Research and Development in Neuromorphic AI for an Anthropomorphic Android to Achieve a Human-centered AI Society

CRF-2025 Project Kick-off Meeting

Sustainable Computing Cluster

2025/07/08

Year 1 Goal: Pioneering Neuromorphic AI for Anthropomorphic Android

- **Research and develop innovative AI hardware**: Developing brain-inspired, energy-efficient designs based on SNN.
- **Research and develop lightweight software:** Creating adaptive real-time decision-making capabilities.
- **Applications**: We will explore applications, such as healthcare and customer service sectors.

From CRF Presentation Slides

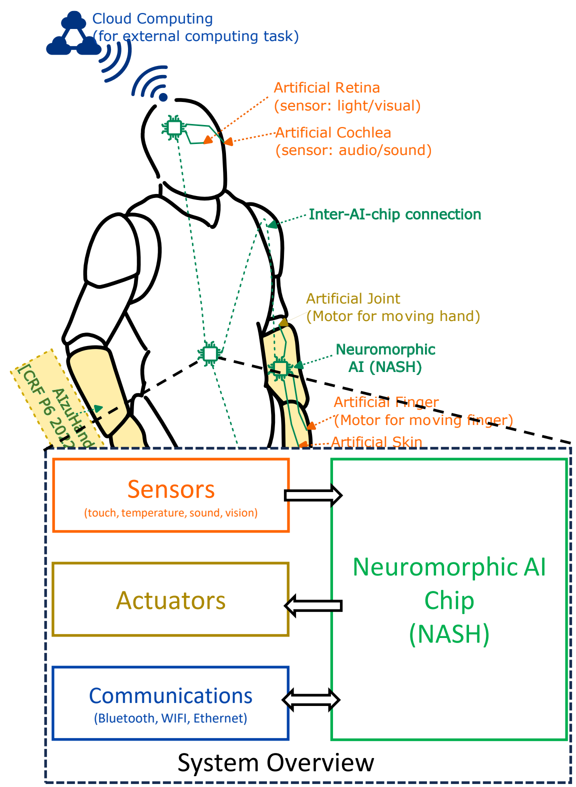
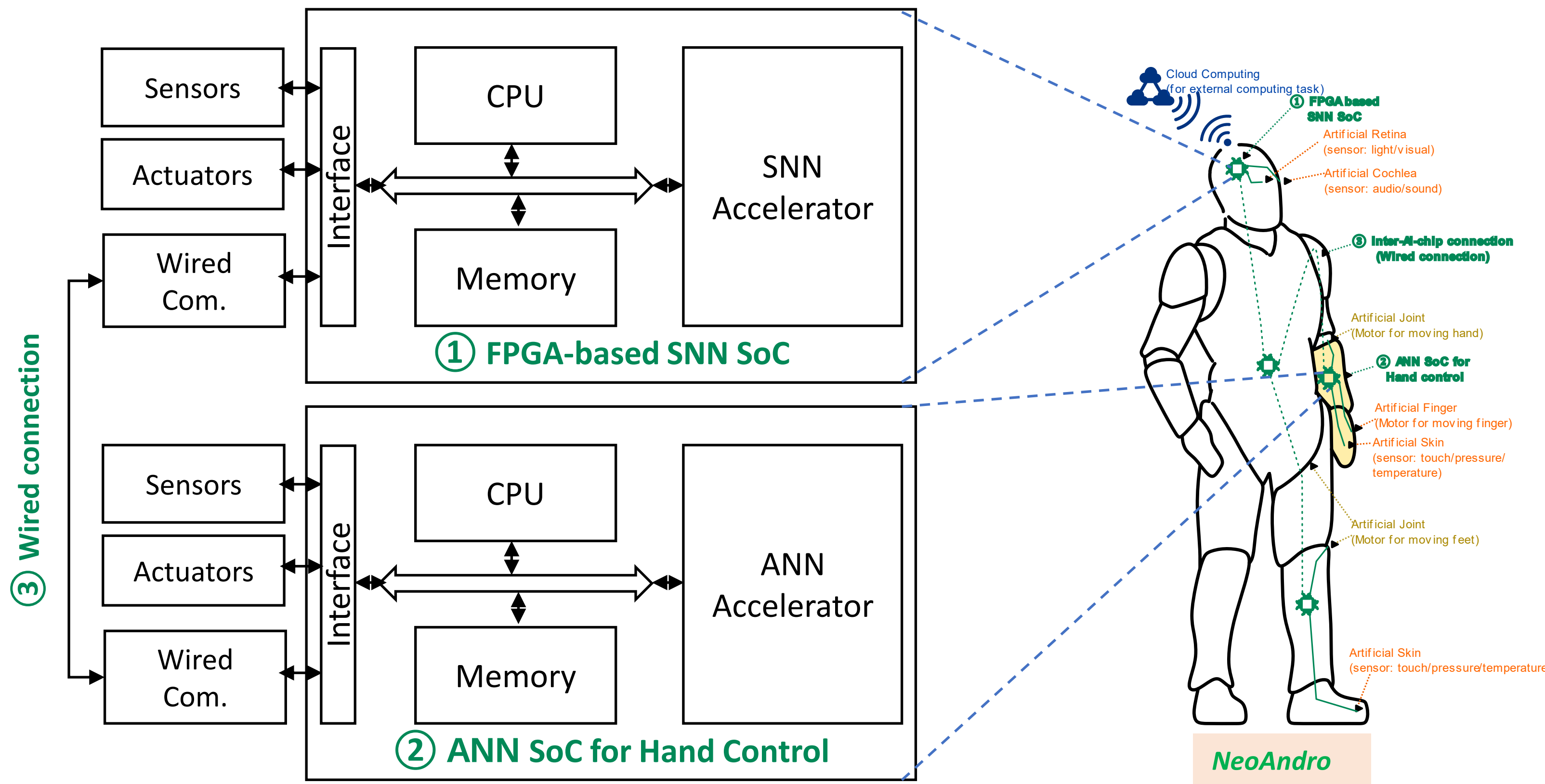


