ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Automatic Page-Turing Photocopier

Team #4

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Abstract

This report introduces a photocopier system which can turn pages automatically. The system features a mechanical structure for precise page handling paired with a camera adaptive LED lighting to capture clear images and a user interface for real-time operation monitoring. It integrates subsystems including a page-turning mechanism ensuring single-page flipping within sixteen seconds, a photocopying unit optimized for varied paper textures through a control panel enabling preset commands and progress tracking. Success metrics focus on flawless single-page accuracy consistent cycle times and automatic shutdown post-task completion. Testing demonstrates the system efficiently processes bound and stapled materials while maintaining scan clarity and operational speed. This innovation cuts manual intervention with a success rate higher than 75 % and improves consistency in archival or bulk scanning tasks. Future enhancements will target scalability for materials in greater size and energy efficiency improvements.

Contents

1 Introduction

1.1 Background and Objective

Photocopiers are the most useful tool in our life, particularly in school, bookstore, library, etc. However, 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, such as 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 types of documents.

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 Block Description

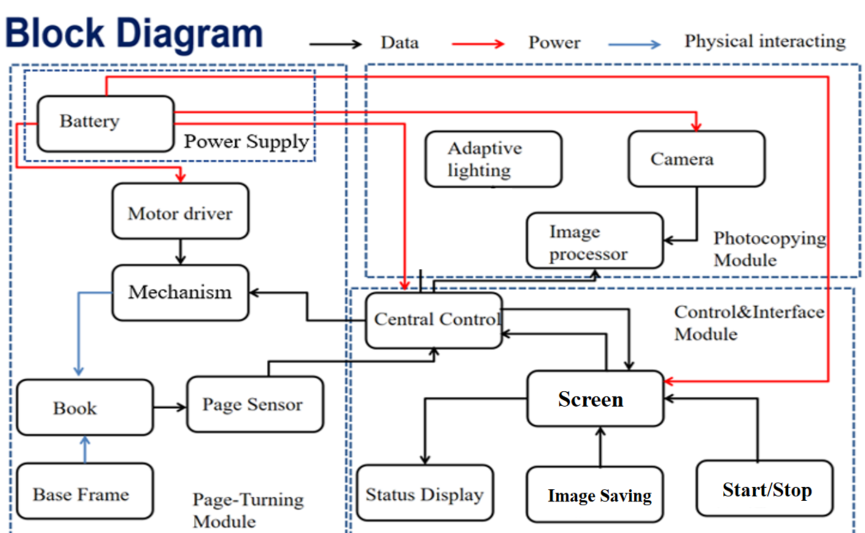


Figure 1: Block Diagram

To achieve the function, four subsystems are required in the whole design as illustrated in Figure 1.

- **Power Supply:** The power supply part connects the other three modules and provides power with proper voltage. 220 V for adaptive light, 3.3 V is provided to the microcontroller. the PCB board is powered via 5V USB input from the PC.
- **Page-turning Module:** The page-turning module consists of a mechanism with 3 DOF. One motor drives roller to separate the pages. One motor drives lead screw for linear motion. The another motor drives movement of rack-and-pinion
- **Photocopying Module:** The photocopying module is equipped with a high-resolution camera, and can process clear and detailed images of each page.
- **Control and Interface Module:** The control and interface module allows users to input commands such as page settings and can display processed images.

1.3 High-Level Requirements List

- The system must complete a single page-turning cycle within 16 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 10 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 mechanism must be capable of handling documents with varying binding types and thicknesses. Its performance will be validated by ensuring successful handling of $\geq 90\%$ of bound materials without causing tearing or misalignment during operation.

