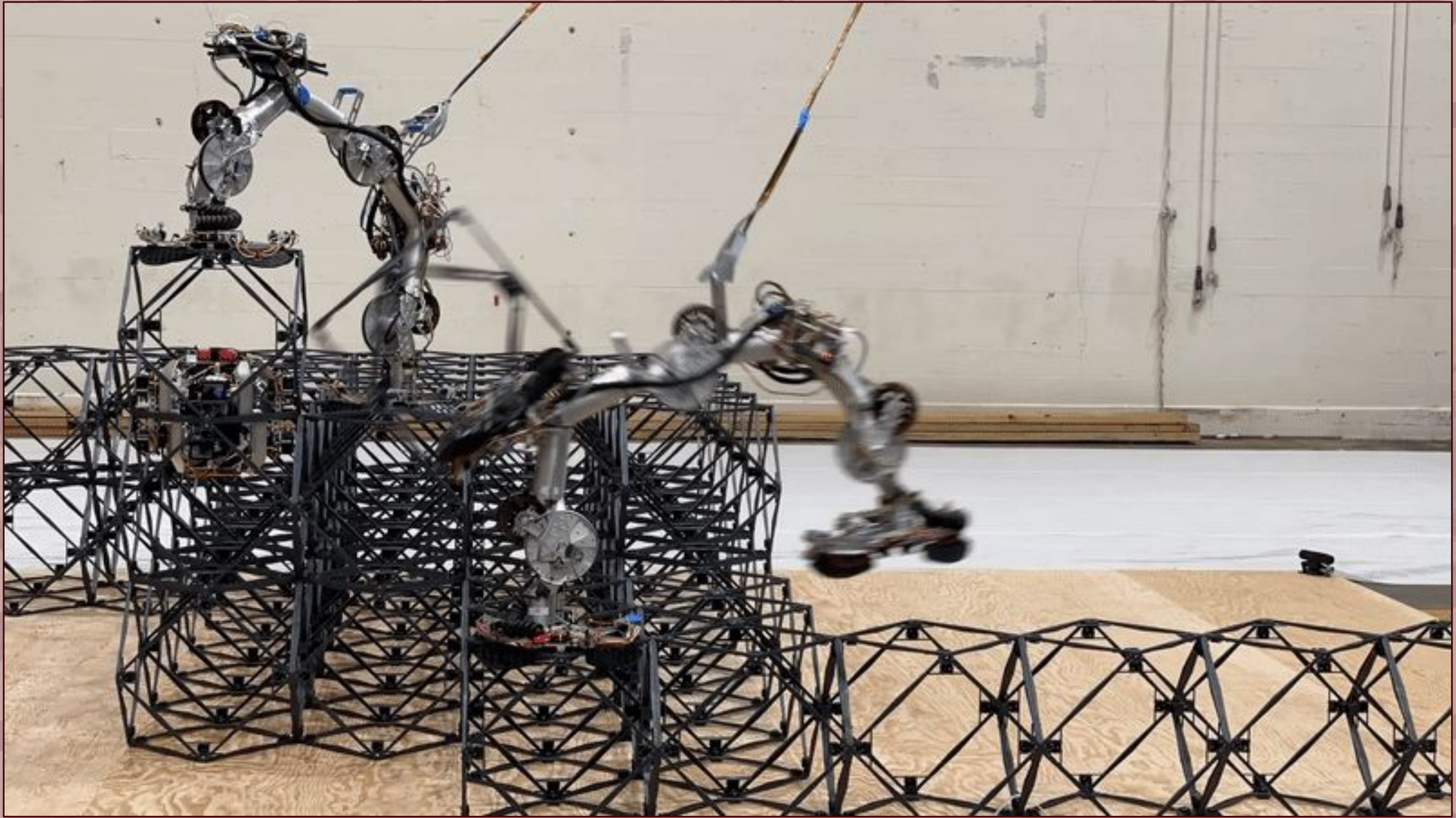
Intelligent System Division

Coded Structures Lab

Automated Reconfigurable Mission Adaptive Digital Assembly Systems
ARMADAS

- Autonomous robotic assembly of large space structures
- Autonomy module determines build order and motion planning
- A swarm of robots, each with a specific task, receiving commands from and reporting to a base station (opsUI)
- Completed ground demonstration in NASA facility