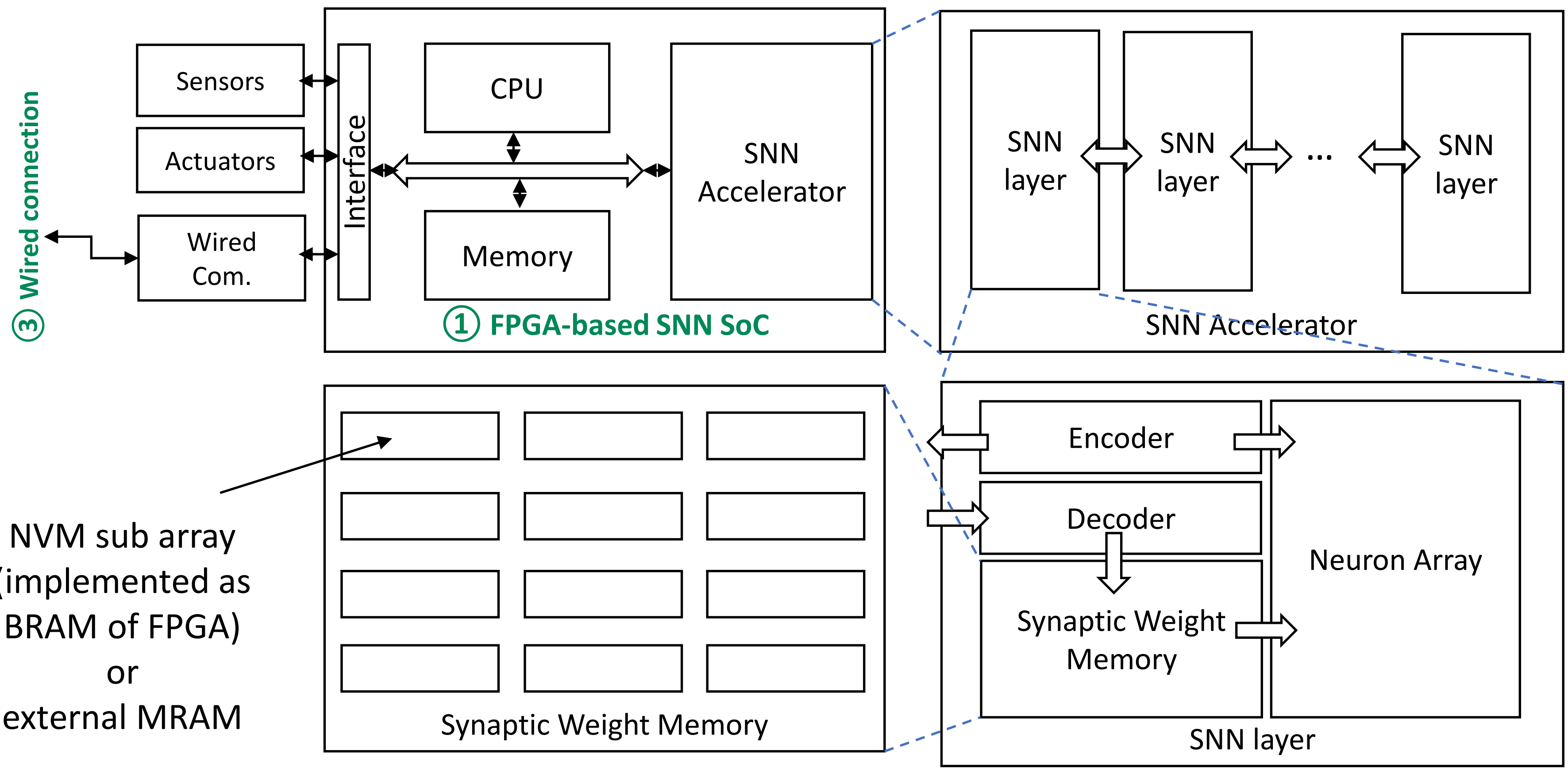
*Fig. 7: **NeoAndro**: Neuromorphic Anthropomorphic Android*

