

# Haobo Fang — Embedded Systems Portfolio

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## Origami-Inspired Modular Soft Robotic Arm

*T-RO manuscript in preparation (team)*

### Demo Video

### Key Tags

FDCAN communication Embedded PID Sensor fusion  
I2C mux Distributed architecture Modular design

### Project Overview

- **Goal:** Segment-level sensing/control modules with synchronized multi-board operation over Controller Area Network (CAN).
- **Realtime:** 400 Hz loop, <2.5 ms end-to-end latency for pneumatic actuation.

### Technical Highlights

- **Two-board distributed control over FDCAN (400 Hz):**  
**Sensor board (I2C mux):**  
3× Magnetic encoders + IMU fusion → CAN stream;  
**Execution board:**  
Target + Feedback → 3× PID → PWM/GPIO valve drivers.
- **Real-time sensor fusion and data conditioning:**  
Magnetic encoder: 12-bit calibrated position;  
IMU: 9-DoF fusion with calibration and filtering;  
I2C mux: serialization of 4 sensor channels without contention.
- **Closed-loop PID control with anti-windup:**  
Independent controller for each cavity;  
Integrator clamped to prevent windup;  
Soft-start initialization with 500-cycle calibration phase.

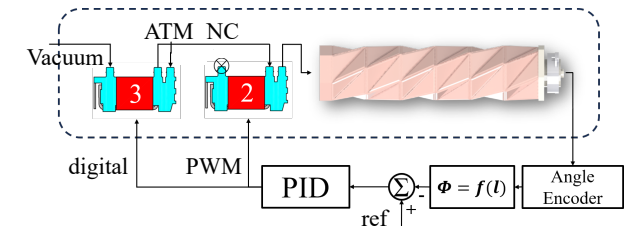
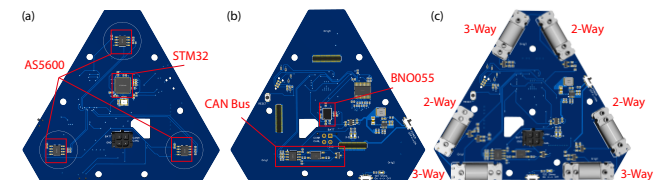
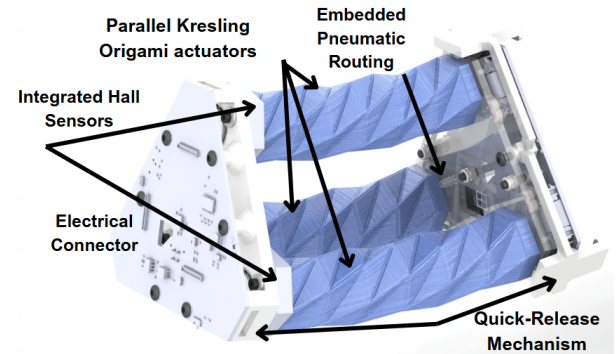
### Ownership & Contributions

- **Embedded maintainer (post-handoff):**  
Stabilized STM32 firmware (TIM/IRQ scheduling + CAN telemetry) to sustain 400 Hz control and <2.5 ms latency.
- **Kinematics modeling contributor:**  
Assisted 3D reconstruction pipeline and IK optimization (Analytical derivation + MATLAB prototyping).
- **Host-side Rust developer:**  
Contributed to host-side control stack in Rust (CAN I/O + System integration).

### Milestones & Early Results

- **Best Poster Award** ICRA 2025 Workshop
- **2025 Robotics Accomplishments** University of Michigan
- **SOTA Manipulation Accuracy**  
circular ( $\varnothing = 50\text{mm}$ ) tracking error  $\leq 0.25\text{ mm}$   
(System-level result; mech/model/control also matter.)

### System Overview



### Hardware & Tech Stack

MCU	STM32G431CBUX
Peripherals	AS5600 encoders BNO055 IMU TCA9548A mux Two-way valves Three-way valves
Interfaces & Buses	I2C FDCAN
RTOS/SDK	Bare-Metal (no RTOS) STM32 HAL TIM-driven IRQ-driven

### Credits & Funding

**Team:** Jiyang Wang, Yuchen You, and Xinqi Zhang  
**Advisors:** Jiaqi Wang and Xiaonan (Sean) Huang  
**Funding:** Hybrid Dynamic Robotics Lab, University of Michigan

# INSIGHT: Smart Assistive Glasses for Low-Vision Navigation

Major Design Experience Project: 2025 Fall

Repo1 (Custom PCB)

Repo2 (Jetson Nano)

Demo & Poster

## Key Tags

SoftAP TCP services    Multimodal streaming    Wake-word detection  
Real-time audio/video pipeline    PSRAM buffering    Wearable edge hub

## Project Overview

- **Problem:** Wearable navigation/scene understanding often remains **costly** and **network-dependent**, limiting reliable multimodal I/O and interactive feedback.
- **Goal:** Build a low-cost, real-time edge I/O hub that supports **bidirectional multimodal streaming**.
- **System:** Custom ESP32-S3 smart-glasses PCB + Jetson Nano AI compute; built for **low-vision, router-free** outdoor use.

