Project Proposal

1. Introduction

- **Project Title:** Portable Automated Macro-Stitching Film Digitizer
- **Team Number:** 23
- **Team Members:** Guyan Wang, Yuhong Chen
- **TA:** Gerasimos Gerogiannis
- **Instructor:** Viktor Gruev

Problem and Background

The resurgence of analog photography has created a technological gap: capturing images on film is desirable for its aesthetic, but digitizing them for online distribution is inefficient. Enthusiasts currently face a "trilemma": professional drum scanners are prohibitively expensive and bulky; flatbed scanners are slow and lack resolution for small formats; and "DSLR scanning" requires complex, non-portable setups involving copy stands and precise alignment. There is currently no portable, standalone device capable of automatically digitizing multiple film formats (35mm and 120 Medium Format) into high-resolution images without a tethered PC.

Solution

We propose a **Portable Automated Film Digitizer** contained within a compact 15cm * 15cm * 20cm enclosure. Unlike traditional scanners that use a linear line-scan sensor, our solution utilizes a **"Macro-Stitching" technique**. The system employs a Raspberry Pi High Quality Camera with a 25mm macro lens setup to capture multiple high-fidelity sub-images of the film.

The film carrier is mounted on a repurposed **Gaertner precision X-Y linear stage**, which has been motorized using modified **Hitec HS-318 servos**. An **STM32F446RE** microcontroller coordinates the motion and lighting, while a **Raspberry Pi 4** handles image capture and uses OpenCV algorithms to stitch the sub-images into a single 4K+ resolution photograph. This hybrid approach achieves professional archival quality in a portable form factor.

Visual Aid Description: *A vertical "tower" design with a footprint of 15 cm * 15 cm. The base contains the battery and power PCB. The Gaertner X-Y stage sits above the electronics, holding the film carrier. The Raspberry Pi HQ camera is mounted to the "ceiling" of the box (20cm height), facing downward. The mechanism moves the film underneath the fixed camera lens.*

High-Level Requirements

1. **Resolution & Stitching:** The system must produce a final stitched image with a minimum resolution of **3840x2160 (4K)** by autonomously moving the film stage to capture and stitch at least 4 overlapping macro frames with a stitching alignment error of less than 5 pixels.
2. **Compact Portability:** The complete device (including battery, optics, and mechanics) must fit within a physical volume of **15cm (L) * 15cm (W) * 20cm (H)** and weigh less than 1.5kg to ensure portability.
3. **Automation Speed:** The system must complete the full cycle of auto-exposure, X-Y scanning motion, image capture, and software stitching for a single frame in under **30 seconds** without human intervention.

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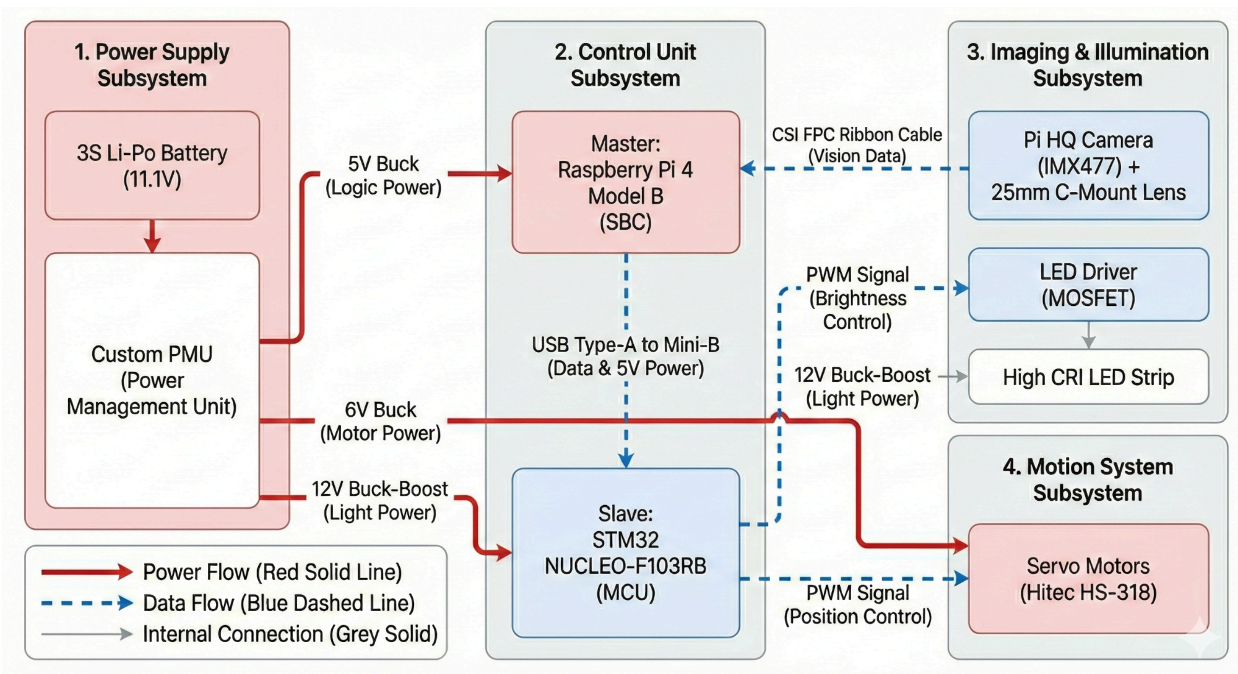
2. Design

Block Diagram



Subsystem Descriptions

1. Power Supply Unit (PMU): This subsystem manages energy distribution from a **3S Li-Po battery (11.1V)**. We utilize a **star topology** design to isolate noisy motor loads from sensitive logic.

