ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Automatic Page-Turing Photocopier

Team #4

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1 Introduction

1.1 Objective

This project aims to revolutionize document scanning by addressing the inefficiencies of traditional photocopiers when handling bound materials, which typically require manual page-turning, leading to slower processing times, increased labor costs, and human error due to fatigue. By developing an automatic page-turning photocopier, we seek to eliminate manual intervention, enhance accuracy, and preserve delicate materials—such as antique books and blueprints—through gentle robotic handling. Additionally, our compact and cost-effective solution improves accessibility while enabling seamless digitization by capturing high-quality images and converting text into editable digital formats. Ultimately, this innovation will save time, reduce manual effort, and minimize wear-and-tear, benefiting industries ranging from libraries and archives to engineering firms and offices.

1.2 Background

Traditional photocopiers designed for bound materials, such as books or manuals, often require manual page turning, leading to inefficiency and user fatigue. Repetitive handling can also result in human error and potential damage to delicate materials like antique books or blueprints. To address these challenges, an automated solution is needed to streamline the scanning process while ensuring precision and care for various document types.

1.3 High-Level Requirements List

- The system must complete a single page-turning cycle within 20 seconds. This is measured from the moment a page is detected to the successful completion of the page flip. The efficiency of the automatic page-turning photocopier will be evaluated by averaging the time taken over 100 consecutive operations.
- This photocopier is required to produce scanned images with no significant shadows or reflections. This will be assessed by evaluating the page area affected by such artifacts under standard testing conditions.
- The robotic arm must be capable of handling documents with varying binding types and thicknesses (ranging from 0.05 to 0.5 mm per sheet). Its performance will be validated by ensuring successful handling of $\geq 95\%$ of bound materials without causing tearing or misalignment during operation.

2 Design

To achieve the function, four subsystems are required in the whole design. These subsystems are power supply, page-turning module, photocopying module and control and interface module. The power supply part connects the other three modules and provide power with proper voltage. The page-turning module consists mechanism with three DOF and can automatically turn pages. The photocopying module equipped with a high-resolution camera, and can process clear and detailed images of each page. The control and interface module allow users to input commands such as page settings and can display processed images.

