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 Review the assignment due date

# final-project-skeleton

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**Team Number: Team25**

**Team Name:**

Team Member Name	Email Address
Tanxuan Li	jeffli88@seas.upenn.edu
Xiao Wang	wang96@seas.upenn.edu
Zhenyao Liu	liu59@seas.upenn.edu

**GitHub Repository URL:** [https://github.com/upenn-embedded/final-project-f25-f25-final\\_project\\_t25.git](https://github.com/upenn-embedded/final-project-f25-f25-final_project_t25.git)

**GitHub Pages Website URL:** [for final submission]\*

# Final Project Proposal

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## 1. Abstract

Our project aims to design and implement an interactive desktop pet robot that can engage in real-time communication with users through voice, visual, and motion responses. The system is built on an ATmega328PB microcontroller, integrating an offline voice recognition module, a temperature and humidity sensor, a TFT LCD display, a DFR0299 voice playback module, micro servos, and a Wi-Fi module.

The robot can recognize voice commands, respond with synthesized or pre-recorded speech, and display dynamic facial expressions and environmental information such as temperature and humidity on the LCD. Additionally, the Wi-Fi module allows users to control the robot through a mobile application, providing an alternative way to interact and customize behaviors.

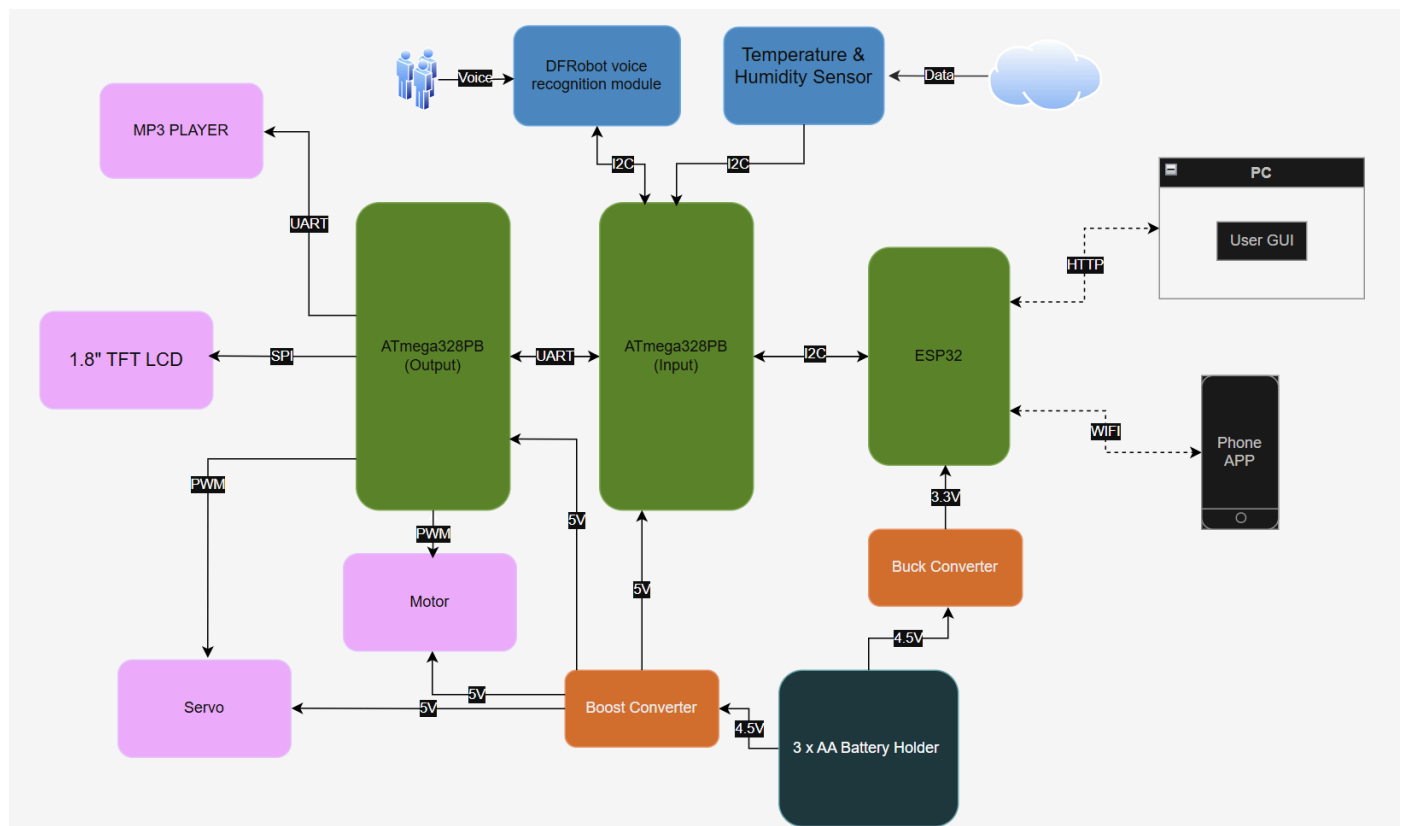
## 2. Motivation

In modern life, people increasingly spend long hours studying or working alone at their desks, often leading to stress and a lack of social interaction. Our project aims to design a smart desktop companion that provides emotional engagement and

environmental awareness through human-machine interaction. By combining voice recognition, facial expression display, and motion response, the robot creates a friendly and interactive experience that brings liveliness to a personal workspace.

### 3. System Block Diagram

System Block Diagram:



**High-level design (per figure):** a two-MCU architecture separates *sensing/comms* from *actuation/UI*. The **Input MCU (ATmega328PB)** aggregates sensors and bridges to Wi-Fi; the **Output MCU (ATmega328PB)** drives motors, servos, display, and audio. An **ESP32** provides Wi-Fi/HTTP links to a **PC GUI** and **phone app**. Power comes from a **3 × AA pack** with dedicated regulation rails.

#### Critical Components & Roles

- **ATmega328PB (Input)**
  - Collects **DFRobot offline voice** (I<sup>2</sup>C) and **Temp/Humidity sensor** (I<sup>2</sup>C).
  - Exchanges commands/status with ESP32 (I<sup>2</sup>C).
  - Sends parsed commands to Output MCU ( **UART** ).
- **ATmega328PB (Output)**
  - Drives **1.8" TFT LCD** ( **SPI** ) for eyes/status.
  - Controls **motors** ( **PWM** ) and **servos** ( **PWM** ).

- Plays feedback audio via **DFPlayer MP3 ( UART )**.
- **ESP32**
  - **Wi-Fi + HTTP** to PC GUI / phone app.
  - Local bridge between network and Input MCU (I<sup>2</sup>C).
- **DFRobot Voice Recognition Module**
  - Local, offline command recognition (I<sup>2</sup>C input → events to Input MCU).
- **Temp & Humidity Sensor**
  - Environmental telemetry (I<sup>2</sup>C to Input MCU).
- **DFPlayer Mini + Speaker**
  - Audio prompts and reactions (UART from Output MCU).
- **Actuators**
  - **4× DC motors** (PWM from Output MCU via motor drivers).
  - **2× micro servos** (PWM from Output MCU).

## Communication Map

- **I<sup>2</sup>C**
  - Input MCU ↔ Voice module
  - Input MCU ↔ Temp/Humidity sensor
  - Input MCU ↔ ESP32 (command/status bridge)
- **UART**
  - Input MCU ↔ Output MCU (bidirectional command channel)
  - Output MCU → DFPlayer Mini (audio control)
- **SPI**
  - Output MCU → 1.8" TFT LCD
- **PWM**
  - Output MCU → 4× Motor driver PWM inputs
  - Output MCU → 2× Servo signal lines
- **Wi-Fi / HTTP**
  - ESP32 ↔ PC GUI / Phone App (remote panel, telemetry)

## Power Regulation

- **Source:** 3×AA battery holder (~4.5 V nominal).
- **Boost Converter (→ 5 V):** motors, servos, DFPlayer, and (if required) the MCUs' 5 V rail.
- **Buck Converter (→ 3.3 V):** ESP32 (requires stable 3.3 V, ≥500 mA peak).

- **Decoupling:**  $\geq 470\text{--}1000\ \mu\text{F}$  on motor rail;  $\geq 100\ \mu\text{F}$  near ESP32;  $0.1\ \mu\text{F}$  at each IC.
- **Grounding:** common ground star-point; keep ESP32 antenna and mic away from motor wiring.