ARMADAS



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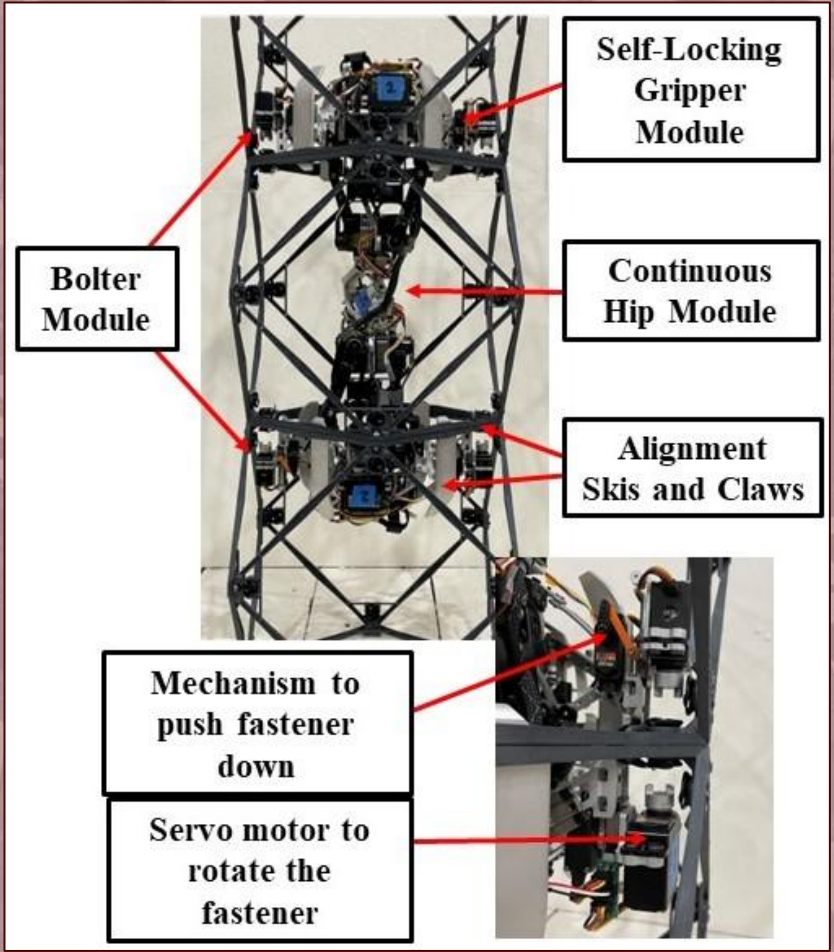
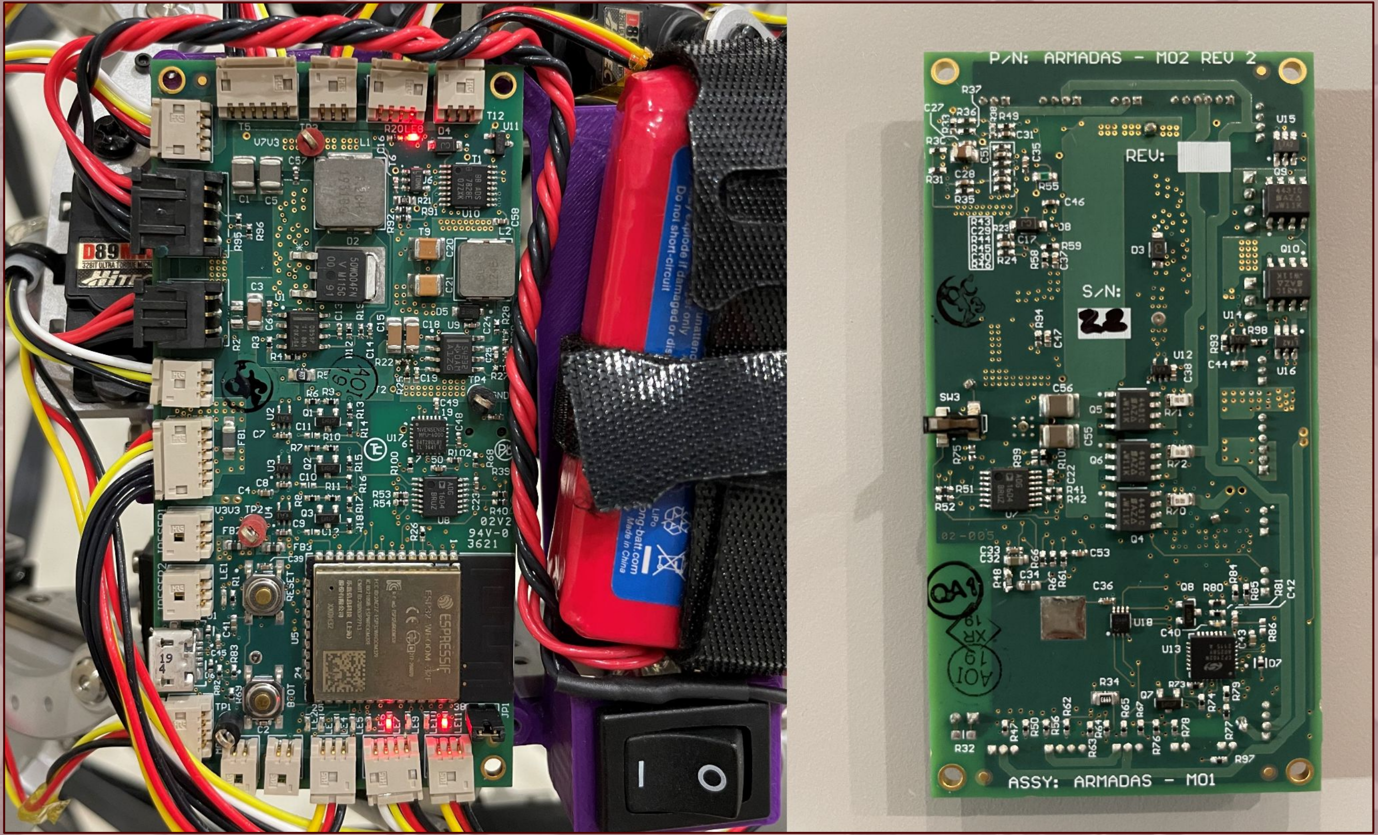
MMIC-I



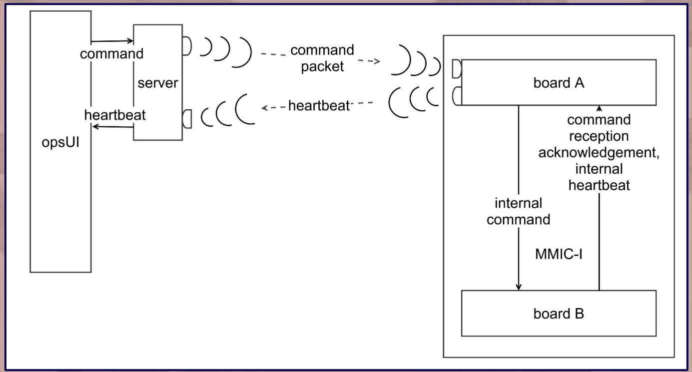
Self-Locking Gripper Module
Bolter Module
Continuous Hip Module
Alignment Skis and Claws
Mechanism to push fastener down
Servo motor to rotate the fastener