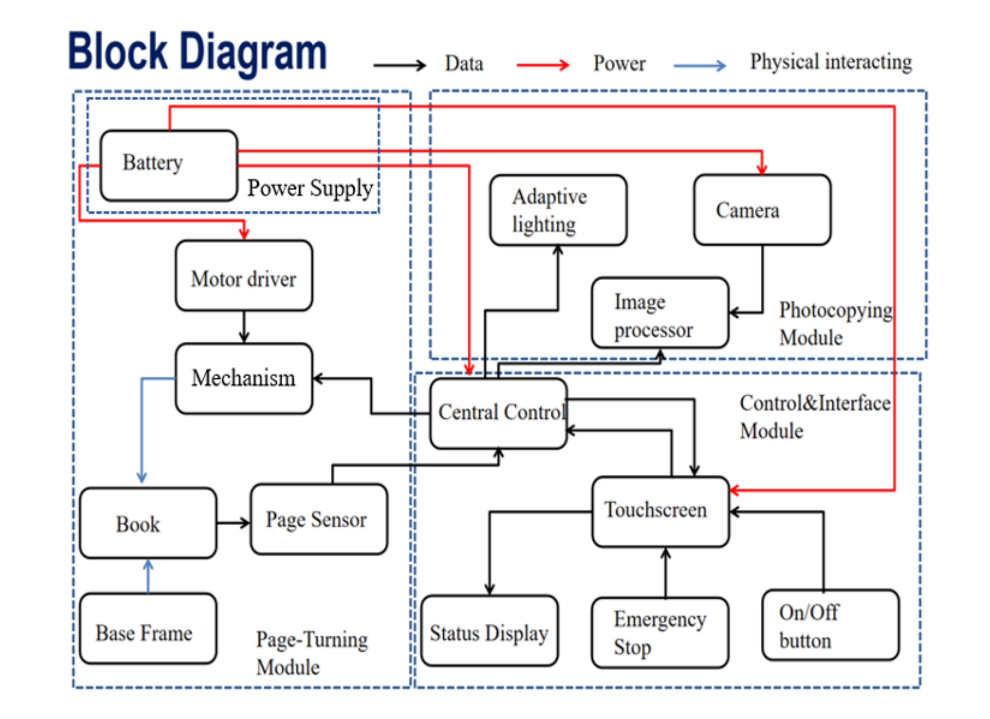

Figure 1: Block Diagram

The physical design shows the whole page-turning mechanism and the camera. The area of the page-turning part is 40cm, and the maximum height is about 60cm which is the height of the camera. For most of the parts, standard parts are used. And the aluminum profile is used to build the base which connect all assembly parts.

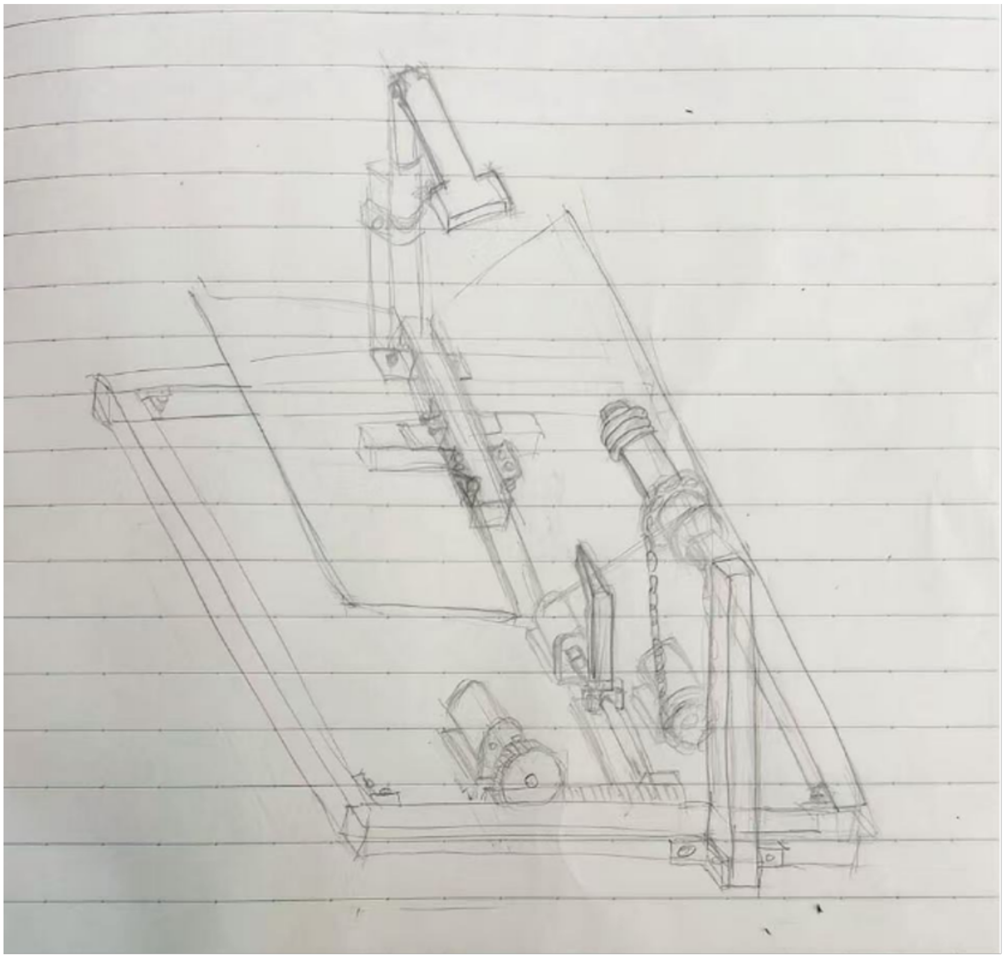

Figure 2: Physical Design Sketch

2.1 Page-Turning Module

The page-turning module consists of mechanism with three DOF and can automatically turn pages. Three motors are powered by the power supply and the speed is controlled by the PWM signal.