2 Design

2.1 Design Procedure

2.1.1 Page-Turning Mechanism

The reason we choose to use a pure mechanical structure instead of controlling the robotic arm is to reduce the volume and mass of the page-turning device in order to achieve the design advantages of a small footprint and portability. The joint motion of the mechanical structure controlled by three motors can be simulated and visualized in SolidWorks which is shown in the right part of figure 2. Using gear and chain to control the rotation of the roller is because it is convenient to fine-tune the relative position of the roller and the motor. Using a lead screw to control the advancement of the insert is because it can more precisely control the relative position to the paper surface. Using a gear and rack to control the left and right page turning of the insert is because it is faster.

2.1.2 Motor Driver

The initial design employs both CCM2 PWM speed controller and L298N dual H-bridge driver. While both types receive PWM signals from STM32F407 to control DC motor speed, the CCM2 driver requires manual operation on its switch to select its working status. In order to include all motors into our automatic procedure, we eventually employ two L298N drivers for one page-seperating motor and two page-turing motors, such that the motor performance can be monitored by the micro-controller.

2.1.3 Photoelectric Sensor

The detection system employs two types of optical sensors to ensure precise and reliable control over the page-turning process. The EX-13A, a normally-open through-beam photoelectric sensor, is used to detect successful page separation, after which, the STM32 immediately stops the page separating motor. Positioned at the page edge, it outputs a low-level signal when the light beam is interrupted by the passage of a page. Upon receiving this signal, the STM32 immediately stops the page separating motor, ensuring that only one page is processed at a time and preventing double-feed errors. The EX-14A, a normally-open diffuse reflective sensor, is mounted near the flipping motor to monitor its rotational position. It detects the presence of reflective surface elements or mechanical markers on the flipping arm, allowing the system to limit motor movement within a defined safe range.

By using optical sensors for real-time feedback instead of relying solely on fixed-duration motor activation, the system gains significant advantages in reliability and adaptability. Page thickness, friction, or mechanical load can vary across books or environments—conditions under which time-based control may lead to inconsistent flipping or misalignment. In contrast, photocoupler-based sensing ensures the system responds dynamically to actual physical states, reducing errors, improving precision, and enhancing system robustness.

2.1.4 Camera

For the camera, we selected a 3264×2448 resolution camera over lower-resolution alternatives such as 1920×1080 or 1280×1024. The primary reason for this decision was the application: capturing images of two pages of a book simultaneously. To ensure that the characters on both pages are clearly identifiable and legible, a high-resolution image is essential. Lower-resolution cameras would result in insufficient detail, making it difficult to recognize smaller text or characters, especially near the center or edges of the pages. Therefore, the higher-resolution camera was the most suitable choice to maintain the clarity and accuracy required for our application.

2.1.5 User Interface

For the user interface, we chose to implement a software-based UI using Qt. Alternative approaches considered included using a physical embedded touchscreen or implementing a web-based interface accessible via browser. While an embedded screen could provide a compact, all-in-one solution, it would significantly increase hardware complexity and cost. A web-based interface would introduce additional networking and browser compatibility concerns. Qt offers a flexible and visually rich framework for desktop applications, supports cross-platform development, and allows for rapid prototyping and customization. This made it an ideal choice for our project, as it enabled us to build an intuitive and responsive interface without the overhead of additional hardware or complex deployment setups.

2.2 Design Details

Based on the design procedure, we can then describe every part in detail and the specific requirements and verification points are listed in table 6.

2.2.1 Page-Turning Module

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.

Figure 2 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, we use standard components. The aluminum profile is used to build the base which connects all assembly parts.