## Technical Highlights

- **SoftAP multi-service TCP hub for bidirectional I/O:**  
Uplink: OV2640 video + Voice command audio;  
Downlink: AI instruction reverse-audio + Haptic guidance.
- **Low-latency multimodal pipelines:**  
OV2640 streams **JPEG** at **~25 FPS** with **low latency**;  
WakeNet detects **“Hi, ESP!”**, records **5 s PCM**, and uploads via a robust TCP service;  
Jetson Nano runs **LLM/navigation + TTS** and streams audio back for on-device playback.
- **FreeRTOS scheduling for robust real-time streaming:**  
Splits the system into **focused tasks** and assigns clear priorities;  
**Socket timeouts + periodic yields** to maintain responsiveness under concurrent TCP services;  
**PSRAM size caps** for in-memory audio buffering to bound latency and memory footprint.
- **Closed-loop tactile guidance channel:**  
Parses fixed-format ASCII commands and maps intensity to **10-bit duty cycle** at **~5 kHz PWM** for left/right vibrators.

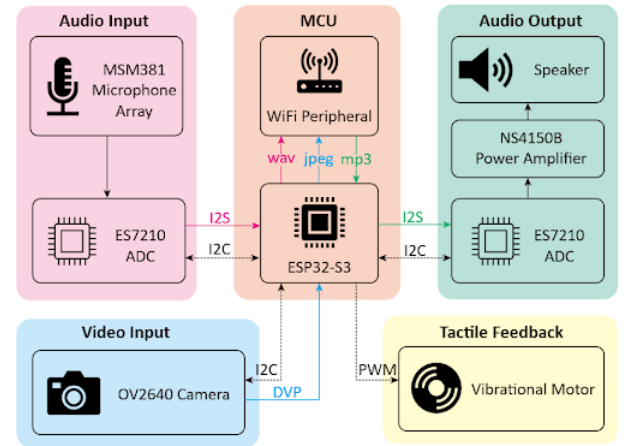
## Ownership & Contributions

- **Embedded lead (primary owner):**  
Owned schematic/PCB layout, board bring-up, and ESP32-S3 firmware (Audio/Video + Networking + RTOS).
- **Jetson Nano (contributor):**  
Integrated modules (LLM/Navigation/TTS) and debugged.

## Credits & Funding

**Team:** Guanyu Xu, Jinlin (Jack) Li, Yizhe (William) Shen, Zhuoyang Chen, and Ruopu Dong  
**Advisors:** EECS 473 (2025 Fall) course staff  
**Funding:** Infineon

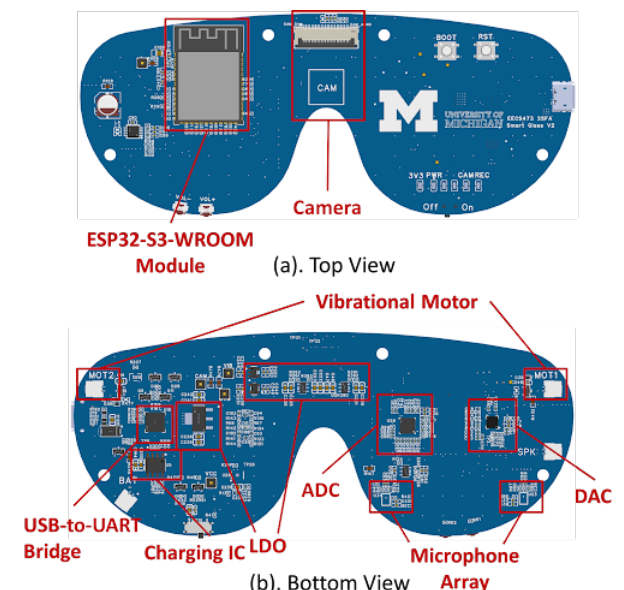
## System Block Diagram



## Tech Stack

- MCU/SoC: ESP32-S3-WROOM-1-N8R8
- Peripherals: OV2640 (DVP JPEG), Mic Array, Speaker/Codec, Vibrators, GPIO Keys
- Interfaces/Buses: DVP, I2S, I2C, LEDC PWM, GPIO
- RTOS/SDK: FreeRTOS, ESP-IDF, ESP-ADF
- Networking: Wi-Fi SoftAP, TCP streaming