CRF: System Architecture



In AY2025, we will focus on ① FPGA-based SNN SoC

① FPGA-based SNN SoC



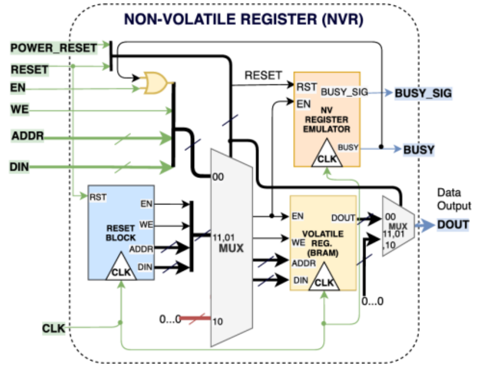
NVM sub array
(implemented as
BRAM of FPGA)
or
external MRAM

① FPGA-based SNN SoC with NVM

(1) Emulating NVM using BRAMs (*1)

- Implement NVM as digital logic circuit with BRAM
- Realize read access time and write access time (*2) of NVM by using counters
- Calculate energy consumption by using access time and typical device parameters (read current, write current, etc.) (*3)

(*1)[Example] NORM by Univ. Tronto
https://dl.acm.org/doi/10.1145/3517812
https://github.com/simoneruffini/NORM



(*2) Typically, read access time of STT-MRAM cell is 2~3 ns and write access one is about 10ns (depends on applied current)
(*3) Typically, read current of STT-MRAM cell is several uA and write one is about 100uA