2.1.1 Mechanism

The page-turning mechanism consists of two main subsystems: Page Separation and Page Turning mechanism. For page separation system, a motor-driven roller system employs a chain transmission to rotate a cylindrical drum. The rotation creates friction between the drum surface and the target page, enabling controlled curling and separation from adjacent pages through this frictional engagement. For page turning mechanism, it is a 2 DOF structure, a lead screw drives the mechanism move forward to insert its tip into the created inter-page gap. Moreover, via a rack-and-pinion system, the mechanism enables lateral movement across the book plane, completing the page flipping motion by carrying the separated page to the opposite side. The coordinated operation between these two electromechanical systems enables full-page turning automation through sequential page separation and guided translocation.

Requirements	Verifications
1. The drum must reliably separate individual pages via friction without adjacent page interference. 2. Achieve $\geq 95\%$ success rate over 100 consecutive cycles (≤ 5 failures). And it should have material compatibility, supporting diverse paper type. 3. The time cost should be as short as possible.	1. Use camera to record drum-paper interaction process. Quantify multi-page pickup rate. 2. Conduct 200-cycle tests on more than 5 types of papers and record the success rate. 3. Record full page-turning cycles (separation to completion) which take no more than 3 seconds. Adjust the speed of motors to make efficient page-turning cycle.

2.1.2 Base Frame

Base Frame is constructed with aluminum profiles to form a rectangular foundation frame, providing rigidity and lightweight support. And the book platform consists of two large acrylic sheets ($\geq A3size$) connected via hinges, enabling angular adjustment which is designed to prevent text distortion/occlusion through optimal plane alignment. Adaptive Supporter for camera is assembled on rectangular foundation frame.

Requirements	Verifications
1. Telescopic rod must enable vertical (200–800 mm) adjustments with ±2 mm repeatability. interference. 2. The book platform must support $\leq 2kg$ static load without deformation.	1. Put books with diverse size on the book platform adjust the angle of hinge to prevent page distortion and occlusion. Conduct vertical adjustments to make the full range of book could be captured. 2. Put books with diverse weight (0.1-2 kg) on book platform for 24 hours. Measure deformation of component which supports the book platform via laser scanning.

2.1.3 Page Sensor

Infrared (IR) emitter-receiver pairs are mounted on the book platform, aligned perpendicular to the page edge trajectory. When a page passes through the sensing zone during turning, the page either occludes the IR beam or enters the proximity range (for translucent pages), altering reflected IR intensity. This induces a resistive change in the phototransistor receiver, modulating the output voltage signal to detect the success of page turning.

Requirements	Verifications
1. Correctly identify page-turning events with $\leq$ 2% false positives (non-page triggers) and $\leq 1\%$ missed detections. 2. Voltage signal transition 10–90% must complete within $\leq$ $10ms$ after page interruption.	1. Test whether the system can judge page turning from output signal of page sensor and conduct 100 times page turns (varying speed/angle) and record detection results system judges. 2. Conduct multiple times page turning process and record the process with high-speed camera. Use an oscilloscope to capture signal rise/fall times during controlled page interruptions.

2.1.4 Motor Driver

The motor drivers are responsible for controlling the page separating and page turning actuators. It consists of two independent driver circuits: the CCM2 PWM speed controller for the page separating motor, and the L298N dual H-bridge driver for the page turning motors. The CCM2 receives a PWM signal from STM32F407 one channel of Timer 3 to control the speed of a DC motor operating in one direction only. The L298N, on the other hand, drives two DC page turning motors with bidirectional control via GPIO signals for direction selection and PWM signals from two channels of Timer 4 for speed modulation.

Requirements	Verifications
1. The page separating motor must operate directionally with adjustable speed between 0–100% duty cycle. 2. The page turning motors must support both forward and reverse rotation with independent PWM-based speed control. 3. The control signals (PWM and GPIO) must be isolated and reliable, with $\leq$ $5ms$ response delay.	1. Measure PWM duty cycle output and confirm it varies with user input 0–100% via oscilloscope. 2. Observe motor behavior and confirm that direction switching is responsive within 5 ms of GPIO signal change.

