

Project Design Document: Group 31

Gamified Focus-Detection Tamogatchi

Design Document

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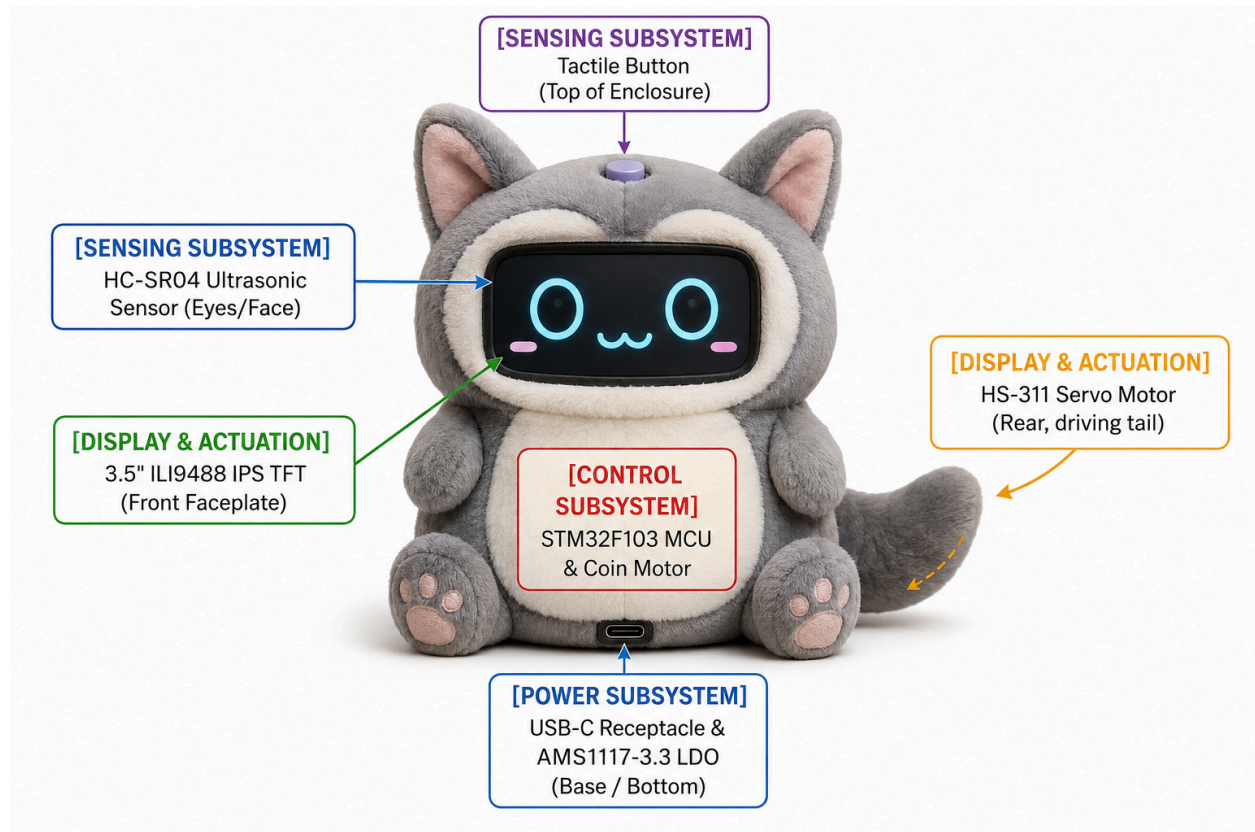
1. Introduction

1.1 Problem and Solution

Digital distractions and constant notifications frequently interrupt workflows and shorten attention spans. Standard software solutions like pop-up alerts or site blockers are easily dismissed or muted within the host workspace itself.

To overcome this, we propose an interactive desktop companion pet that provides non-invasive, physical feedback instead of dismissible on-screen pop-ups. A host-side background application tracks webcam presence, active applications, and peripheral input frequency to compute an explainable focus score sent over USB serial. An STM32-based custom PCB decodes these updates into a four-state behavioral machine, driving real-time facial expressions on a 3.5-inch IPS display and actuating a servo-driven tail. The device also incorporates an ultrasonic sensor and tactile button to enable localized desk-level interactions such as petting or snoozing.