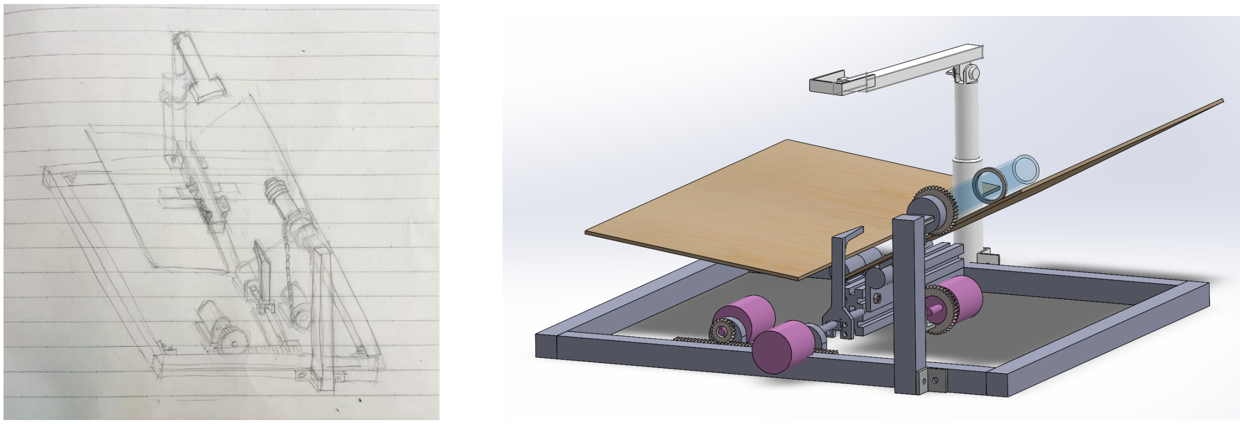


Figure 2: Mechanism Sketch

The number of motor revolutions required to move the lead screw by a certain distance is calculated as:

$$N = \frac{d}{L} = \frac{30mm}{1.2mm} = 25 \tag{1}$$

where d is the linear displacement of the lead screw, L is the lead of the screw (i.e., the distance the nut moves per revolution), and N is the number of motor revolutions.

The relationship between the linear displacement of the rack and the number of motor rotations is given by:

$$N = \frac{d}{2\pi r} = \frac{64.6mm}{2\pi * 15mm} = 0.685 \tag{2}$$

where d denotes the displacement of the linear motion, r represents the radius of the gear, and N indicates the number of rotations (cycles) driven by the motor.

The overall physical diagram of the page-turning part is shown in figure 3. It can be seen that the book placed on the base frame is very compatible with other mechanical structures.

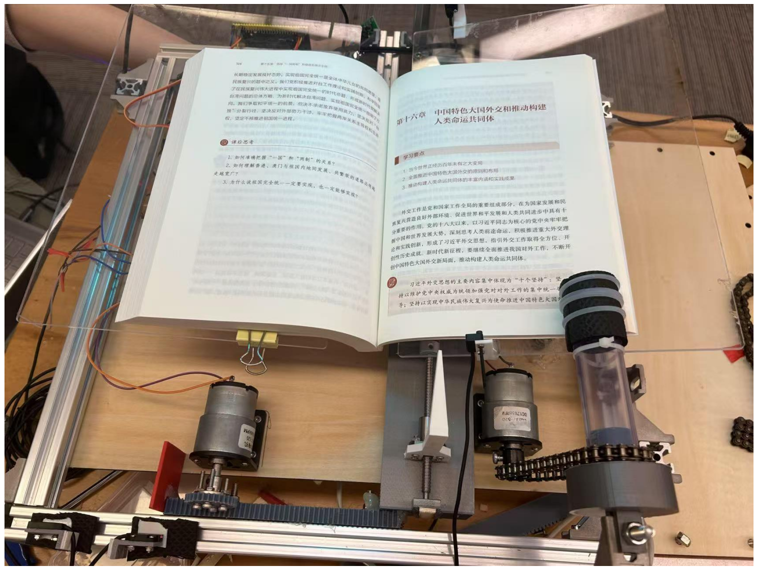


Figure 3: Physical diagram

Base Frame is constructed with aluminum profiles to form a rectangular foundation frame, providing rigidity and lightweight support. 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.

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.

The motor drivers are responsible for controlling the page separating and page turning actuators. In the project, three motors are controlled by two L298N dual H-bridge drivers. One L298N driver is capable of driving two 12V DC motors with bidirectional control via GPIO signals for direction selection and PWM signals from two channels of STM32F407 Timer for speed modulation.