(2) Use external NVM

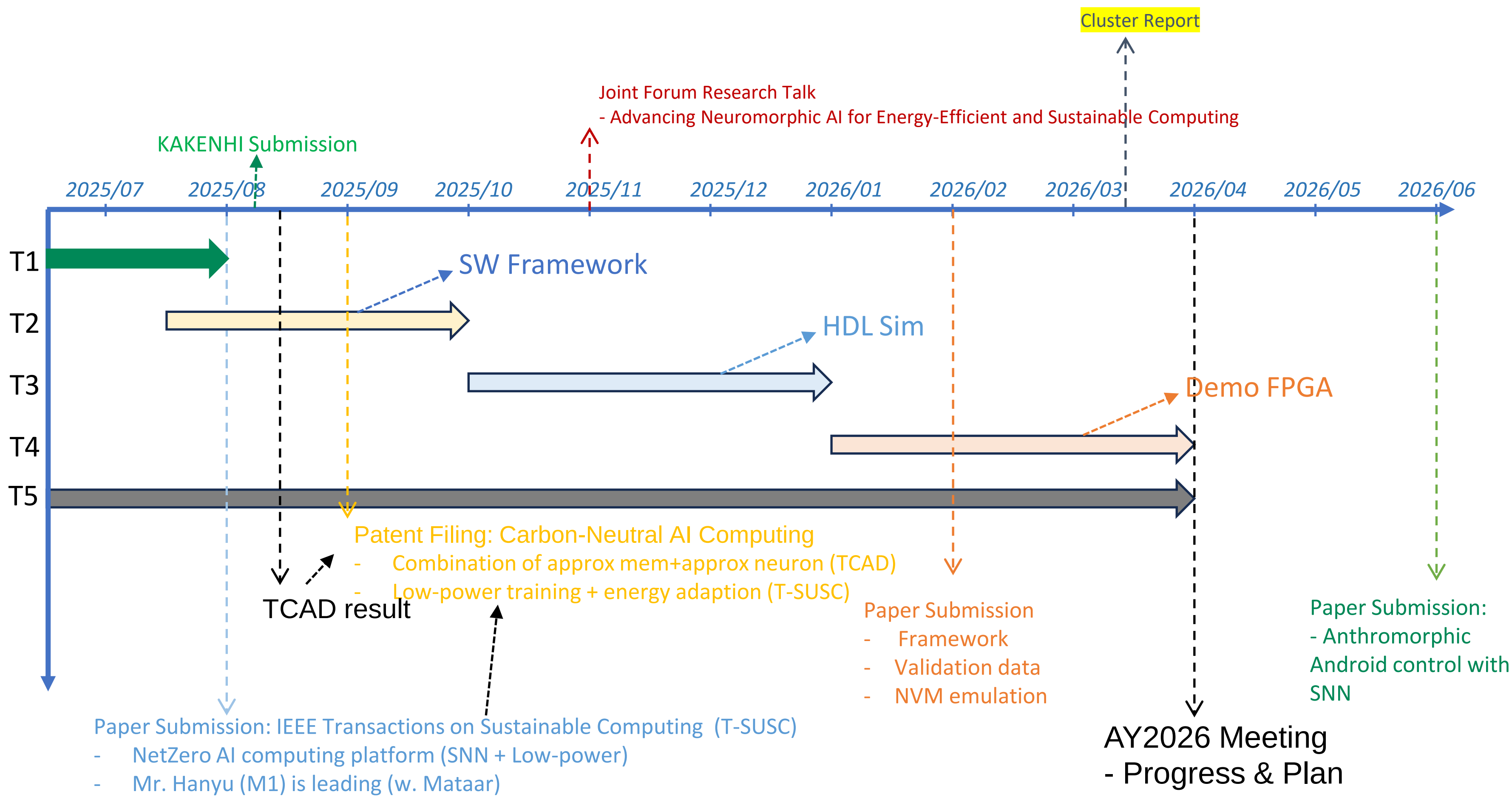
(*4) https://www.hdl.co.jp/EDX-303/
(*5) https://ieeexplore.ieee.org/document/11038377

- Use Humandata's FPGA board with Eversipin's STT-MRAM (*4)
- Use discrete STT-MRAM IC and connect FPGA board
  -> In (*5), there is a CNN's demo using AMD's FPGA and STT-MRAM IC

AY2025: ① FPGA based SNN SoC

- [T1] SNN deployment on FPGA [DANG]
  - A training flow with Pytorch
  - A HW emulation framework:
  - A conversion framework: Pytorch -> Verilog HDL.
  - A flow for SoC on FPGA
  - Publications:
    - [TCAD (major)] approximate SNN architecture
    - [Preparing] Framework for carbon-neutral SNN inference/training by adjusting hardware/model configuration to compensate for the energy harvesting.
- [T2] NVM emulation [SUZUKI]
  - Behavior model for implementing FPGA
  - Energy model for calculating energy consumption
  - FPGA implementation using "virtual" NVM
  - FPGA implementation using "real" NVM