2.2 Photocopying Module

The page-turning module consists mechanism with three DOF and can automatically turn pages. Three motors are powered by the power supply and the speed is controlled by the PWM signal.

2.2.1 Image Processor

The Image Processor receives high-resolution images via USB from the Camera and performs critical functions to ensure photocopy quality: page dewarping, noise reduction, contrast adjustment, and OCR. Processed images are sent to the Central Control Module for display or storage. The subsystem interfaces with the Camera (USB 2.0/3.0 at 480 Mbps/5 Gbps), Control & Interface Module (real-time status updates), and Photocopying Module (output validation).

Requirements	**Verifications**
1. Processing time: $\leq$3 seconds per page at 300 DPI. 2. Dewarping accuracy: Flatten pages to $\leq \pm$1.5mm deviation from a flat plane with $\leq 2°$ skew. 3. OCR accuracy (if enabled): $\geq$ 95% character accuracy for 12pt fonts.	1. Record the processing time for 10 pages and check the processing time. 2. Scan a book page with a 1.5mm grid overlay and verify skew via software (e.g., OpenCV's HoughLines). 3. Process 10 pages with mixed fonts. Compare OCR output (Tesseract) to ground-truth text using difflib.

2.2.2 Camera

The camera module utilizes an OV5640 CMOS sensor to capture high-resolution images (up to 5MP) of book pages after each successful flip. The camera interfaces with the STM32F407 via its DCMI for image acquisition, and image data is then transmitted to a PC via UART over CH340 USB-to-Serial converter. The UART link ensures lightweight, stable communication for image file transfer at a reasonable frame rate, considering the limited onboard memory of the microcontroller. This setup offloads image storage and processing to the host computer, reducing system complexity while maintaining scan quality. The OV5640 is chosen for its autofocus capability, high resolution, and compatibility with STM32F4 DCMI.

Requirements	Verifications
1. The camera must capture images with minimum resolution of 1280×720 pixels. 2. Image data must be transferred over UART to PC at ≥ 115200 bps without frame corruption. 3. The capture process must synchronize with page turning completion, with trigger latency ≤ 10 ms.	1. Test image resolution by saving sample frames from the camera and verifying pixel dimensions. 2. Measure UART transmission time and confirm correct image reception via checksum validation on PC. 3. Perform 50 consecutive capture-transfer cycles and confirm success rate $>$98% with no data loss or corruption.

2.3 Control & Interface Module

The control & interface module allow users to input commands such as page settings and can display processed images. The module is powered by power supply and can transfer signals with other modules. The page turning information determines the number of times the page turning mechanism is repeated, and it can show the stored image from the photocopying module.

2.3.1 screen

The Touchscreen serves as the primary user interface, providing real-time system status and accepting user inputs (on/off, emergency stop). The Touchscreen interfaces with the Control Module, displaying processed images from the Image Processor.

Requirements	Verifications
1. User Input Registration: Accurately detect On/Off and Emergency Stop touches within $\leq$500ms latency. 2. Latency: Update status information within $\leq$1s of system changes.	1. Simulate 10 On/Off and Emergency Stop touches to check the functionalities and measure the response time. 2. Time display updates when triggering system status changes.

2.3.2 Emergency Stop

The emergency stop button is implemented via a physical push-button switch connected to a GPIO pin on the PCB, configured to trigger an external interrupt (EXTI). When pressed, the button generates an interrupt signal, invoking an ISR (Interrupt Service Routine) that immediately disables all motor PWM outputs and stops ongoing processes such as page turning or scanning. The button operates under active-low logic, with internal pull-up enabled on the microcontroller input.

Requirements	Verifications
1. Emergency stop must trigger an interrupt. 2. The button must be debounced to avoid false triggers (mechanical bounce ≤ 10 ms). 3. The system must remain halted until a manual reset or power cycle is performed.	1. Simulate emergency stop during various operation states (idle, flipping, scanning) and verify system halts immediately and consistently.