## PCB Layout



Key Tags

- Multi-robot game
- STM32 NUCLEO
- PixyCam vision localization
- IMU gesture control
- Bluetooth (HC-05)
- LED grid feedback
- PID yaw control
- UART DMA (non-blocking RX)
- Haptic feedback

Project Overview

- **Goal:** Build a **interactive** parking game that demonstrates end-to-end embedded integration: **vision-based localization**, **gesture-based teleoperation**, and **real-time arena feedback**.
- **Setting:** Four Zumo robots compete to **claim as many parking spots as possible** on a 4x4 ft LED-marked field. Each round spawns **10 random spots**, which flip from **white (available)** to a robot's team color (**occupied**) upon capture.

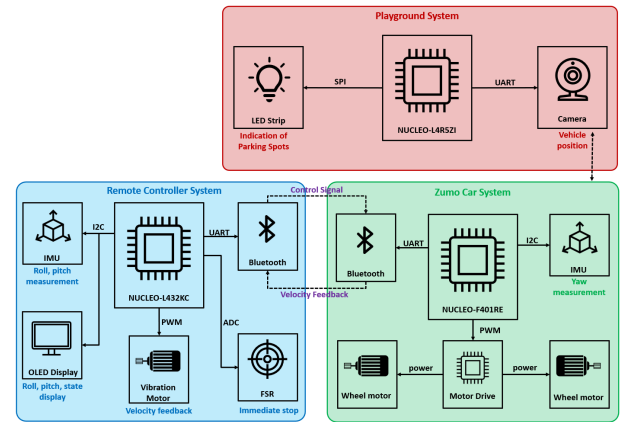
Technical Highlights

- **Three-module embedded architecture:**  
**Joystick:** IMU(I2C) → Command Mapping → BT (UART);  
**Zumo:** IMU yaw → PID → PWM → Telemetry (Speed & Yaw);  
**Arena:** PixyCam → Occupancy state machine → LED (SPI).
- **Arena: Vision localization & LED rendering:**  
 Overhead **PixyCam** tracks each robot via **unique color tags**;  
 Field controller maps positions to parking lots and updates **spot occupancy** in real time;  
 SPI-driven **LED strips** visualize availability and ownership, providing an **instant, legible scoreboard**.
- **Joystick: IMU drive commands & Safety feedback:**  
 Handheld **IMU roll/pitch** maps to steering/throttle, with an **FSR-based** emergency stop;  
 A **vibrator** mirrors speed and an **OLED** displays live status.
- **Zumo: Closed-loop drive control & DMA telemetry:**  
 Uses **IMU yaw** for **PID-based steering**;  
 Utilizes **UART RX via DMA + IRQ-driven parsing** to avoid blocking the control loop;  
 Reports **velocity feedback** over Bluetooth.

Constraints & Solutions

- **Noisy sensors (IMU drift):**  
 Deadbanding + **Exponential smoothing (IIR)** + **Simple Moving Average (SMA)**
- **Multi-node communication robustness:**  
 Simple framing + Sanity checks on Bluetooth packets

System Block Diagram



Hardware & Tech Stack

- MCU Dev Boards**
  - NUCLEO-L432KC (Joystick)
  - NUCLEO-F401RE (Zumo)
  - NUCLEO-L4R5ZI (Arena)
- Perception**
  - PixyCam
  - GY-511 IMU
  - FSR
- Control & Feedback**
  - Zumo motors
  - LED strips
  - Vibrators
  - SSD1306 OLED
- Communications**
  - UART(DMA RX)
  - I2C
  - SPI
  - Bluetooth (HC-05)
- RTOS/SDK**
  - Bare-Metal
  - STM32 HAL
  - DMA-driven
  - IRQ-driven

Ownership & Contributions

- **Embedded lead (primary contributor):**  
 STM32 firmware modules across subsystems
- **System bring-up & debugging:**  
 Multi-board wiring/verification + PixyCam calibration + End-to-end demo readiness

Credits

**Team:** Haobo Fang, Guanyu Xu, Xiang Jiang, Varun Agrawal  
**Advisors:** EECS 373 (2025 Winter) course staff