Schedule



Cluster Report
Joint Forum Research Talk
- Advancing Neuromorphic AI for Energy-Efficient and Sustainable Computing
KAKENHI Submission
2025/07
2025/08
2025/09
2025/10
2025/11
2025/12
2026/01
2026/02
2026/03
2026/04
2026/05
2026/06
T1
T2
T3
T4
T5
SW Framework
HDL Sim
Demo FPGA
Patent Filing: Carbon-Neutral AI Computing
- Combination of approx mem+approx neuron (TCAD)
- Low-power training + energy adaption (T-SUSC)
TCAD result
Paper Submission
- Framework
- Validation data
- NVM emulation
Paper Submission:
- Anthromorphic Android control with SNN
AY2026 Meeting
- Progress & Plan
Paper Submission: IEEE Transactions on Sustainable Computing (T-SUSC)
- NetZero AI computing platform (SNN + Low-power)
- Mr. Hanyu (M1) is leading (w. Mataar)

Other HW parts

② ANN SoC for Hand Control

- For AY2025, we can reuse the existing system (ANN/SNN) on a Raspberry Pi to control the hand.
- We will discuss in AY2026 for this system (in 2026/04)

③ Inter-AI-chip connection (wired)

- Reserve for AY2026
- Potentially: I2C

④ Cloud connection (wireless)

- Reserve for AY2027

Distributed Android Cooperative Learning and Communication

Cooperative learning and communication

- Sensor and data sharing design
- Communication methods and protocols
- Task specification

RL-Based Android Control for Path Planning and Object Manipulation

- Multi-agent path coordination
- Obstacle avoidance and scene interaction
- Real-time re-planning for dynamic environments
- Object manipulation via reinforcement learning