1.2 Visual Aid

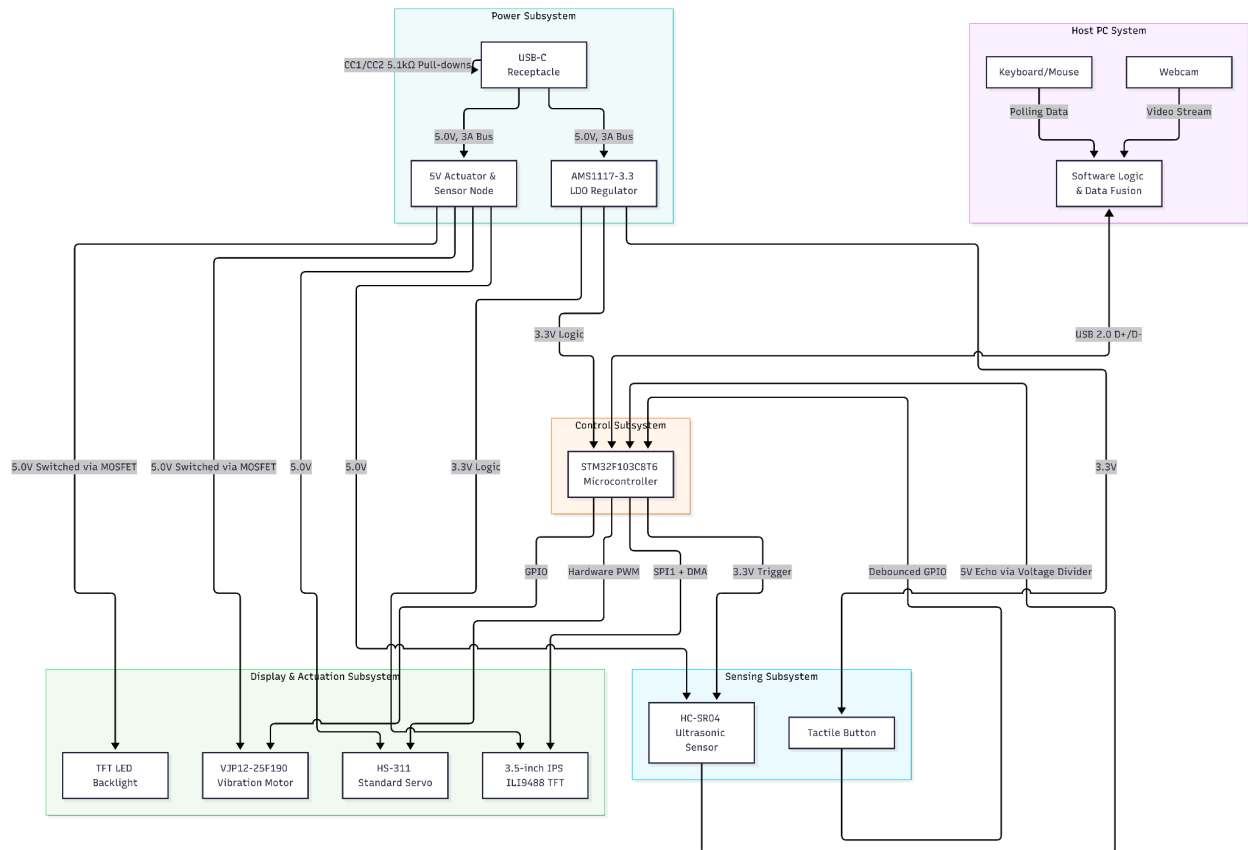


The physical desktop companion operates as an active, localized peripheral within the user's primary workstation environment. It connects to the host computer through a single USB-C cable, which supplies 5.0 V DC power and carries bidirectional serial communication. A background host application computes a normalized focus score from webcam presence, peripheral activity, and active software windows, streaming this data to the companion every two seconds. The device translates these scores into physical, real-time feedback—animating facial expressions on a 3.5-inch IPS display, moving a servo-driven mechanical tail, and pulsing a vibration motor for key alerts. Concurrently, the user directly interacts with the device via an angled ultrasonic sensor for hand gestures and a top-mounted tactile pushbutton for snoozing notifications.