## Data/Control Flow

1. User speaks  $\rightarrow$  Voice module (I<sup>2</sup>C)  $\rightarrow$  Input MCU parses  $\rightarrow$  sends CMD via UART to Output MCU.
2. Remote panel (PC/phone)  $\rightarrow$  HTTP over Wi-Fi  $\rightarrow$  ESP32  $\rightarrow$  I<sup>2</sup>C to Input MCU  $\rightarrow$  UART to Output MCU.
3. Output MCU executes: PWM motors/servos, updates TFT (SPI), triggers DFPlayer (UART).
4. Status/telemetry (sensor values, heartbeats) flow back to ESP32  $\rightarrow$  HTTP  $\rightarrow$  PC/phone UI.

# 4. Design Sketches

- **Overall Appearance:**

The system is designed as a **desktop companion robot (“desk pet”)**. It reacts to human voice and remote commands, displaying animated “eye” expressions on its TFT screen and responding through motion and sound.

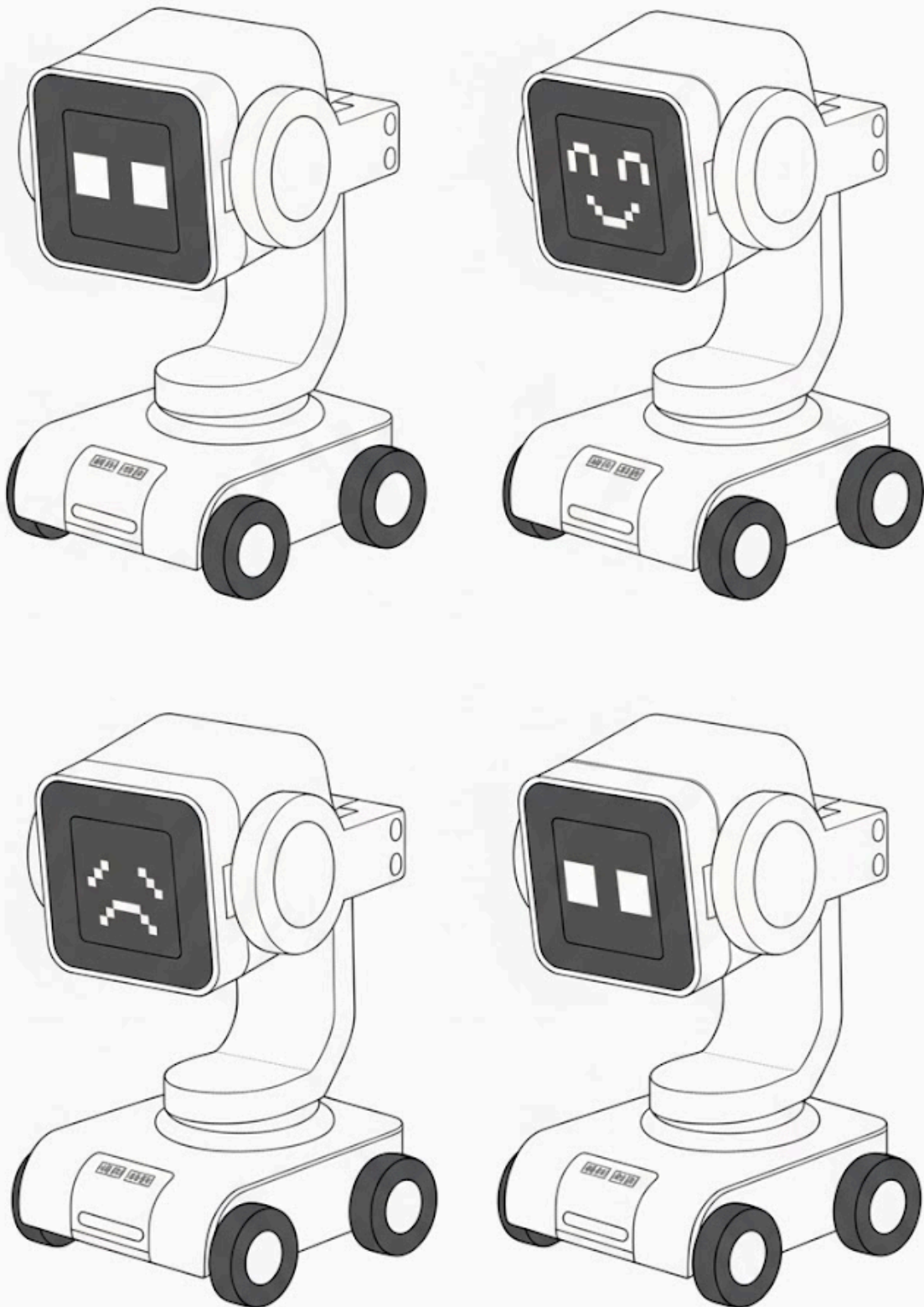
- **Functional Layout (see figure above):**