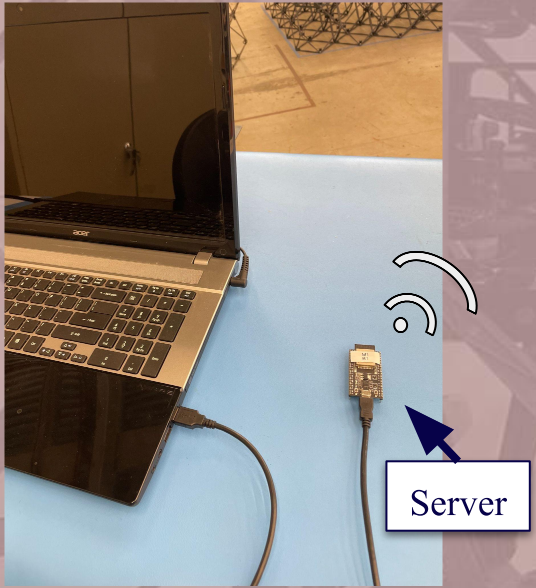
AVIONICS

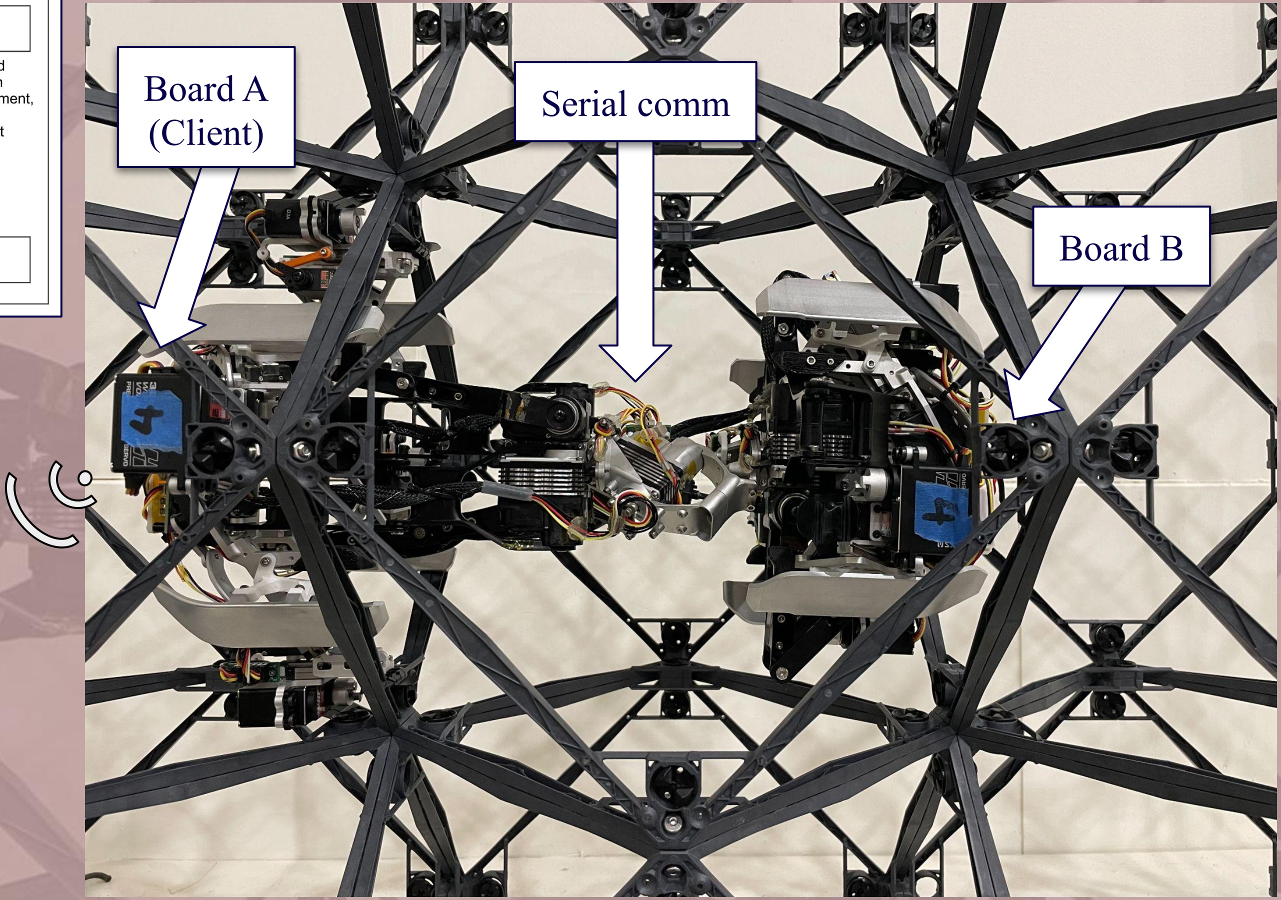
ESP32-WROOM-32E
Lithium Polymer Batteries
IMU
8-channels ADC with I2C
4-channel multiplexer
Magnetic encoder



FIRMWARE ARCHITECTURE







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FIRMWARE ARCHITECTURE: Server

AUTONOMY ALGORITHMS

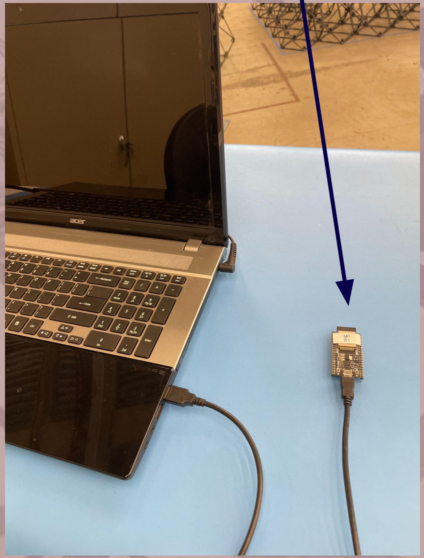
- Input: parameters of the desired structure
- Output: build order and motion planning for robots

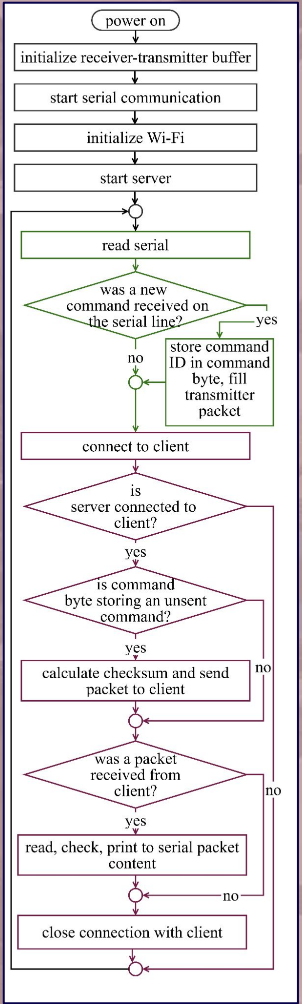
SERVER

- Sends/receives packets for the opsUI

OPERATION SOFTWARE & UI (opsUI)

- Executes motion planning
- Periodically asks robots for heartbeat packet and displays content on the UI
- Sends motion commands to the robots





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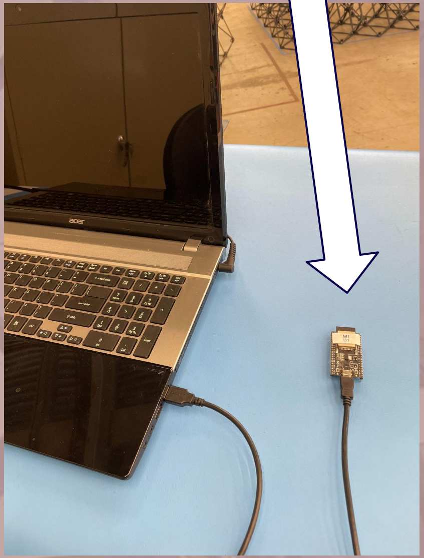
FIRMWARE ARCHITECTURE: Client