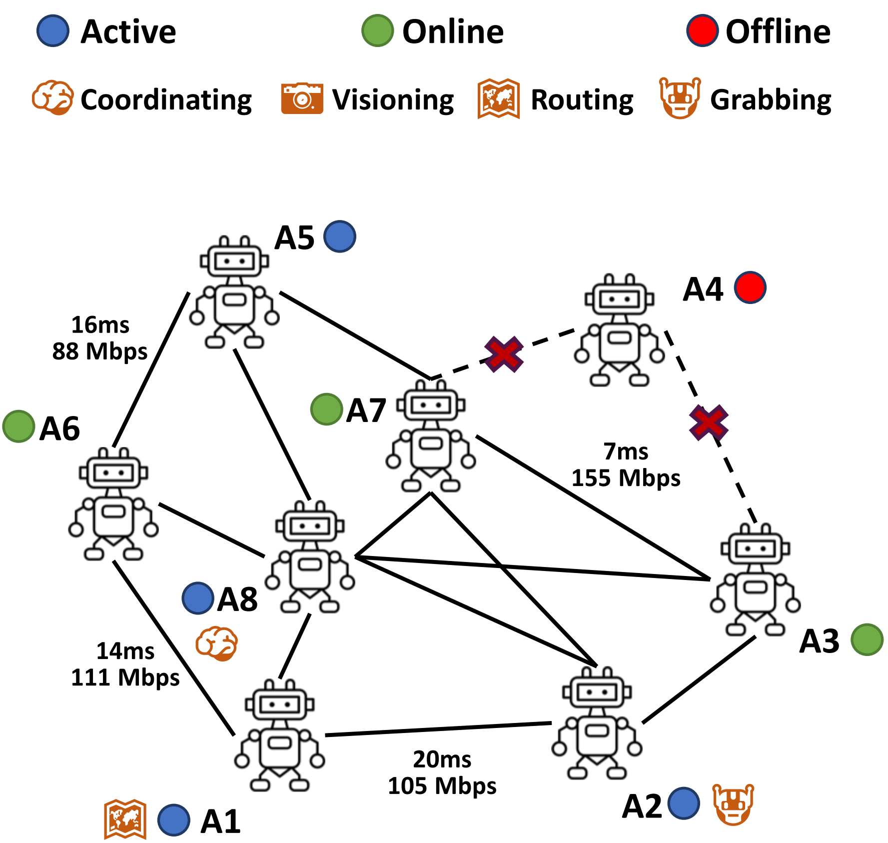
Android design

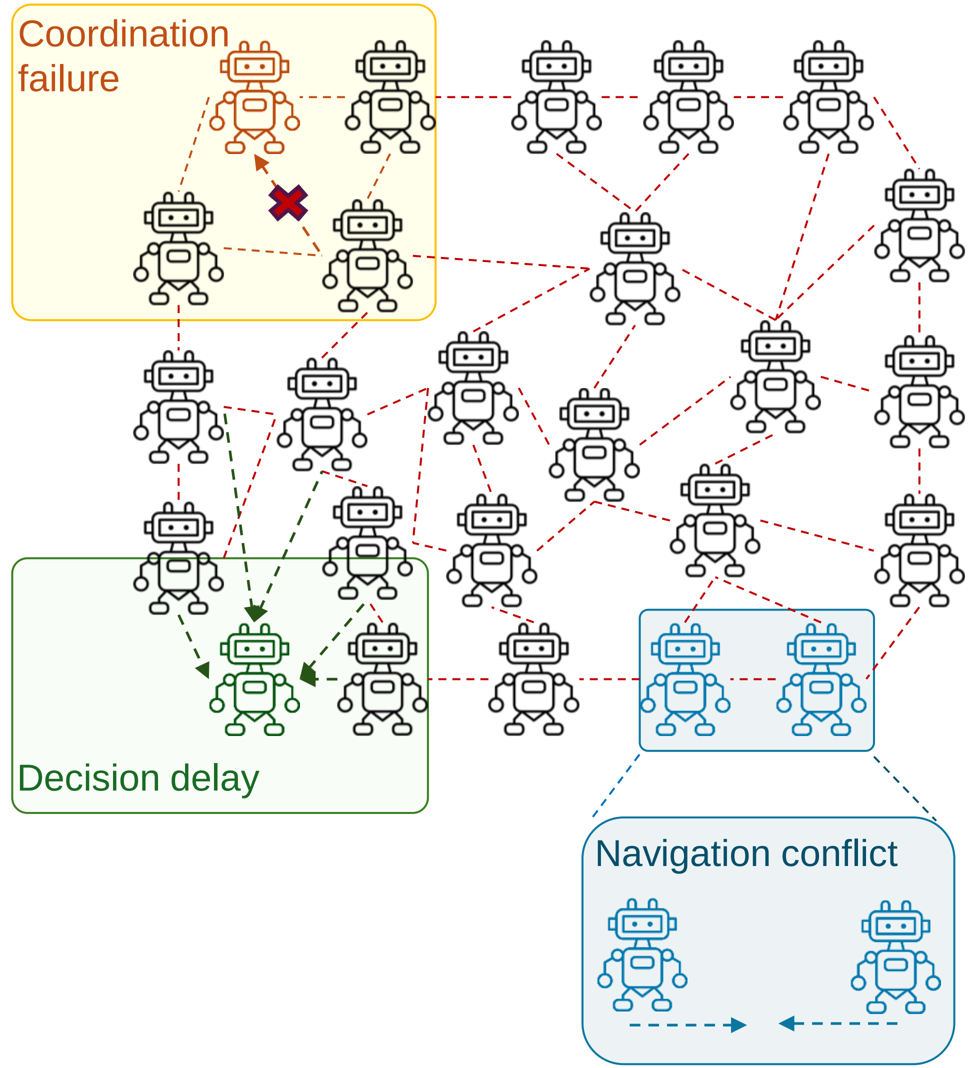
- Component 3D print
- Full body assembly
- Actuator integration
- Function design and implementation
- Final test

Cooperative Learning and Communication – Scalability

Core Metrics for Evaluating Scalability	
Metric	**Description**
Coordination Success Rate	Percentage of multi-android tasks completed without conflict or failure
Single-Task Success Rate	Percentage of individual tasks completed correctly despite increased system load
Decision Latency	Average time for each android to make decisions as team size grows