- **ATmega328PB (Input MCU)** collects data from the **voice recognition sensor** and **temperature/humidity sensor**, then communicates with the **ESP32** via I<sup>2</sup>C.
- **ESP32** handles Wi-Fi communication with the **PC User GUI** and **Phone App** via HTTP/Wi-Fi.
- **ATmega328PB (Output MCU)** drives the **TFT display**, **DFPlayer MP3 module**, **motors**, and **servos** using SPI, UART, and PWM interfaces.
- **Power** is provided by a **3×AA battery pack**, with a **boost converter** for 5 V peripherals and a **buck converter** for 3.3 V logic and ESP32.

- **Critical Design Features:**

- Compact and **cute robotic form** that expresses emotions through the screen and sound.
- **Offline speech recognition** for direct command response without internet.
- **Wi-Fi remote control** via PC and phone dashboard for movement and reaction commands.
- Integrated **multimodal feedback** : voice, motion, and display.
- **Manufacturing & Assembly:**
  - **3D printing** will be used to create the outer shell and mounting brackets.
  - The structure will be assembled on an **acrylic baseplate** for stability.
  - **No advanced machining** required—hand tools and a 3D printer are sufficient.
  - Power supplied by **AA batteries** in a detachable holder with switch for easy replacement.

Sketch for this project:



## 5. Software Requirements Specification (SRS)

### 5.1 Definitions, Abbreviations

- **MCU:** ATmega328PB microcontroller
- **DFR0299:** MP3 module, controlled via UART serial commands
- **LCD (ST7735):** 1.8" 128×160 SPI TFT color display controller, SPI protocol
- **AHT20:** Adafruit AHT20 Temperature & Humidity Sensor, I<sup>2</sup>C interface
- **Micro Servo:** TowerPro SG92R, PWM control
- **ASR:** Automatic Speech Recognition
- **NDJSON:** Newline-Delimited JSON stream protocol for HTTP communication
- **CMD:** Control Command (MOVE, STOP, TURN, SERVO, etc.)
- **UI:** Remote control user interface (PC web or mobile web/app)

## 5.2 Functionality

ID	Description
SRS-01	The AHT20 temperature reading shall retain 1 °C resolution, and the humidity display shall retain 1 % RH resolution.
SRS-02	LCD partial area refresh shall complete within $\leq 50$ ms.
SRS-03	After a normal playback trigger, the DFR0299 shall transmit a complete command frame to the MCU and receive acknowledgement (or busy signal) within $\leq 500$ ms.
SRS-04	Micro Servo actived by 50Hz pulse, then read the duty cycle and respond to the a certain angle basic on the duty cycle value.
SRS-05	The offline speech recognition module shall recognize at least 10 predefined voice commands (e.g., forward, back, left, right, stop, hello) with an accuracy $\geq 85$ % under indoor noise $\leq 65$ dB. The end-to-end latency (from end of speech to command reception by MCU) shall be $\leq 600$ ms.
SRS-06	Communication between MCU and PC (via ESP32/HTTP bridge) shall implement a sequence-acknowledgment mechanism.



ID	Description
SRS-07	The remote control panel (desktop & mobile) shall provide MOVE/STOP/TURN/SERVO/EMOTE/SAY controls. The visible feedback latency (UI action → MCU acknowledgment) shall be $\leq 200$ ms (95th percentile).

## 6. Hardware Requirements Specification (HRS)

### 6.1 Definitions, Abbreviations

- **VCC / 5 V / 3V3:** Power rails
- **MCU:** ATmega328PB microcontroller
- **DFR0299:** MP3 module, controlled via UART serial commands
- **LCD (ST7735):** 1.8" 128×160 SPI TFT color display controller, SPI protocol
- **AHT20:** Adafruit AHT20 Temperature & Humidity Sensor, I<sup>2</sup>C interface
- **Micro Servo:** TowerPro SG92R, PWM control
- **3D printing:** To print the case and connections
- **Power Regulator:** Adjust the input power to 3.3V and 5V
- **ASR:** Automatic Speech Recognition