- **Input:** 11.1V Battery via XT60 connector with a BMS for safety.

- **Outputs:**
    - **5V Rail:** High-current Buck converter (3A+) to power the Raspberry Pi 4.
    - **6V Rail:** Independent Buck converter to power the modified HS-318 servos, preventing voltage sag on logic lines during motor stalls.
    - **12V Rail:** Buck-Boost converter to drive the high-CRI LED backlight, ensuring flicker-free constant voltage regardless of battery level.

2. Motion System (Actuators): This subsystem is responsible for the precise positioning of the film negative relative to the fixed camera.

- **Hardware:** We utilize a **Gaertner X-Y Precision Translation Stage** which provides industrial-grade stability and linearity.
- **Actuation:** Two **Hitec HS-318 Standard Servos** are mechanically modified for **continuous rotation** (internal potentiometer and physical stops removed). These are coupled directly to the stage's micrometer knobs via custom 3D-printed couplers.
- **Control:** The STM32 drives these servos in an open-loop configuration (time-based movement) to perform the scanning grid pattern required for stitching.

3. Imaging & Illumination:

- **Camera: Raspberry Pi High Quality Camera (IMX477)** connected via CSI cable.
- **Optics:** A **25mm f/1.4 C-Mount Lens** combined with a **10mm extension tube** is used to achieve a macro field of view (15mm * 11mm) at a working distance of 8.5cm. This fits vertically within the 20cm height limit.
- **Lighting:** A custom LED backlight array (CRI >95) provides illumination. Brightness is controlled via PWM from the STM32 to accommodate different film densities.

4. Control Unit (Microprocessors):

- **STM32F446RE:** Acts as the real-time hardware controller. It handles PWM generation for the servos and LEDs. It receives high-level commands (e.g., "Move to Position A") from the Pi via UART.
- **Raspberry Pi 4B:** Acts as the master computer. It handles the User Interface, triggers the camera via `libcamera`, and executes the Python/OpenCV script to stitch the captured images into a final 4K panorama.

Subsystem Requirements

- **Power Supply:**

    - Must provide stable 5.0V - 0.2V to the Raspberry Pi under full load (CPU + Camera active).
    - Must provide 12V output with <50mV ripple to LEDs to prevent "banding" in the rolling shutter camera.

- **Motion System:**

    - The Gaertner stage driven by HS-318 servos must achieve a linear travel distance of **50mm** in both X and Y directions to cover a 6x4.5cm medium format negative.
    - The system must hold the film stationary for 200ms during capture with zero vibration drift.
- **Imaging System:**

    - The optical setup must achieve a focus working distance between **8cm and 10cm** to fit within the Z-axis enclosure limit.
    - The camera must capture RAW Bayer data to allow for software inversion of color negatives.

Risk Analysis

The most difficult part of the design is the **Motion Control of the Modified Servos**. By modifying standard HS-318 servos for continuous rotation, we lose the internal position feedback (closed-loop control). We are effectively turning them into DC gear motors.

- **Risk:** The STM32 may not know *exactly* where the stage is, leading to insufficient overlap for the stitching algorithm.
- **Mitigation:** We will implement a "Time-vs-Distance" calibration routine. Since the Gaertner stage has a fixed screw pitch (linear distance per rotation) and the servos have a consistent speed at a fixed voltage, we will map "PWM Duration" to "Millimeters Moved". If drift is too high, we will add simple limit switches to the stage ends for "Homing" before every scan.

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3. Societal Impact, Engineering Standards, Ethics, and Safety

Societal Impact

This project democratizes the preservation of analog history. By lowering the cost and complexity of high-resolution film scanning, we allow families to archive historical negatives and artists to share work without relying on environmentally hazardous chemical printing or expensive labs.

Engineering Standards

- **IEEE 802.11 (Wi-Fi):** The Raspberry Pi 4 utilizes Wi-Fi for file transfer; we will ensure compliance with regional spectrum regulations by using standard certified modules.
- **USB 2.0/3.0 Standards:** The interface between the STM32 and Pi (power) and external connections adheres to USB voltage and current specifications.
- **JPEG/TIFF Standards:** The output files will adhere to ISO/IEC 10918-1 (JPEG) to ensure compatibility with all modern viewing devices.

Ethics

We adhere to the **IEEE Code of Ethics**, specifically:

- *Clause 1 (Safety):* We prioritize user safety regarding the lithium battery design.
- *Clause 7 (Credit):* We acknowledge the use of open-source libraries (OpenCV, Libcamera) and will not claim them as our own work.
- *Ethical Concern:* Digitization allows for rapid copying of copyrighted photographs. While we cannot prevent misuse, we will include notices in our documentation advising users to digitize only content they own or have permission to use.

Safety

- **Lithium Battery Safety:** 3S Li-Po batteries present a fire risk if overcharged or shorted. We will integrate a BMS (Battery Management System) to monitor voltage and current, and use a dedicated fuse on the Power PCB input.
- **Mechanical Pinch Points:** The motorized X-Y stage creates pinch points. We will enclose the mechanism in the "black box" housing, ensuring no moving parts are accessible during operation.
- **LED Eye Safety:** High-intensity LEDs are used. The device is designed to be a closed optical system (light tight box), preventing user exposure to high-brightness glare.

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4. Citations and References

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STMicroelectronics, "UM1724: STM32 Nucleo-64 boards (MB1136)," *User Manual*, Rev 17, 2024.

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