Cooperative Learning and Communication – Scalability

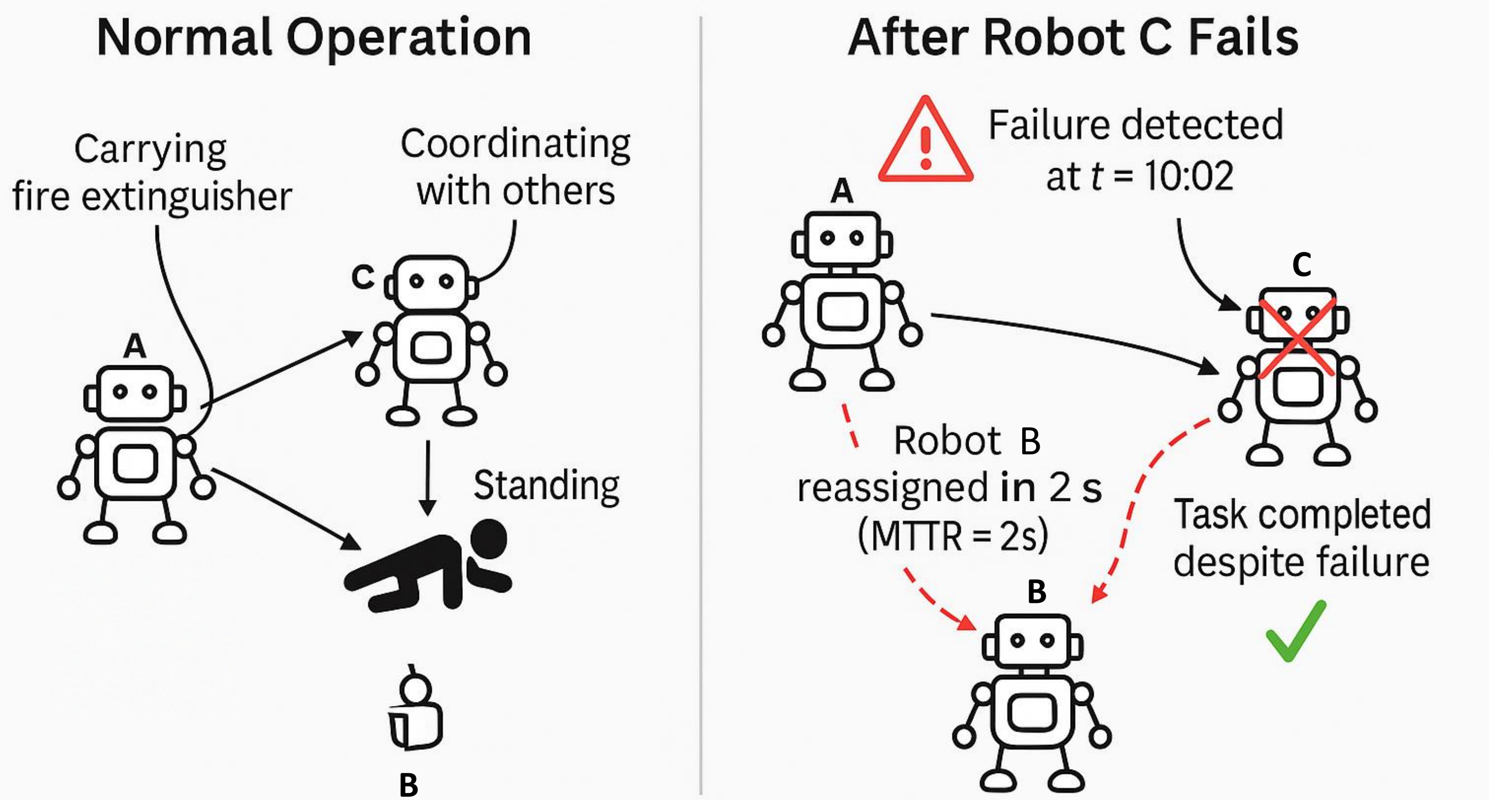




Cooperative Learning and Communication – Reliability

Core Metrics for Evaluating Reliability	
Metric	**Description**
Completion Rate under Faults	Percentage of tasks successfully completed even when one or more robots fail
MTTR (Mean Time To Recovery)	Average time the system takes to recover from a robot failure (e.g., detect, reassign, continue)
MTTF (Mean Time To Failure)	The average time before an individual android fails due to internal issues

Cooperative Learning and Communication – Reliability



Reliability: *The system's ability* to detect, react, and adapt when something goes wrong.