1.3 High-Level Requirements List

- **Requirement 1:** The host PC application must aggregate webcam presence and peripheral inputs into a 0–100 focus score and transmit packets over USB serial every $2000\text{ ms} \pm 100\text{ ms}$ while using under 10% host CPU
- **Requirement 2:** The custom PCB must negotiate a 5V, 3A power state via USB-C CC pull-down resistors to keep the 3.3V rail within $\pm 0.1\text{ V}$ under maximum display and servo loads.
- **Requirement 3:** Upon receiving a state command, the STM32 must use DMA to update the TFT display within 100 ms and actuate the tail servo through at least a 90-degree sweep within 500 ms

2.1 Block Diagram Overview



The overall system architecture is partitioned into five interconnected subsystems: Host PC System, Power Subsystem, Control Subsystem, Sensing Subsystem, and Display & Actuation Subsystem. The Host PC System monitors user presence via webcam, peripheral input activity, and active software titles, computing a normalized 0–100 focus score streamed over Full-Speed USB serial to the custom PCB. A native USB-C receptacle negotiates a 5.0 V, up to 3.0 A power state via dual 5.1 k Ω Configuration Channel pull-down resistors, routing unregulated 5.0 V to high-current electromechanical components while feeding an AMS1117-3.3 LDO to provide a regulated 3.3 V logic rail. At the core, an STM32F103C8T6 microcontroller manages a deterministic four-state behavioral engine, receiving host telemetry while collecting localized desk interactions from a hardware-debounced tactile push-button and

an HC-SR04 ultrasonic sensor. The controller then executes behavioral feedback by driving a 3.5-inch ILI9488 IPS TFT display via DMA-backed SPI, sweeping an HS-311 tail-wagging servo via 50 Hz PWM, and modulating a coin vibration motor and display backlight through dedicated MOSFET switches.

2.2 Physical Design

The companion is housed in a Polycase XR-57P enclosure with 3D-printed features. The front holds a 3.5-inch TFT display, the top integrates angled ultrasonic sensors and a tactile button, and the rear houses a mechanical tail servo. The custom PCB and USB-C receptacle are secured at the base.

2.3 Subsystem Design & Block Descriptions

2.3.1 Power Subsystem

- The Power Subsystem routes 5.0 V from a USB-C source using dual 5.1 kΩ pull-down resistors. High-current loads use the 5.0 V rail, buffered by a 470 μF decoupling capacitor, while an AMS1117-3.3 LDO provides a clean 3.3 V logic rail.

Requirements & Verification Table: Subsystem A

Requirement	Verification Procedure	Status / Target
1. CC termination resistance measures 5.1 kΩ ±5% to ground.	Measure resistance between CC1/CC2 and ground while unpowered.	4.85 kΩ – 5.35 kΩ

Requirement	Verification Procedure	Status / Target
2. Logic rail maintains 3.3 V ± 0.1 V under steady load.	Measure DC voltage at 3.3 V test point with maximum MCU/display load.	3.20 V – 3.40 V
3. Motor stall prevents 5.0 V rail dropping below 4.5 V.	Stall the servo for 500 ms and measure 5.0 V bus voltage on an oscilloscope.	≥ 4.50 V

- **2.3.2 Control Subsystem**

- Centered on a 72 MHz STM32F103C8T6 microcontroller, this subsystem evaluates incoming telemetry and manages a four-state behavioral machine. It updates the display via DMA-backed SPI and drives the tail and backlight using hardware PWM.

Requirements & Verification Table: Control Subsystem

Requirement	Verification Procedure	Status / Target
1. Packet parsing executes within 10 ms.	1. Toggle a debug pin during serial parsing and measure pulse width.	≤ 10 ms
2. SPI clock maintains ≥ 18 MHz during DMA.	1. Probe SCK pin during an active display memory transfer.	≥ 18.0 MHz

Requirement	Verification Procedure	Status / Target
3. TIM2 generates 50 Hz PWM for the servo.	1. Probe PA0 PWM output at multiple commanded sweep angles.	20.0 ms period

- 2.3.3 Sensing Subsystem**
 - This subsystem manages physical interaction. The HC-SR04 ultrasonic sensor utilizes a voltage divider to safely step its 5.0 V echo pulse down to 3.33 V. The tactile button uses an RC filter for hardware debouncing (1.0 ms time constant).

Requirements & Verification Table: Sensing Subsystem

Requirement	Verification Procedure	Status / Target
1. Echo signal scaled ≤ 3.45 V at MCU input.	1. Probe the voltage divider node during active distance ranging.	3.15 V – 3.45 V
2. Tactile button RC circuit eliminates bounce.	1. Probe the EXTI pin and depress button 20 times to confirm clean edges.	0 false edges

2.3.4 Display & Actuation Subsystem

Provides behavioral feedback using a 3.5-inch ILI9488 TFT display and an HS-311 servo. A vibration motor is switched via a 2N7002 MOSFET, clamped with a 1N4148 flyback diode to prevent inductive voltage kickback.