### 6.2 Functionality

ID	Description
HRS-01	The AHT20 shall be powered by 3.3 V, with power ripple $\leq 50$ mV pp. The physical connection length should be $\leq 20$ cm and routed away from high dv/dt signals.
HRS-02	The LCD shall display temperature and humidity readings, five facial expressions, and text responses to voice commands.
HRS-03	Upon a normal speech trigger, the DFR0299 shall produce the first audible syllable within $\leq 1.5$ s, and shall be capable of playing ten

ID	Description
	distinct response phrases.
HRS-04	The micro servo requires a continuous 50 Hz PWM signal (corresponding to a 20 ms period). Within each cycle, the servo angle is precisely determined by the width of the high-level pulse, typically ranging from 1 ms to 2 ms.
HRS-05	The motor controlled by the PWM signal that on and off the MOSFET.
HRS-06	Module–MCU link (I <sup>2</sup> C 400 kHz or UART 115200) shall run 10 min error-free (CRC/frame = 0).
HRS-07	The power supply should be able to support MCU and peripheral. Max current ≥ 2A.

## 7. Bill of Materials (BOM)

[ESE5190 F25 Final Project BOM.xlsx - Google Sheets](#)

### Core Components

- **ATmega328PB Xplained Mini × 2** – Main MCUs; one handles inputs (sensors, voice, Wi-Fi), the other handles outputs (motors, servos, display).
- **FeatherS2 (ESP32-S2)** – Wi-Fi bridge for HTTP communication with PC/mobile app.

### Input & Communication

- **Gravity: Offline Voice Recognition Sensor (DFRobot)** – Local speech command recognition (I<sup>2</sup>C).
- **Temperature & Humidity Sensor (e.g., BME280/SHT31)** – Environment telemetry for UI display.

### Output & Feedback

- **1.8" 128×160 TFT LCD (ST7735)** – Display robot “eye” and status (SPI).
- **DFPlayer Mini MP3 Module + 3 W Speaker** – Audio output for responses and sound effects.

### Actuation

- **Micro Servo (TowerPro SG92R) × 2** – Control eye/head movement (via PCA9685).
- **DC Gear Motor × 4 (TT/N20 type)** – Drive 4 wheels for motion control.
- **TB6612FNG Motor Driver × 2** – Dual-channel drivers, one per motor pair.
- **PCA9685 16-ch PWM Module** – I<sup>2</sup>C PWM expander for servos/LEDs.
- **65 mm Multi-Hub Wheels × 4** – Wheels for TT/N20 motors.

## Power & Regulation

- **Boost Regulator (3×AA → 3.3 V)** – Stable logic/ESP32 power ( $\geq 1$  A).
- **Buck Regulator (5 V Output)** – Power rail for motors/servos ( $\geq 3$  A).
- **Alkaline AA Batteries × 3 + Holder w/ Switch** – Primary power source.
- **Bulk Capacitors (470–1000  $\mu$ F)** – Filter motor surges and Wi-Fi peaks.
- **Level Shifter (BSS138)** – I<sup>2</sup>C 5 V ↔ 3.3 V conversion if needed.
- **Emergency Stop Button** – Safety cutoff for PWM outputs.

# 8. Final Demo Goals

- **Demonstration Setup**
  - The robot will be placed on a tabletop or smooth indoor floor.
  - Powered by 3×AA batteries through regulated 3.3 V and 5 V rails.
  - Controlled through a **PC web dashboard** and **mobile app interface** over Wi-Fi.
- **Core Demonstrations**
  - **Speech Interaction:**
    - Say voice commands such as “*forward*,” “*stop*,” “*turn left*,” or “*hello*” to trigger immediate robot actions.
    - Display visual feedback (eye animation on TFT screen) and audio confirmation via DFPlayer.
  - **Wi-Fi Communication:**
    - ESP32 bridges commands between the robot and PC/mobile remote panel.
    - Real-time control and status feedback demonstrated through a browser UI.
  - **Remote Control Panel:**
    - Web interface buttons to control motion, servos, and expressions.

- Command latency and heartbeat reliability shown live ( $RTT \leq 80$  ms).

- **Physical Constraints**

- Indoor space ( $\approx 2\text{ m} \times 2\text{ m}$ ) required for safe movement.
- Flat surface; lightweight chassis; wired USB debugging available.
- No external network required—ESP32 operates as local access point or on lab Wi-Fi.