2.2.2 Photocopying Module

The photocopying module is responsible for accurately reproducing the content of pages by capturing high-resolution images, processing them for clarity, and sending the final output. The Image Processor receives high-resolution images via USB from the Camera and performs critical functions to ensure photocopy quality: page dewarping, noise reduction, and contrast adjustment. 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).

2.2.3 Control & Interface Module

The control & interface module consists of a micro-controller and an user interface on PC.

The STM32F407 micro-controller serves as the central control unit, responsible for coordinating the operation of all functional modules, as shown in figure 12. First, it generates PWM signals and GPIO outputs to drive and regulate three DC motors through external driver circuits, which precisely controls the page separation and turning procedure. Second, it establishes UART-based serial communication with a host PC via the CH340 interface to interact with the user interface. Third, it processes digital input signals generated by optical sensors (EX-13A and EX-14A photoelectric switches) to detect the passage of paper during the flipping process and control the motion range of the page turning motors. Lastly, it utilizes external interrupt commands to invoke an ISR (Interrupt Service Routine) that immediately disables all motor PWM outputs and stops ongoing processes such as page turning or scanning.

The user interface is a desktop application designed using Qt, providing a clear and intuitive control panel for the photocopier and image processing system. It displays real-time system status updates—such as ”Ready,” ”Scanning,” or ”Processing”—and includes interactive buttons for starting and stopping both image capture and processing tasks. Users can easily trigger the photocopier to begin scanning pages and initiate the image processor to process the captured images. This integration of control and feedback in a single interface streamlines operation, improves usability, and eliminates the need for manual hardware interaction. The layout is clean and user-friendly, enabling efficient control of the complete workflow from capture to output. Figure 4 demonstrates the user interface layout.

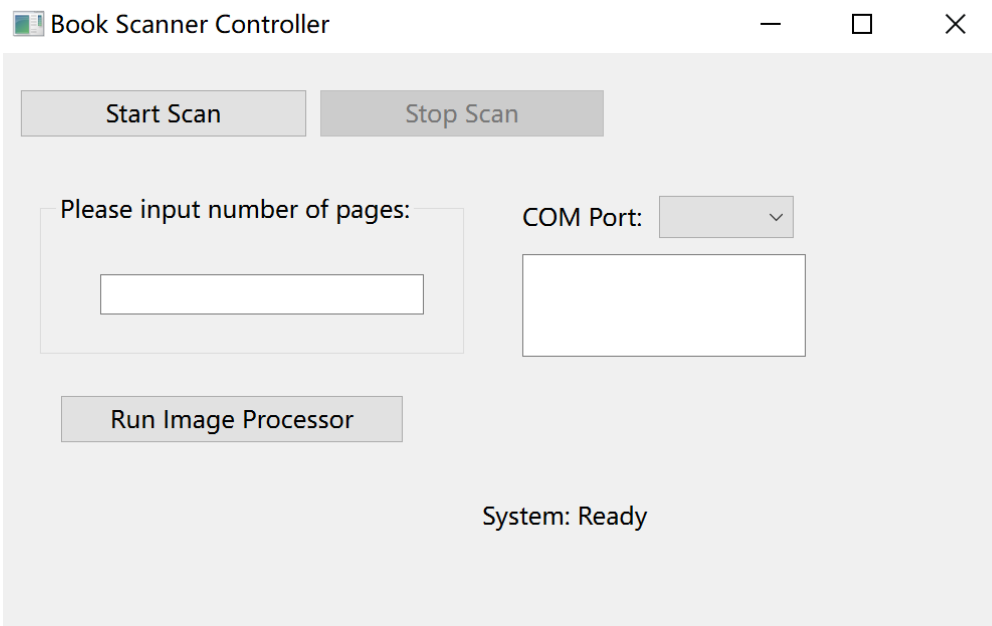


Figure 4: User Interface

2.2.4 Power Supply

The power supply module is divided into two coordinated sections: a low-voltage control circuit and a high-current actuator circuit.