Requirements & Verification Table: Display & Actuation Subsystem

Requirement	Verification Procedure	Status / Target
1. Servo completes $\geq 90^\circ$ sweep under 500 ms.	1. Command sweep and measure transition time / peak current.	≤ 500 ms, ≤ 800 mA
2. Display delta rendering completes in ≤ 100 ms.	1. Measure debug pin pulse during a full DMA graphical state update.	≤ 100 ms
3. Flyback diode clamps motor turn-off transients.	1. Probe the MOSFET drain during 1 Hz motor toggling to check overshoot.	≤ 6.0 V peak

2.3.5 Host Software Subsystem

A background application tracks productive windows, peripheral inputs, and webcam face detection using a 2.0 s sliding window. It calculates an exponentially smoothed focus score and sends it over serial.

Requirements & Verification Table: Host Software Subsystem

Requirement	Verification Procedure	Status / Target
1. Host CPU utilization remains below 10%.	1. Run app alongside standard tools and log average OS CPU metrics.	$< 10.0\%$ load
2. Telemetry packets sent every 2000 ms ± 100 ms.	1. Sniff serial traffic and measure intervals between 100 consecutive frames.	2000 ms ± 100 ms

2.4 Tolerance Analysis

The critical interface is the Power Subsystem 5.0 V bus stability and LDO thermal junction management under maximum load transients.

Worst-Case Current Budget: Peak load (display, sensors, MCU, and motor stall) totals 1055 mA. This is well within the 3000 mA USB-C limit, leaving a 1945 mA margin.

Bus Voltage Droop Analysis:

Assuming an 800 mA servo load step over 200 μ s with a 470 μ F capacitor and 0.15 Ω cable resistance:

$$\Delta V_{\text{bus}} = (I_{\text{step}} \times t_{\text{transient}}) / C_{\text{bulk}} = (0.8 \text{ A} \times 200 \mu\text{s}) / 470 \mu\text{F} = 0.34 \text{ V}$$

Under a nominal 5.00 V supply, the minimum bus voltage drops to 4.54 V, which safely satisfies the 4.50 V USB minimum requirement.

Thermal Dissipation Analysis: The AMS1117-3.3 regulator powers the MCU and display logic (60 mA total). At a 5.25 V max input, power dissipation is 0.117 W. With an internal enclosure ambient temperature of 45°C and thermal resistance of 90°C/W:

$$T_J = 45^\circ\text{C} + (0.117 \text{ W} \times 90^\circ\text{C/W}) = 55.53^\circ\text{C}$$

The junction temperature of 55.53°C leaves a safety margin of 69.47°C below the 125°C limit, ensuring the regulator will not thermally shut down.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Cost

Formula: Labor Cost = Hourly Rate (\$/hr) $\times$ Hours to Complete

Team Member	Hourly Rate (\$/hr)	Hours	Total Labor Cost (\$)
Khushi Murthy	\$40.00	120	\$4,800.00

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Michael Yang	\$40.00	120	\$4,800.00
Noah Yi	\$40.00	120	\$4,800.00
Total Labor	—	360	\$14,400.00

3.1.2 Parts & Services Cost

Description	Manufacturer & Part #	Qty	Unit Cost (\$)	Total Cost (\$)
STM32 Microcontroller	STMicroelectronics, STM32F103C8T6	1	\$3.50	\$3.50
3.5-inch TFT Display	ILI9488	1	\$12.00	\$12.00
Tail Servo Motor	Hitec, HS-311	1	\$9.99	\$9.99
Ultrasonic Ranging Sensor	HC-SR04	1	\$2.50	\$2.50
Custom PCB Fabrication	JLCPCB, 2-Layer Board	5	\$2.00	\$10.00

Description	Manufacturer & Part #	Qty	Unit Cost (\$)	Total Cost (\$)
3D Printed Enclosure	Polycase, XR-57P Base	1	\$15.00	\$15.00
Miscellaneous Passive Components	Digi-Key / Various	1	\$8.00	\$8.00
Total Parts & Services	—	—	—	\$60.99

3.1.3 Grand Total

Category	Cost (\$)
Total Labor Cost	\$14,400.00
Total Parts & Services Cost	\$60.99
Grand Total	\$14,460.99

3.2 Schedule

Provide a weekly project schedule identifying tasks, milestones, and assigned responsibilities.