2.4 Power Supply

The power supply module provides regulated and isolated power to both control electronics and high-current actuators. For the control system, the PCB board is powered via 5V USB input from the PC, through the CH340 USB-to-serial interface. 5V is passed to the board's onboard low dropout (LDO) regulator to generate 3.3V for the microcontroller and its peripherals. During firmware programming, the board can alternatively be powered by the programmer, which supports both 5V and 3.3V logic levels. For the motor drivers, a dedicated 12V/10A DC power supply is used. It converts standard 220V AC mains input to 12V DC output, sufficient to drive the CCM2 and L298N modules and their connected motors. The motor power circuit is electrically isolated from the microcontroller power domain to prevent noise and voltage fluctuations from affecting system stability.

2.5 Tolerance Analysis

One significant tolerance we need consider is the page friction problem. Since our goal is that only one page can be turned at one time, we should make sure that the mechanism structure meets this requirement. Based on the free body diagram, we can list equations below:

$$N_1 = mgcos(\theta) + Fcos(\theta) \tag{1}$$

$$f_r = \mu_r N_1 + Fcos \tag{2}$$

$$N_2 = mgcos(\theta) + N_1 \tag{3}$$

$$f_{p1} = \mu_p N_2 \tag{4}$$

$$N_3 = mgcos(\theta) + N_2 \tag{5}$$

$$f_{p2} = \mu_p N_3 frac \tag{6}$$

Where:
θ is the angle between the book supporter and the ground;
μ_1 is the friction coefficient between a page and the silicone ring;
μ_2 is the friction coefficient between adjacent pages;
m is the mass of one page, $m = 3.52\,\mathrm{g}$;
g is the gravitational acceleration, $g = 9.81\,\mathrm{m/s^2}$;
λ is the proportion of the contact area between two adjacent sheets of paper;
F is the force applied by the silicone ring.

To make sure the first page can be motivated, we have this relationship:

$$f_r > f_{p1} - mgcos(\theta) + F_p - Fsin(\theta) \tag{7}$$

Where F_p is the force required to bend the page, F_p = 0.0205N. And to make sure the other pages stays unmoved, we have this relationship:

$$f_{p1} > f_{p2} - mgsin(\theta) + F_p \tag{8}$$

The range of F and frac can be obtained by varying the value of . Thus, the proportion of the contact area between two adjacent sheets of paper should be greater than 80%. For most common cases, we assume the average proportion value is 0.9. Then we can get the range of force that 0.0739N $\leq F \leq 0.1N$. In this case, The force range is 0.09N +/-0.01N (+/-11%). In conclusion, the tolerance for the force acting on page is 11%.