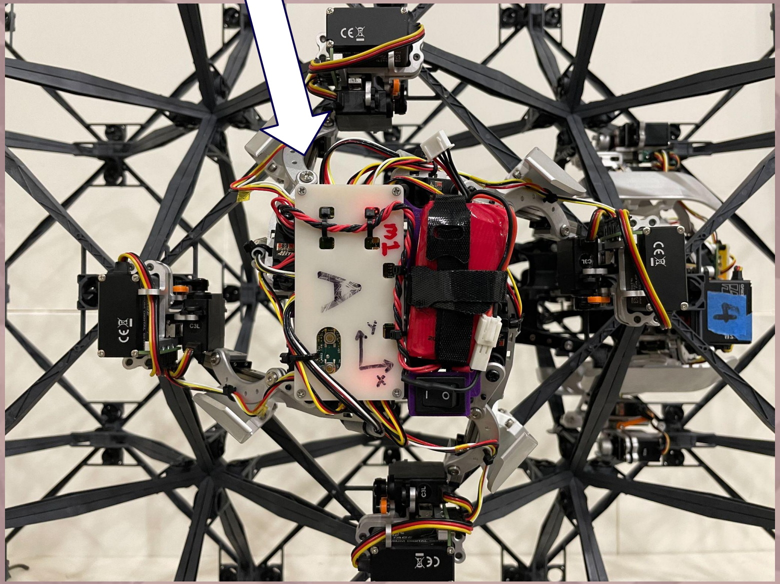
WIFI SERVER

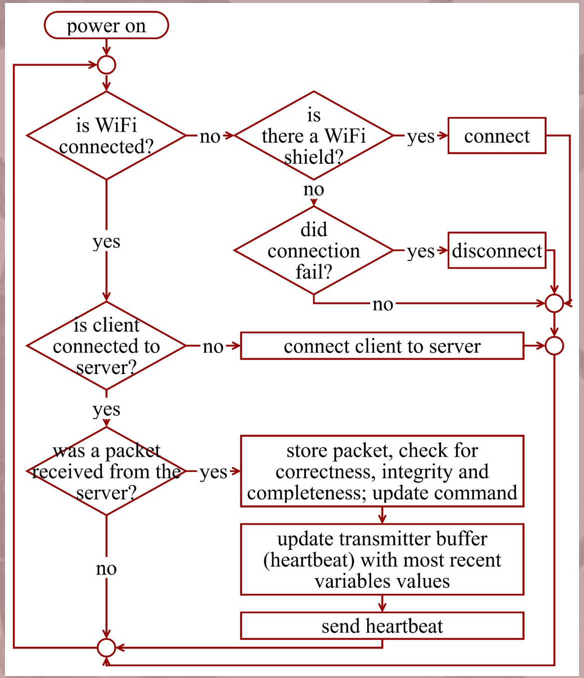
- Sends/receives packets to/from robot

WIFI CLIENT

- Sends/receives packets to/from server
- Runs on Core 0







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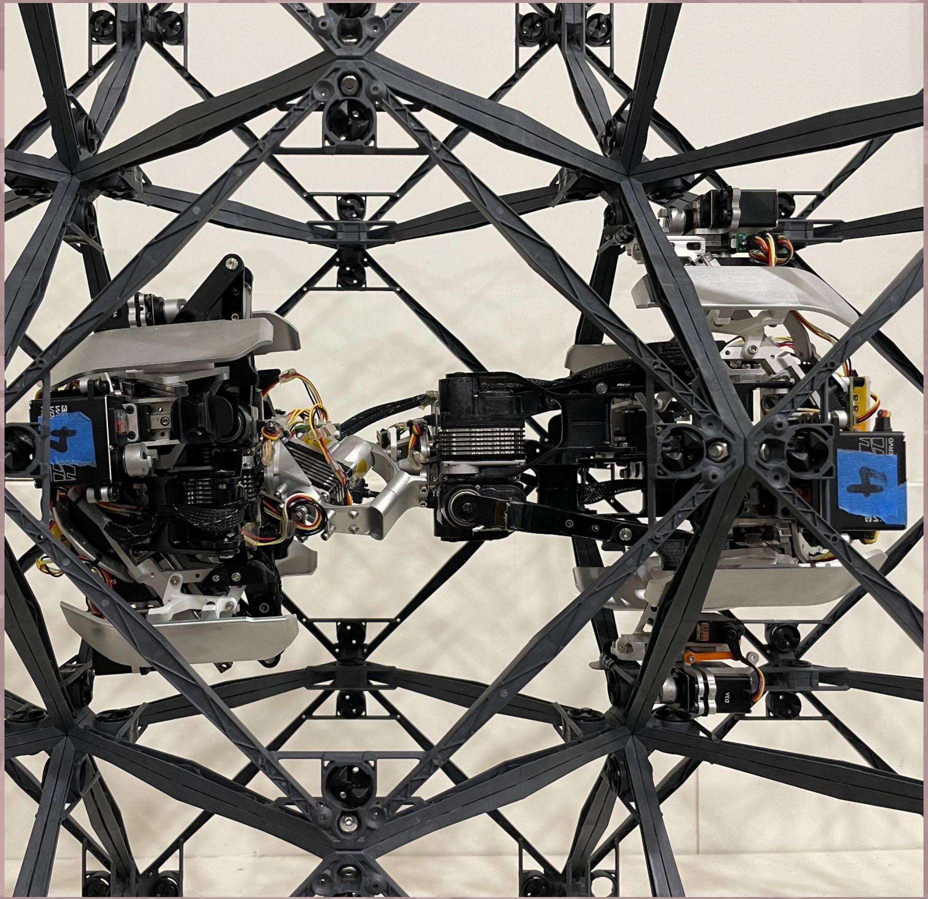
FIRMWARE ARCHITECTURE: Boards