The control section is powered via a 5V supply from the host PC through the CH340 USB-to-serial interface. This 5V input is regulated on the PCB by an onboard low-dropout voltage regulator to provide a stable 3.3V supply for the STM32F407 microcontroller and other low-power peripherals.

The motors and optical sensors are powered by a dedicated 12V DC power source, which is derived from a step-down transformer connected to a 220V AC power source.

Although the voltage domains are separated to ensure proper power distribution, both sections share a common ground to maintain signal integrity and ensure reliable logic-level interfacing between the STM32F407 and external devices.

2.3 Tolerance Analysis

One significant tolerance we need to 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:

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

$$f_r = \mu_r N_1 + Fcos \tag{4}$$

$$N_2 = mgcos(\theta) + N_1 \tag{5}$$

$$f_{p1} = \mu_p N_2 \tag{6}$$

$$N_3 = mgcos(\theta) + N_2 \tag{7}$$

$$f_{p2} = \mu_p N_3 frac \tag{8}$$

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:

$$f_r > f_{p1} - mgcos(\theta) + F_p - Fsin(\theta) \tag{9}$$

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

$$f_{p1} > f_{p2} - mgsin(\theta) + F_p \tag{10}$$

The range of F and frac can be obtained by varying the value of the other variables. 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 0.0739 N $\leq F \leq 0.1N$. In this case, the force range is 0.09 N +/-0.01 N (+/-11%). In conclusion, the tolerance for the force acting on a page is 11%.

3 Design Verification

3.1 Page-Turning Module

3.1.1 Mechanism

To verify the time required for each cycle of the page-flipping photocopying work, we used a camera to record multiple consecutive processes. By reading the start and end times of each stage, we can obtain the average time required for one cycle. Based on the video screenshots and time shown in figure 5, we have obtained that the average time required for one cycle of the page-flipping photocopying is 14 seconds.