- **Evaluation Metrics**

- Successful local and online speech recognition ( $\geq 85\%$  accuracy).
- Stable motion control via remote panel (no packet loss  $> 1\%$ ).
- Consistent power operation—no brownouts during Wi-Fi transmission.

## 9. Sprint Planning

Milestone	Functionality Achieved	Distribution of Work
Sprint #1	Voice Recognition, Speaker, Sensor Reading	It can perform speech recognition, perceive the surrounding environment in multiple aspects, carry out accurate measurements, and enable the speaker to play preset sounds.
Sprint #2	LCD and fixed the bugs last week. First draft of the 3D case. WIFI	The screen can display the corresponding preset expressions, estimated at around 5 to 10 types. Make a prototype of the case based on the components. Able to communicate with the computer through the Wi-Fi module
MVP Demo	Able to move forward and backwards, nod and shake. Second draft of the case.	Can move based on the input instructions.
Final Demo	Assemble and print the 3D case	Assemble everything.

# Sprint Review #1

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**Last week's progress**

**Current state of project**

**Next week's plan**

# Sprint Review #2

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**Last week's progress**

**Current state of project**

**Next week's plan**

# MVP Demo

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1. Show a system block diagram & explain the hardware implementation.
2. Explain your firmware implementation, including application logic and critical drivers you've written.
3. Demo your device.
4. Have you achieved some or all of your Software Requirements Specification (SRS)?
  1. Show how you collected data and the outcomes.
5. Have you achieved some or all of your Hardware Requirements Specification (HRS)?
  1. Show how you collected data and the outcomes.

6. Show off the remaining elements that will make your project whole: mechanical casework, supporting graphical user interface (GUI), web portal, etc.
7. What is the riskiest part remaining of your project?
  1. How do you plan to de-risk this?
8. What questions or help do you need from the teaching team?

# Final Project Report

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Don't forget to make the GitHub pages public website! If you've never made a GitHub pages website before, you can follow this webpage (though, substitute your final project repository for the GitHub username one in the quickstart guide):

<https://docs.github.com/en/pages/quickstart>

## 1. Video

[Insert final project video here]

- The video must demonstrate your key functionality.
- The video must be 5 minutes or less.
- Ensure your video link is accessible to the teaching team. Unlisted YouTube videos or Google Drive uploads with SEAS account access work well.
- Points will be removed if the audio quality is poor - say, if you filmed your video in a noisy electrical engineering lab.

## 2. Images

[Insert final project images here]

*Include photos of your device from a few angles. If you have a casework, show both the exterior and interior (where the good EE bits are!).*

## 3. Results

*What were your results? Namely, what was the final solution/design to your problem?*

**3.1 Software Requirements Specification (SRS) Results**

*Based on your quantified system performance, comment on how you achieved or fell short of your expected requirements.*

*Did your requirements change? If so, why? Failing to meet a requirement is acceptable; understanding the reason why is critical!*

*Validate at least two requirements, showing how you tested and your proof of work (videos, images, logic analyzer/oscilloscope captures, etc.).*

ID	Description	Validation Outcome
SRS-01	The IMU 3-axis acceleration will be measured with 16-bit depth every 100 milliseconds +/-10 milliseconds.	Confirmed, logged output from the MCU is saved to "validation" folder in GitHub repository.

**3.2 Hardware Requirements Specification (HRS) Results**

*Based on your quantified system performance, comment on how you achieved or fell short of your expected requirements.*

*Did your requirements change? If so, why? Failing to meet a requirement is acceptable; understanding the reason why is critical!*

*Validate at least two requirements, showing how you tested and your proof of work (videos, images, logic analyzer/oscilloscope captures, etc.).*

ID	Description	Validation Outcome
HRS-01	A distance sensor shall be used for obstacle detection. The sensor shall detect obstacles at a maximum distance of at least 10 cm.	Confirmed, sensed obstacles up to 15cm. Video in "validation" folder, shows tape measure and logged output to terminal.

**4. Conclusion**

Reflect on your project. Some questions to address:

- What did you learn from it?
- What went well?
- What accomplishments are you proud of?
- What did you learn/gain from this experience?
- Did you have to change your approach?
- What could have been done differently?
- Did you encounter obstacles that you didn't anticipate?
- What could be a next step for this project?

## References

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Fill in your references here as you work on your final project. Describe any libraries used here.