Control Loop A

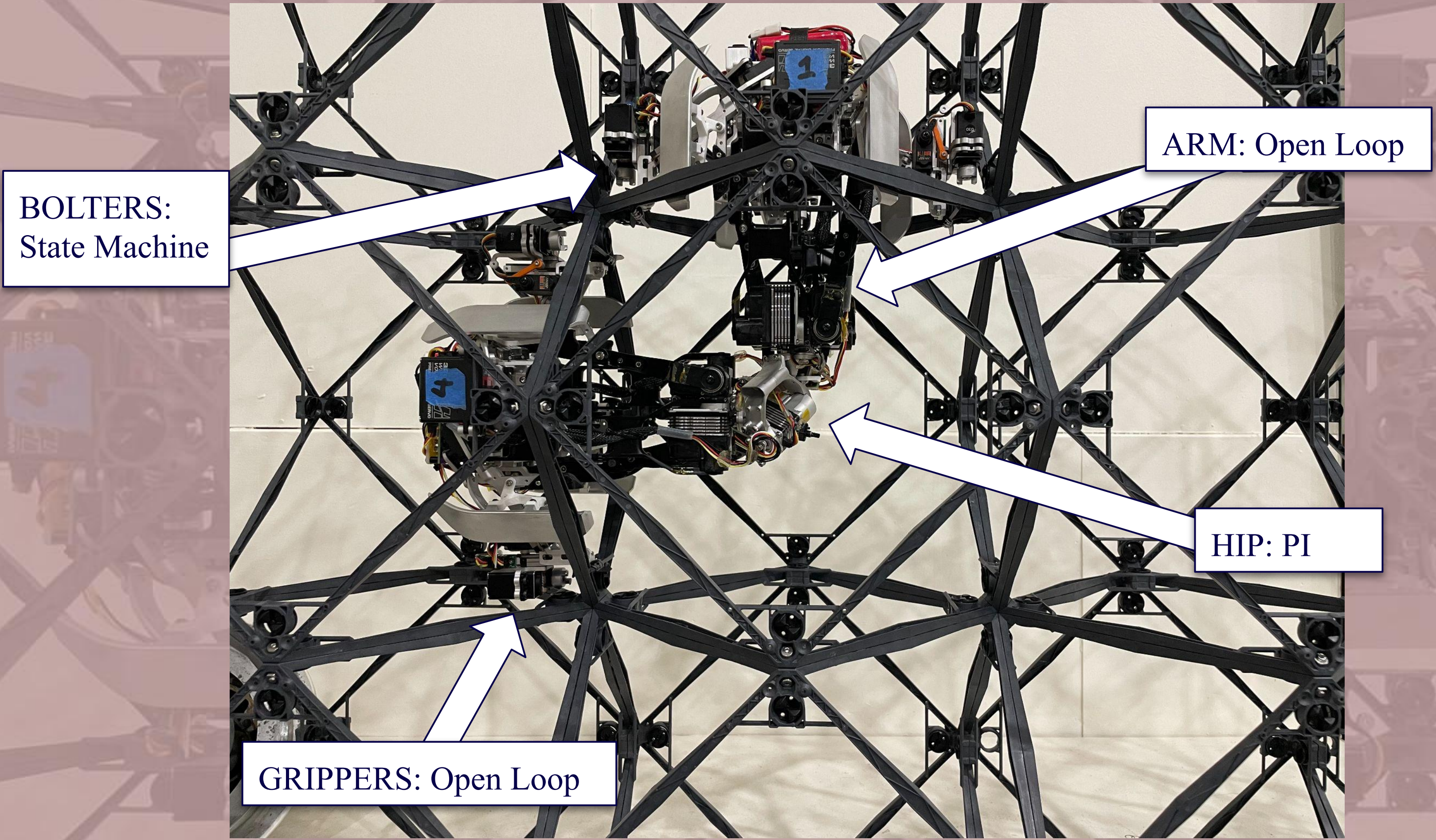
- Primary board
- Responsible for: motion generation, operating mode and autonomous fault detection, actuate motors on A side and hip,
- Sends commands to B and reads feedback
- Runs on Core 1



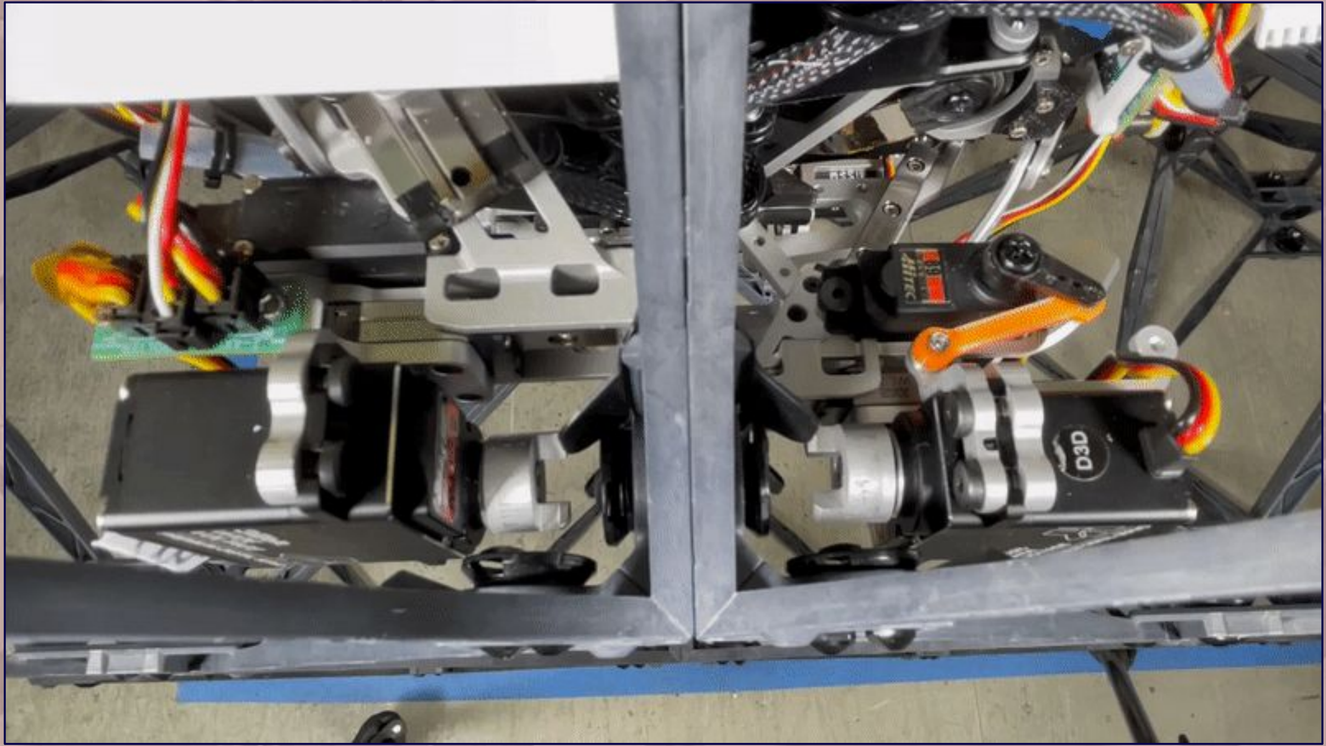
Control Loop B

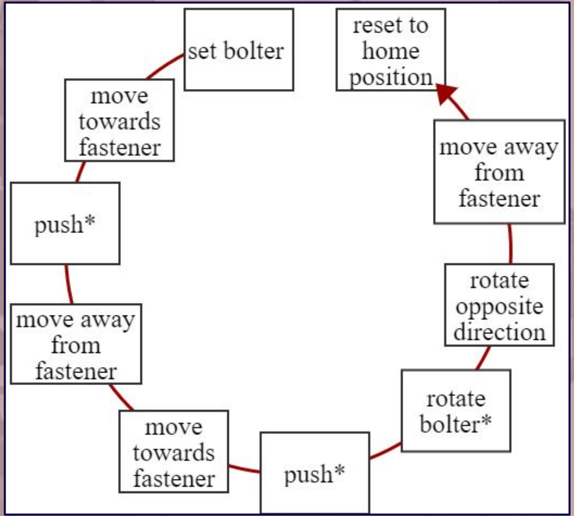
- Auxiliary board
- Responsible for actuating all motors on the B side, when commanded by A
- Sends heartbeat to A