Week	Planned Task / Activity	Milestone / Deliverable
Week 1	System architecture definition & component selection	Design Document draft
Week 2	Detailed schematic capture & simulation	Schematic approval
Week 3	PCB layout & component ordering	Gerber files submitted
Week 4	Subsystem breadboarding & firmware development	Initial firmware built
Week 5	PCB assembly & power stage testing	Hardware power-on test
Week 6	Sensor integration & communication protocol debugging	Sensor data read verified
Week 7	System integration & physical enclosure fitting	Integrated prototype
Week 8	Full system testing, refinement, & safety verification	Final functional demo

4. Ethics, Safety, and Societal Impact

4.1 Societal Impact

The desktop companion is designed to help users build better focus habits and manage task switching without relying on intrusive screen pop-ups or harsh alerts. Instead of punishing distractions, it gives immediate, clear physical feedback that encourages self-regulation without increasing stress.

To keep energy use low and avoid extra hardware, the device powers directly over USB-C using standard 5.1 k Ω pull-down resistors for standard 5 V supply. All vision processing runs locally on the host machine rather than streaming data to cloud services, which protects privacy and reduces unnecessary network traffic. Physical indicators like display animations, servo motion, and light vibration make feedback intuitive and accessible without depending solely on audio signals or screen space.

4.2 Engineering Standards

- **USB-IF (Universal Serial Bus Type-C Specification):** Followed for safe power sink negotiation using dual 5.1 k Ω pull-down resistors on the CC lines, allowing up to 3 A at 5 V over standard USB serial communication.
- **UL 62368-1 (Thermal & Electrical Safety):** Ensures the LDO voltage regulator operates at a safe calculated junction temperature (55.53°C), well below the 125°C thermal limit to prevent heat buildup inside the 3D-printed plastic housing.
- **ISO/IEC 27001 (Data Protection Guidelines):** Guided our local-only processing model so video frames are evaluated immediately in local memory and never saved or transmitted.

4.3 Code of Ethics & Ethical Considerations

Our design directly aligns with the **IEEE Code of Ethics (Section I, Point 1)** regarding user privacy and safety:

- **User Privacy:** Because webcam monitoring poses a privacy concern, all computer vision models run locally on the host PC. Frames are processed in RAM for presence detection and deleted immediately; no video or image data is ever logged, stored, or sent externally.
- **Constructive Feedback:** Feedback mechanisms are kept gentle and informative rather than punitive, avoiding intrusive monitoring or harsh alarms that cause stress.
- **Hardware Protection:** We incorporated dedicated flyback diodes and bulk capacitance on motor power lines to prevent inductive voltage spikes and overcurrent draw from damaging host hardware or internal components.

4.4 Hazards and Safety Concerns

- **Electrical Hazards:** Operating on 5 V USB power avoids high-voltage mains and battery safety concerns. Primary risks are motor inductive kickback and current surges during servo stall (up to 800 mA), which can cause voltage droop or component stress if unmitigated.
- **Mechanical Hazards:** The moving servo tail presents minor pinch risks at the pivot point during operation.
- **Assembly Hazards:** Standard bench risks include soldering iron burn risks, solder fumes, and isopropyl alcohol handling during PCB cleaning.

4.5 Safety Mitigation & Procedures

- **Circuit Protections:** A 1N4148 flyback diode across the vibration motor clamps inductive spikes. A 470 μF decoupling capacitor sits near the power header to absorb motor current spikes, keeping the 5 V rail above 4.5 V during stalls. Dual 5.1 k Ω CC resistors ensure standard USB power draw.

- **Thermal Safety:** Thermal calculations verify that the 3.3 V LDO stays around 55.5°C under full display and MCU load, keeping it nearly 70°C below its shutdown limit.
- **Mechanical & Bench Safety:** Moving servo components are enclosed within the plush outer casing to prevent accidental contact. Board assembly and soldering take place in well-ventilated labs using fume extractors.

5. Citations

1. STMicroelectronics, *STM32F103C8T6 ARM Cortex-M3 Microcontroller Datasheet*
2. Advanced Monolithic Systems, *AMS1117 Low Dropout Voltage Regulator Datasheet*
3. Hitec RCD, *HS-311 Standard Servo Specifications*
4. SparkFun Electronics, *HC-SR04 Ultrasonic Sensor Datasheet*
5. Ilitek, *ILI9488 a-Si TFT LCD Single Chip Driver Datasheet*
6. IEEE, "IEEE Code of Ethics," IEEE Policy 7.8. [Online]. Available:
<https://www.ieee.org/about/corporate/governance/p7-8>