Edge AI Based Voice Command Integration for a Built-in-House Robotic Arm

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ABSTRACT

For the 2025 Summer Engineering Internship, we developed edge Machine Learning (ML) for voice recognition and integrated it with an existing built-in-house teleoperated robotic arm. In addition, we improved the computer-aided design (CAD) model of the previous version to enhance accessibility for diagnosis and repair. The voice command feature showcases both cutting-edge telerobotic operations using spoken commands and proof of concept for the integration of edge AI/ML with existing embedded systems. The advances that were made will soon be included into Biola's engineering curriculum. We began by assembling and testing the hardware components of the robotic arm, then configured the Arduino Nano 33 BLE (Bluetooth Low Energy) to capture and process audio input. Using Edge Impulse, we trained a custom neural network model to recognize specific voice commands. Finally, we integrated the trained model into the system and wrote control code to trigger arm movements based on classified keywords. This project demonstrates the application of machine learning and its potential for voice-enabled robotics.

OBJECTIVES

- **Integrate voice control** into a teleoperated robotic arm using the Arduino Nano 33 BLE and a custom-trained neural network
- **Implement two functional voice commands**, "home" and "stop," for partial robotic arm control based on keyword recognition
- **Improve the CAD model and optimize hardware layout** of the robotic arm by addressing issues including more accessible servo attachment, board accessibility, and wiring clutter
- **Expand the range of motion** and mechanical functionality through code adjustments
- **Demonstrate the potential of AI** by applying edge-deployed machine learning models for real-time audio classification on devices

HARDWARE AND COST

- PCA9685 Adafruit 16-Channel Servo Driver	$14.95
- Arduino Nano 33 BLE Rev2 Board	$23.10
- 10 Kohms Potentiometers	$9.99
- 7.4V Lithium-Ion Battery Pack	$14.99
- DS3225 Servo Motors (x2)	$32.99
- MG996R Servo Motors (x2)	$6.99
- SG90 Micro Servo Motor	$1.99
Total:	$105.00

Figure 1. Arduino Nano

Figure 2. DS3225, MG996r, SG90 Servo Motors

SOFTWARE DEVELOPMENT PLATFORMS

Arduino IDE

Audacity

Edge Impulse

Google Colab

RESEARCH & DEVELOPMENT

- Researched how audio classification models function on embedded systems
- Explored publicly available voice command datasets
- Recorded, cut, and labeled custom audio samples tailored to our chosen commands using Audacity
- Used Google Colab (Python) to develop code for:
  - Data processing
  - Feature extraction
  - Model Testing
- Mixed and formatted audio samples for compatibility with Edge Impulse for training requirements

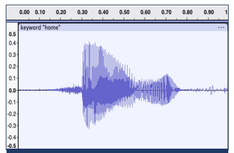

Figure 3. Sample waveform of keyword "Home"

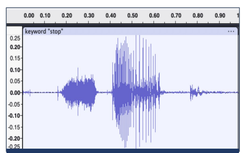

Figure 4. Sample waveform of keyword "Stop"

BUILDING AND DEPLOYING THE NEURAL NETWORK

- Developed a neural network to recognize specific voice commands for robotic arm control
- Used Edge Impulse to upload audio data and configure a model for keyword detection on the Arduino Nano 33 BLE
- Initially aimed to recognize five voice commands—one for each joint of the arm—paired with potentiometer control
- Encountered hardware limitations: the Nano 33 BLE could not support five separate keywords due to memory and processing constraints
- Conducted trial-and-error testing to evaluate model performance under different keyword loads
- Determined that the board could reliably handle only two keywords without sacrificing accuracy or speed
- Simplified the control strategy to use two generalized commands: "home" for moving the robotic arm to a home position and "stop" to deactivate the position control by potentiometer inputs

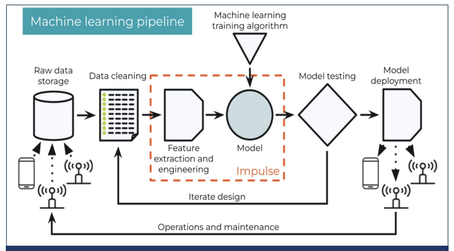

Figure 5. Machine Learning Pipeline

CAD MODEL

Previous Models:

Figure 6. Robotic Arm Design

Figure 7.Controller Design

Improvements:

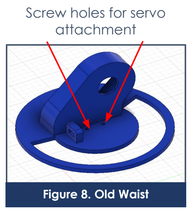

Figure 8. Old Waist

Problem: Difficulty detaching arm from base servo motor

Improvement: Screw holes relocation and implementation of a middleman

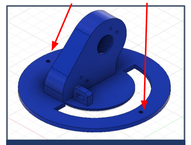

Figure 9. New Waist

Figure 10. Middleman

Figure 11. Old Base

Problem: Inconvenience accessing the PCA9685 servo driver and Arduino Nano boards

Improvement: Detachable structure and circuitry stand implementation

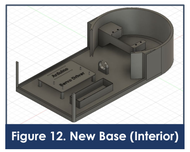

Figure 12. New Base (Interior)

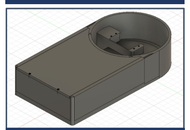

Figure 13. New Base (Exterior)

NEW ROBOTIC ARM ASSEMBLY

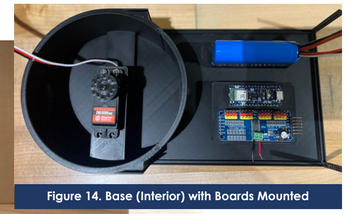

Figure 14. Base (Interior) with Boards Mounted

Figure 15. Fully Assembled Robotic Arm

INTEGRATING VOICE COMMANDS WITH THE ROBOTIC ARM

- Merged the trained keyword-spotting neural network with the robotic arm control code in Arduino IDE
- Used the potentiometers to move the robotic arm to a desired home position and recorded the corresponding servo outputs
- Mapped the two functional voice commands:
  - "Home": returns the robotic arm to the preconfigured home position, then enable position control by potentiometer inputs
  - "Stop": brings all servo motor movement to an immediate stop
- Tested the robotic arm with voice commands and teleoperation

FUTURE WORK

- Expand the number of recognized voice commands by using more capable hardware
- Implement multi-stage voice control (e.g. select joint → "shoulder" followed by an angle value) for greater autonomous operation
- Improve the robustness of voice recognition by strengthening the ability to detect keywords in a variety of voices and accents, and in noisy environments through larger datasets
- Automate the robotic arm motion and enable it to perform meaningful tasks such as "pick" and "place"
- Investigate other possibilities of edge AI integration, e.g. camera vision and pattern recognition, with the robotic arm

RESOURCES

1. "How to Do Speech Recognition with Arduino." DigiKey, https://youtu.be/fRSVQ4Fkwjc?si=wW5F8V2PC8jr6Sv1.
2. "Machine Learning Pipeline." Edge Impulse, https://docs.edgeimpulse.com/docs/concepts/edge-ai-fundamentals/edge-ai-lifecycle.
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4. Adafruit PCA9685 16-Channel Servo Driver User Manual https://cdn-learn.adafruit.com/downloads/pdf/16-channel-pwm-servo-driver.pdf
5. Arduino Nano 33 BLE Documentation https://store-usa.arduino.cc/products/nano-33-ble-sense-rev2

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