CONTROLLER

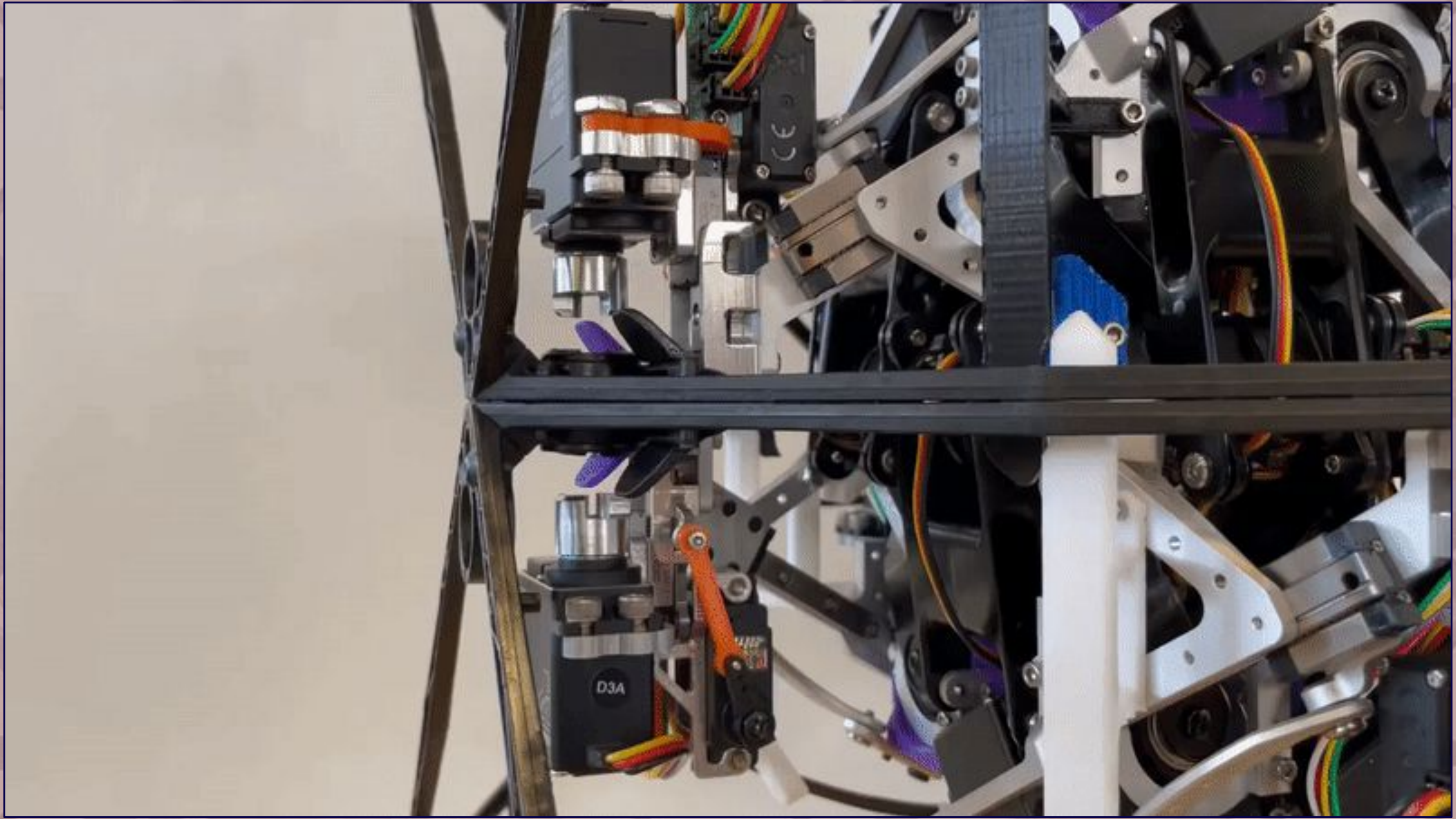

BOLTERS: State Machine
ARM: Open Loop
HIP: PI
GRIPPERS: Open Loop

CONTROLLER: Bolter State Machine





CONTROLLER: Unbolting



MOTION GENERATION

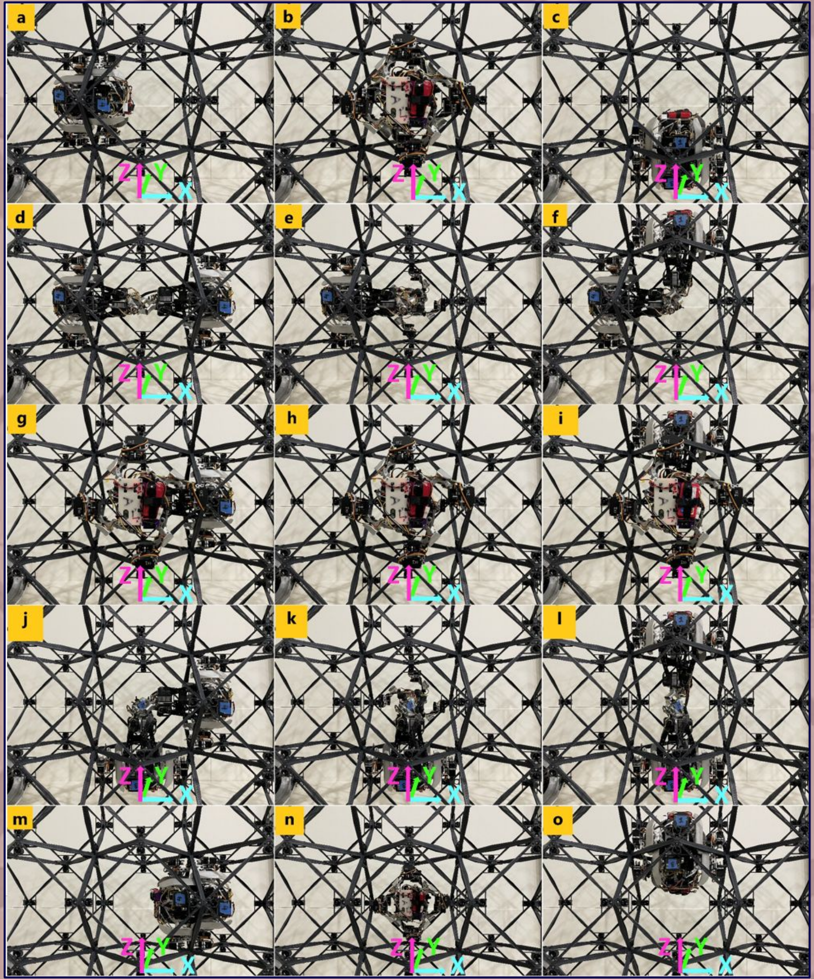
High level

Low Level

- State transition command
- Intermediate states transitions
- Primitives
- State Machine
- Actuator motion