RL-Based Android Control for Path Planning and Object Manipulation

Step 1. RL-Based Modeling and Simulation Setup

- Get hands-on experience with the MATLAB Simulink environment, focusing on the RL Toolbox and building basic dynamic systems
- Prepare a comprehensive explanation of core RL concepts, key formulas, and common deployment environments.
- Develop a RL-based model of AIzuHand
- Advanced Research: Investigate leveraging LLM to enhance the RL agent's learning process

Step 2. Task-Level Simulation in MATLAB Simulink

- Define detailed input and output for object manipulation execution (e.g., grasp & release)
- Simulate object manipulation (grasp & release) in MATLAB Simulink
- Define detailed input and output for path planning (e.g., start point and destination, obstacle and walls)
- Simulate path planning in MATLAB Simulink

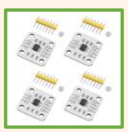
Step 3. Add Multi-Android Coordination

- Use multi-agent RL for coordinated path planning (Evaluation metric: Joint success rate, average agent reward / team reward, task completion time)
- Implement a distributed communication framework that allows androids to exchange key state information (e.g., position, planned trajectory) to support decentralized coordination in real time

Core Functions – Inputs and Outputs

Function	Input	Output	Android's Use (Purpose)
Vision	Image	Object	Manipulation (e.g., grasp)
	Image + depth map or 3D point cloud (e.g., .png [16-bit], .npy, .pcd)	Obstacle + 3D position	Path planning
	Videos (a set of image frames)	Real-time trajectory	Dynamic interaction (i.e., obstacle avoidance)
Voice Recognition	Analog signal	Structured command data (e.g., {action: "bring", object: "cup"})	Command recognition (e.g., move, grasp)
	Digital pulse-code modulation (PCM) audio stream	3D position	Voice source localization
Grasp /Release	Target object position and orientation + desired action + end-effector pose	Trajectory of end-effector + Control signals to actuators	Physical manipulation actions (e.g., grasp, release)
Walking	Starting point and destination + environment map (obstacles, walls)	Collison-free path	Path planning
	Planned path, current status	Actuator commands	Physical move for each step

Android Design Status

Phase	Current Status	Expect Due
Mechanical Design (3D Print)	Complete 	-
Full Body Assembly	         Sensors, knurled nuts, bolts and screws, bearings (8 arrived, 1 on delivery) (Expected arrival: mid of July, 2025)	July 25 (Fri), 2025
Actuator Integration	Motor (5010 & M6C12) Arrived	July 25 (Fri), 2025

Task	Sub-Task	2025 Jul	2025 Aug	2025 Sep	2025 Oct	2025 Nov	2025 Dec	2026 Jan	2026 Feb	2026 Mar	2026 Apr	2026 May	2026 Jun
Distributed Android	Problem formulation (scalability & reliability)												
	Propose algorithms												
	Conduct evaluation & write Jnl. Paper												
	Investigate practical scenarios (Optional)												
Path Planning	Prepare RL fundamental explanation												
	Investigate RL in Simulink												
	Write Conf. paper												
	Object manipulation in Simulink												
	Path planning in Simulink												
	Write Jnl. paper												
Android Physical Design	Full body assembly												
	Initial actuator integration												
	Single-actuator function testing												
	Write conf. paper												
	Full actuator integration												
	Integrated function tests												
	Write Jnl. paper												

AY2025 Expected Achievement

- [HARDWARE] DANG & SUZUKI
  - 2 Journal, 2 Conference papers
  - 1 Patent Applications
  - 1 KAKENHI 2026 (ALL SuScom Members), 2 External (DANG, WANG - applied already)
- [ANDROID] WANG & BEN
  - 2 Journal, 2 Conference papers
  - 1 Patent Applications
  - 1 KAKENHI 2026 (WANG, BEN)