2.6 Schematics

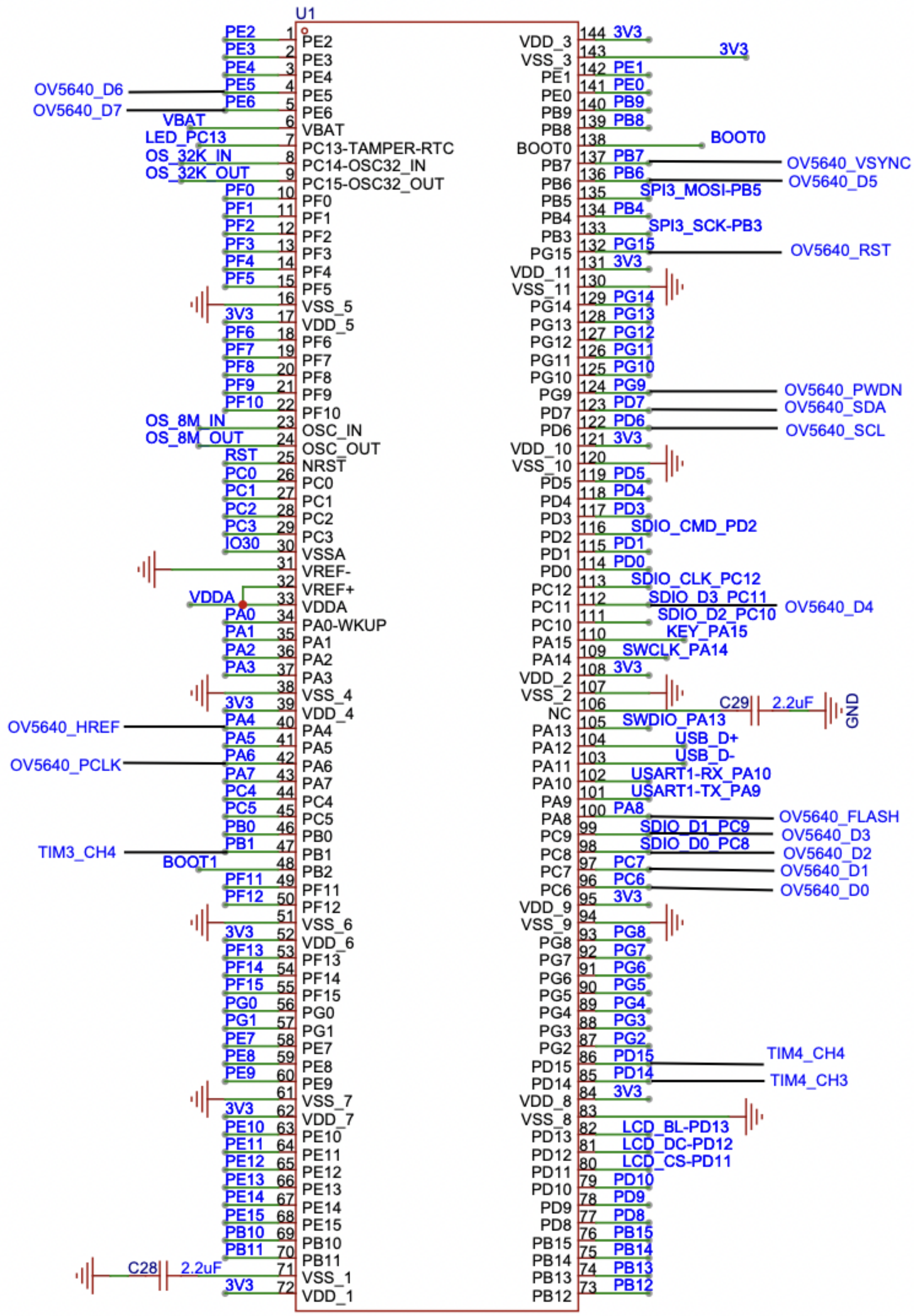

Figure 3: Control Module Schematic

2.7 Board Layout

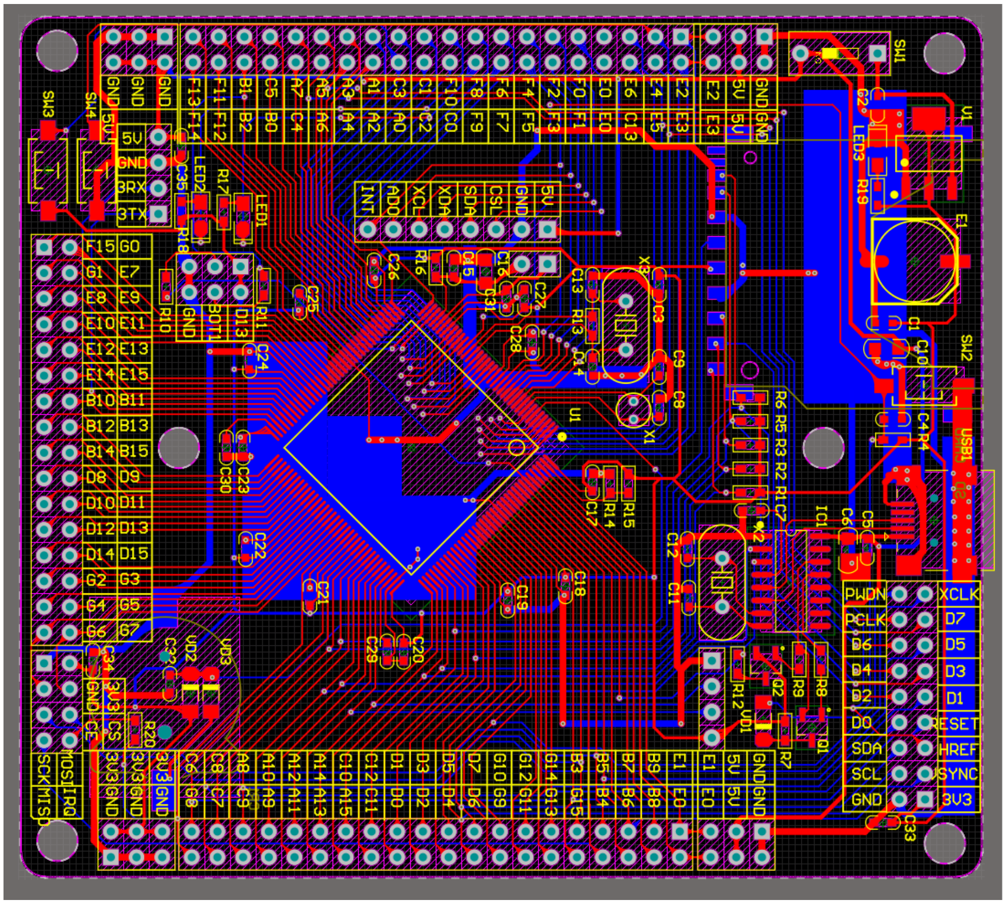

Figure 4: PCB Layout

3 Costs

The labor cost is estimated as ¥24/hour and 5 hours per week for 2 person. The overall working weeks for the final design is considered as 14 weeks.

$$Cost_{manual} = 2 \times 24 \times 5 \times 14 = ¥3460$$

Table 1: Components Price List

Part	**Description**	**Price (¥)**	**Qty**	**Total (¥)**
JGB37-520 motor	12V,66r/min	25.00	3	75.00
power supply	220V to 12V	37.00	1	37.00
hinge	JY263AL-B	11.50	2	23.00
Bolt and nut	M5	0.27	20	5.40
Bracket	M5,2020	1.30	15	19.50
hollow cylinder	$\phi 25, 1m$	10.56	0.2	2.11
Elastic ring	Silica gel	4.40	1	4.40
screw rod	100mm	294.00	1	294.00
bearing	–	2.75	2	5.50
gear chain	–	53.00	1	53.00
Aluminum profile	2020	14.00	6	84.00
connector	3D printing	0.49	5	2.45
Acric supporter	laser cutting	1.50	1	1.50
camera supporter	–	29.00	1	29.00
camera	OV5640	59.00	1	59.00
controller	TB6612FNG	7.47	1	7.47
ST-LINK chip	–	12.69	1	12.69
STM32 Board	F407ZGT6	53.61	1	53.61
			Grand Total	**768.63**

So for our prototype building, the overall cost is estimated to be ¥ 4228.63. If our design products are put into the market and mass manufactured, the labor cost can be reduced to one percent of the original. Thus, the total cost for one product is ¥ 803.23.