- Go from state ‘a’ to ‘b’
- Have to do a-c and c-b
- FwdExtend and Turn90clock
- Activate FwdExtend state machine
- Send given PWM to servo

MOTION GENERATION



		Target State														
		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
Initial State	a				4	8	7									
	b							7	4	8						
	c										8	7	4			
	d	1				8	7	5			6			2		
	e	1			4		*		3			*			2	
	f	1			4	*				*			3			2
	g		1		3				4	*	*			2		
	h		1			6		7		8		5			2	
	i		1				*	*	4				3			2
	j			1	3			*				*	4	2		
	k			1		*			3		*		4		2	
	l			1			5			6	8	7				2
	m				3			5			6					
	n					6			3			5				
	o						5			6			3			

fwdContract backContract fwdExtend backExtend
fwdTurnCW fwdTurnCCW backTurnCW backTurnCCW

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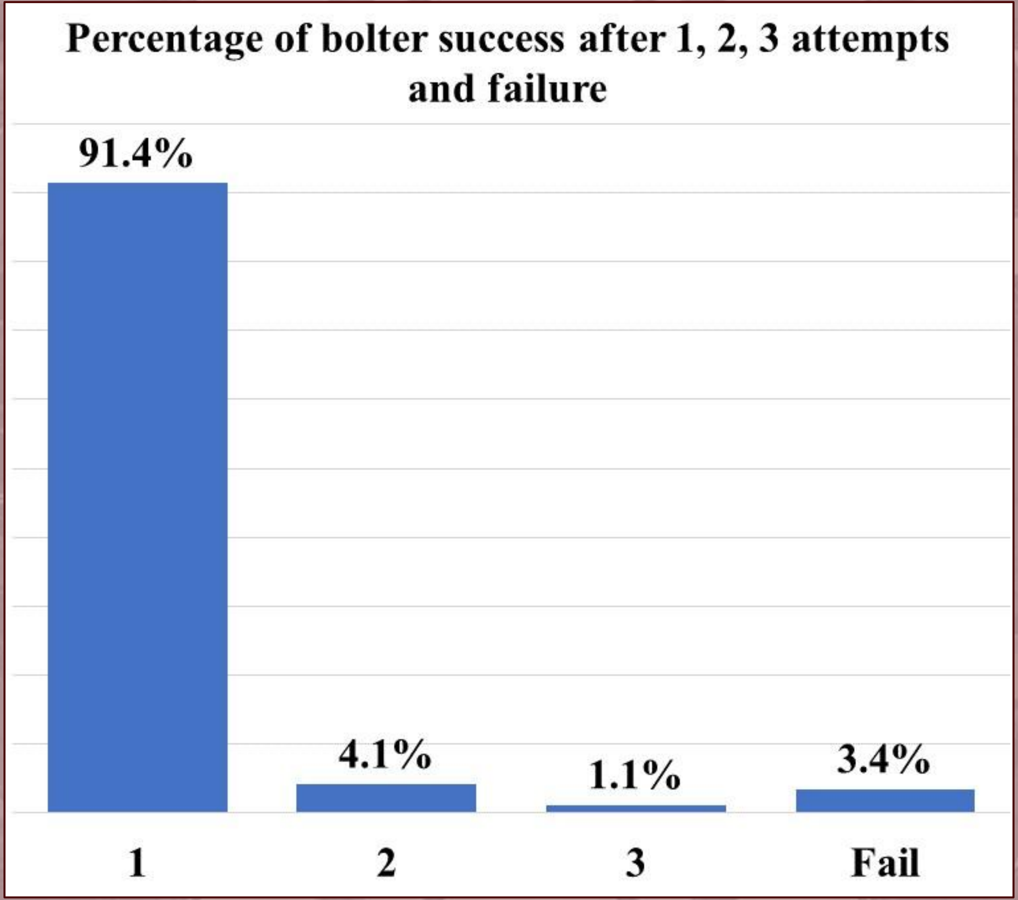
OPERATING MODES & AUTONOMOUS FAULT DETECTION

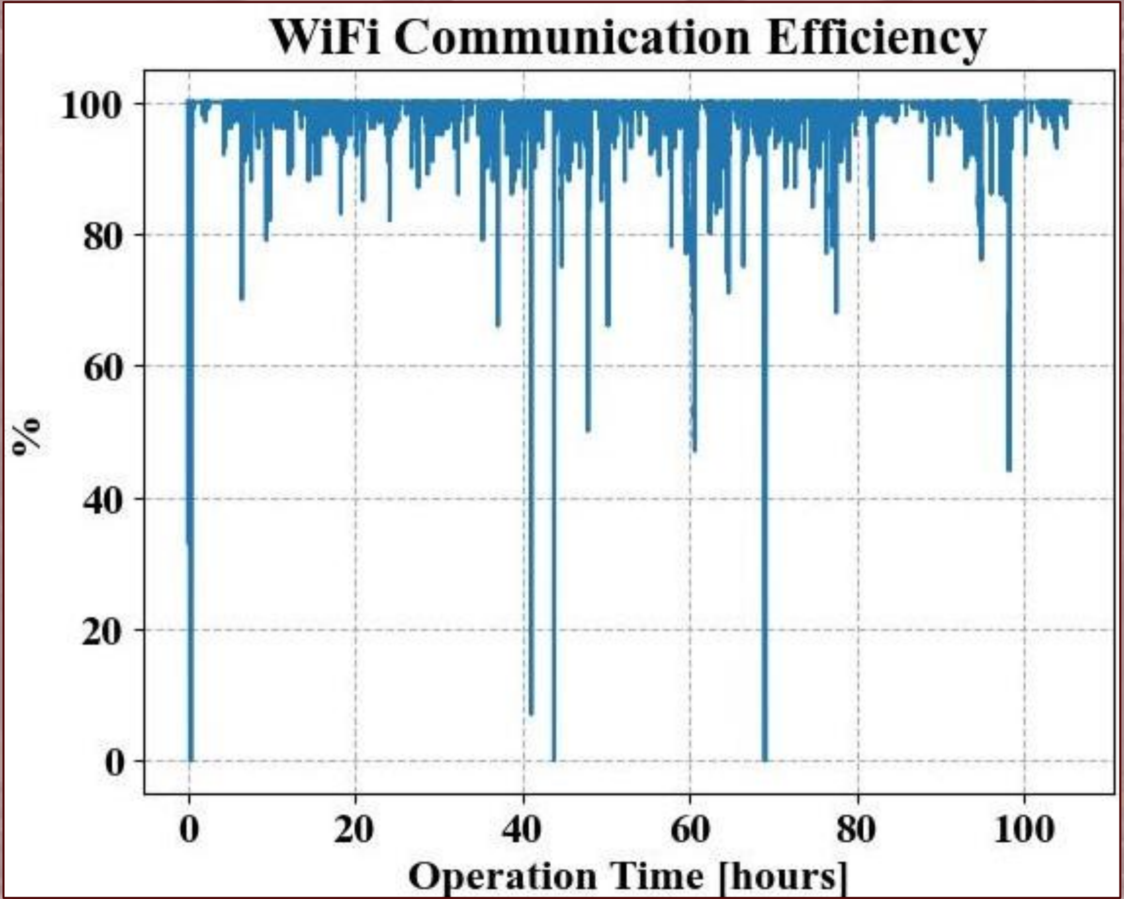
	Standby mode	Operational mode	Safed mode
Entry	Upon startup, fault, command	Command only	Fault, command
Power availability to modules	No	Yes	Limited: hold hip/arms position only
Command availability	Limited: transition to other mode only	Yes	Limited: to hip/arms actuators only
Exit	Command	Fault, command	Command

Fault	Triggers when	Mode
(Un)Bolting failure	After trying three consecutive times, the bolter module wasn't able to bolt successfully	Standby
Arm not fully contracted	After executing an arm contraction command, the contraction is not sensed by hardware	Safed
Bolter module overcurrent	Bolter electrical current rises above a given threshold	Safed
Gripper module overcurrent	Gripper electrical current rises above a given threshold	Safed
Locomotion module overcurrent	Locomotion electrical current rises above a given threshold	Safed
Hip mismatch	Entering operational mode, the hip angle reading differs substantially from its supposed value	Safed
Initial state mismatch	Receiving a reconfiguration command, the detected and communicated robot states do not match	Standby
Internal communication loss	Board A stops receiving B's heartbeat for a given time interval and/or when B doesn't acknowledge reception of a command repeatedly sent by A, through wired connection internal to the robot	Safed Safed
Locomotion module overcurrent	Locomotion electrical current rises above a given threshold	Safed
Low battery	Battery level falls below a certain threshold for a given time interval	Standby
Assembly system operation	Externally injected through command	Standby

BOLTER RELIABILITY DATA



WIFI RELIABILITY DATA



CONCLUSION

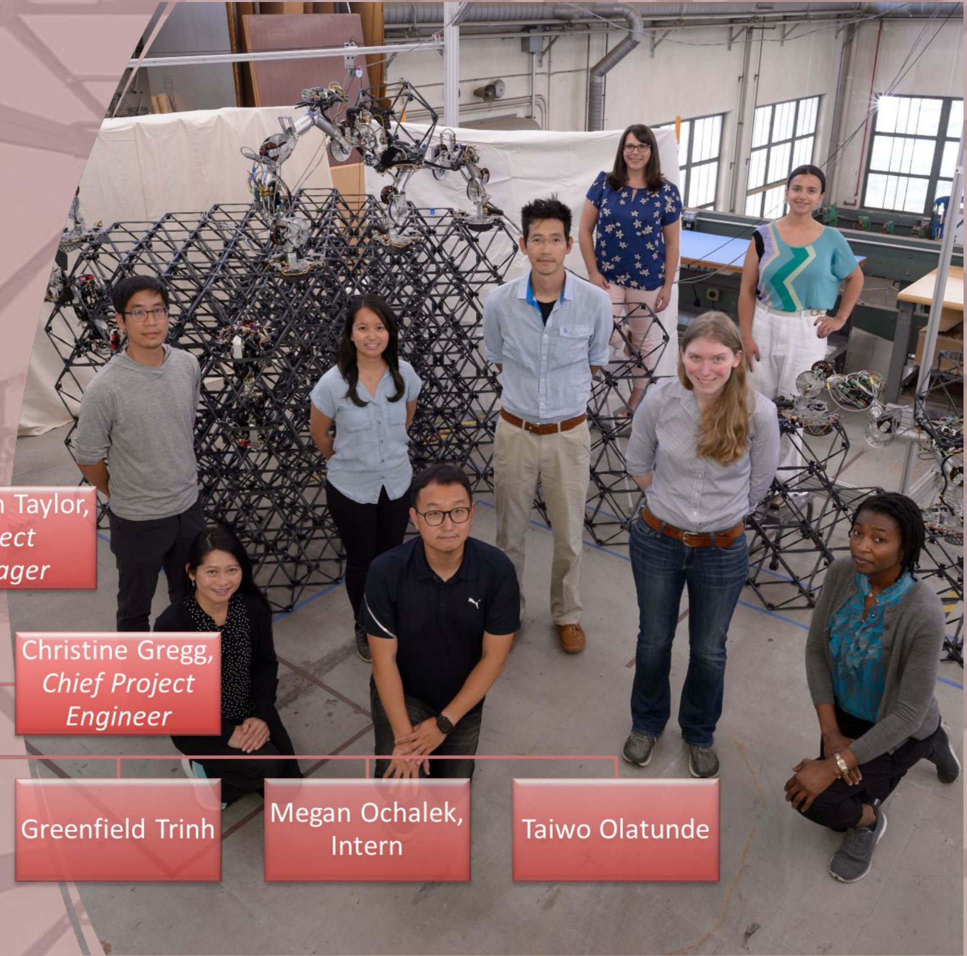
- The Mobile Metamaterial Internal Co-Integrator (MMIC-I) is one of the ARMADAS relative robots, responsible for securing, or bolting, to the structure all the contact faces of a voxel that has just been placed by another robot.
- MMIC-I's firmware runs on custom designed controller boards to control two symmetric sides: A and B.
- Board A hosts the WiFi client, the motion primitives and motion planning, the bolter state machine, operating modes and autonomous fault detection. The WiFi client-server implementation allows the base station to send command packets and receive heartbeat packets containing the overall status of the robot.
- Board B only executes commands sent by A through a wired serial connection. B sends a continuous heartbeat to A, sharing the latest current/target angles and the voltage/current measurements. Whenever A sends a command, B acknowledges reception.
- Experimental data collected during the ARMADAS ground demonstration was presented and discussed.

FUTURE WORK

- Space qualify ARMADAS system: build flight-ready versions of MMIC-I's hardware and firmware
- Use communication protocols with international standards.

ACKNOWLEDGEMENTS

ARMADAS TEAM



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Questions?