4 Schedule

Week	Yingying Gao	Yiying Lyu	Xuan Zhu	Shuchang Dong
2/24/25	RFA writing	RFA writing	RFA writing	RFA writing
3/3/25	Read relative paper and search similar products and design page-turning mechanism CAD model	Read relative paper and search similar products and design page-turning mechanism CAD model	Searching relative paper and get familiar with professional software for PCB design	Searching and learning image processing technology
3/10/25	Doing PCB design exercise Discussion and Project Proposal writing	Doing PCB design exercise Discussion and Project Proposal writing	Doing PCB design exercise Discussion and Project Proposal writing	Doing PCB design exercise Discussion and Project Proposal writing
3/17/25	Conduct experiments to verify the feasibility of page-turning mechanism.	Conduct experiments to verify the feasibility of page-turning mechanism.	Select suitable Microcontrollers and doing experiments on the microcontroller	Doing experiments on image processing
3/24/25	Purchase the aluminum profile and other materials assemble the base frame	3D printing the component we made and assemble the base frame	Conducting experiments on firmware flashing	Doing experiment on different filters on image processing, like Laplacian, Gaussian Blur
3/31/25	Assemble the base frame and camera holder	Assemble the base frame and camera holder. Purchase LED strips and a power supply	Doing experiments on controlling the speed and rotation orientation of motors	Doing experiments on dewarping
4/7/25	Design document writing	Design document writing	Design document writing	Design document writing
4/14/25	Realize the basic function of page turning mechanism	Assemble the camera and adjust its position to ensure the shooting range is appropriate.	Complete the firmware flashing of the microcontroller that controls the camera.	Modify the algorithm to improve the clarity of the text after image processing
4/21/25	Doing experiments on the stability and efficiency of the page-turning mechanism	Modify the CAD model based on the problem exists and prepare for the second prototype	Complete the design and fabrication of the first version of the PCB.	Improve the scanning clarity for complex cases, such as handwritten text.
4/28/25	Conduct experiments on the second	Conduct experiments on the second	Optimize and modify the design based on the first	Conduct experiments on the clarity of

	version of the prototype to test the success rate and efficiency of the page-turning function.	version of the prototype to test the success rate and efficiency of the page-turning function.	version of the PCB, and fabricate the second version of the PCB.	image processing under different environmental conditions, such as varying brightness.
5/5/25	Complete the integration of the page-turning module and the image processing module.	Complete the integration of the page-turning module and the image processing module.	Complete the integration of the page-turning module and the image processing module.	Complete the integration of the page-turning module and the image processing module.
5/12/25	Add the interface module and conduct experiment	Conduct the experiments and record the problems exist	work and bugfix on data transmission protocol	Design and build the interface module
5/19/25	Doing environment test	Doing environment test	Doing environment test	Doing environment test
5/26/25	Prepare final presentation and finish the final report	Prepare final presentation and finish the final report	Prepare final presentation and finish the final report	Prepare final presentation and finish the final report

5 Ethics and Safety

According to the IEEE Ethics Framework[1], the design needs to have human well-being at its core. Data privacy should be considered in terms of human rights and privacy protection. Scanners may process sensitive documents, such as personal documents, files, etc., and ensure that data collection, storage, and transmission are encrypted to prevent unauthorized access or disclosure. For example, the scanned file must be protected by an encryption algorithm, and the cache of the storage media must be periodically cleared. The functions, data uses and potential risks of the equipment need to be informed to the user in advance to ensure that the user agrees with the operation process.

Responsibility and accountability need to clarify the subject of responsibility. Define the responsibilities of the manufacturer, operator, or maintainer if a device failure results in document damage or data disclosure. Device operation logs are recorded to facilitate fault tracing.

The environmental and sustainability aspect is to choose to use recyclable or low environmental impact materials and reduce e-waste. Increase the efficiency ratio of the motor drive system and save energy.

Physical safety is limited in the design of mechanical structures to ensure that the operator's body is not harmed. The motor drive parts need to be equipped with protective covers to prevent the user from physical damage caused by contact with moving parts such as gears or chains. At the same time, the page turning mechanism should limit the maximum pressure to avoid damage to the fragile paper or paper jam resulting in mechanical failure. In addition, it is also necessary to set an emergency stop button to deal with sudden failures.

Data security is related to ethics, mainly the protection of data content. The built-in storage device must support encryption to prevent data from being illegally extracted. When a device is uploaded to a network, configure a firewall and update firmware periodically to defend agains

Reference

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[2] “page-dewarp,” PyPI, Feb. 13, 2025. https://pypi.org/project/page-dewarp/

[3] Lmmx, “GitHub - lmmx/page-dewarp: Document image dewarping library using a cubic sheet model,” GitHub. https://github.com/lmmx/page-dewarp

[4] “Python Image Processing: Document Photo Scanning (Manually Building a Scanner) — Image Scanning Based on Python,” CSDN Blog https://blog.csdn.net/Mikumiku339/article/details/114766705