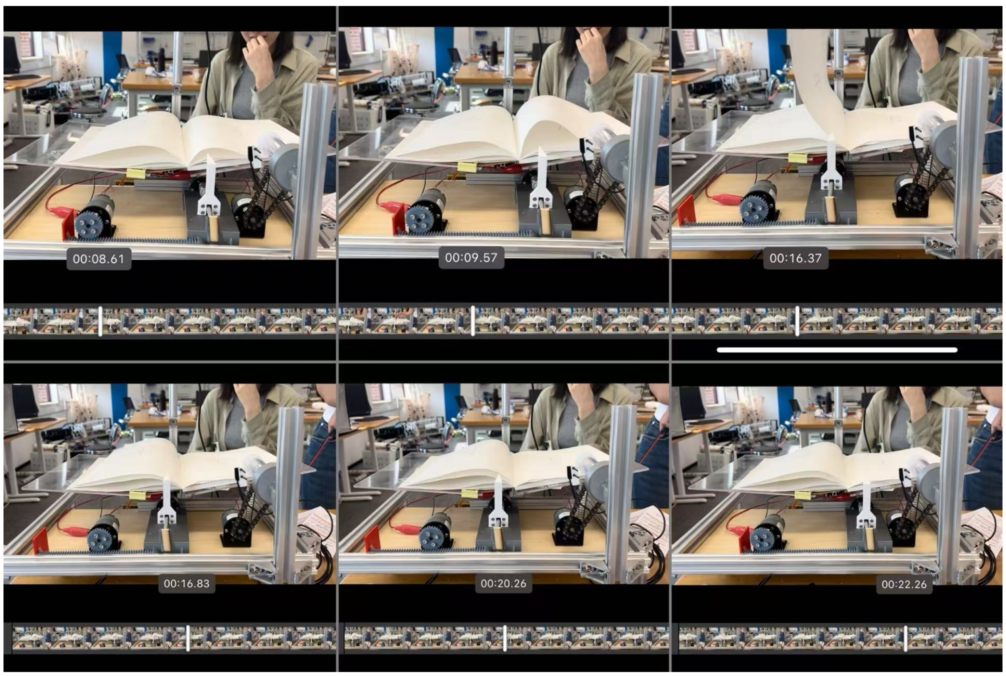


Figure 5: Whole Cycle with Time Label

For the B5-sized bound notebooks, we conducted a flipping test of four consecutive sets of five pages each, totaling 20 flips. Based on the average calculation, the ratio of the successfully flipped pages to the total number of flips is approximately 75 %. The successful flipping rate of the thicker bound books is also basically similar. When the roller comes into contact with the pages of the book, the problem of multiple pages being turned only occurs when turning the first page. This is due to the excessive pressure exerted by the roller on the page. This problem does not occur in the process of turning the subsequent pages.

3.1.2 Base Frame

We selected four types of bound materials with varying sizes and weights for testing. All four materials were able to avoid page distortion and occlusion by adjusting the hinge angle. In addition, we measured the deformation of the planar support rod, as well as the change in the inclined surface angle under prolonged maximum load conditions (i.e., the gravitational force of each bound material). Table 1 reflects the degree error for four different types of materials.

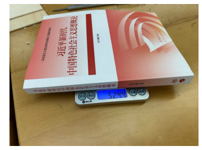
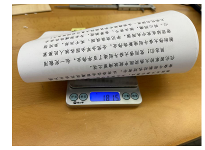
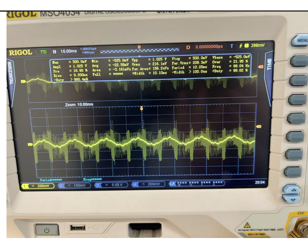
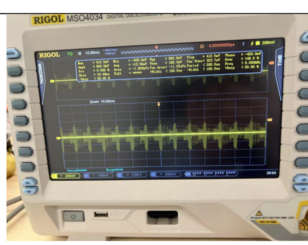
Materials				
Mass	340.1 g	228.1 g	524.4 kg	181.5 kg
Deformation	0 mm	0 mm	0 mm	0 mm
Degree error	1°	0°	2°	0°

Table 1: experiment2

3.1.3 Page Sensor

We conducted a series of experiments and recorded whether a stable zero-voltage phase appeared on the oscilloscope, while also verifying whether the system successfully received and utilized the sensor signal through code execution. The logic of the test program was as follows: during each page-turning process, when the book page blocked the propagation path of the infrared beam and the voltage transitioned from a fluctuating state to a stable zero, the motor controlling the roller would immediately stop rotating. A total of 20 page-turning experiments were carried out. In all 20 trials, a stable zero-voltage phase was observed on the oscilloscope, and the roller motor stopped functioning each time following the voltage drop to zero. And in each trail, the period of stable zero-voltage phase is about 30 ms.

	When the infrared signal emitted by the sensor successfully reaches the receiver, the oscilloscope shows that the voltage is in a fluctuating state.
	When the turning of a book page obstructs the transmission of the infrared beam, the receiver fails to detect the signal, and the oscilloscope registers zero voltage across the sensor.

	During the process of a page being turned, the oscilloscope displays a fluctuating voltage signal, with a short interval of stable zero voltage, indicating that the infrared beam was momentarily obstructed as the page passed through its path. The subsequent resumption of voltage fluctuations signifies that the page has completed its turn and no longer blocks the infrared transmission.

Table 2: Page sensor

3.1.4 Motor Driver

To verify the correct generation of PWM signals, we used an oscilloscope to measure the the PWM signal generated by STM32F407, which was intended to increase the duty cycle from 40% to 100%. The results showed a linear correlation between input percentage and output duty cycle, varying from 40.8% to 99.6%, closely matching the expected $40-100\%$ range. Representative waveform snapshots are shown in figure 6. The signal frequency remained stable at 2 kHz, with negligible jitter.

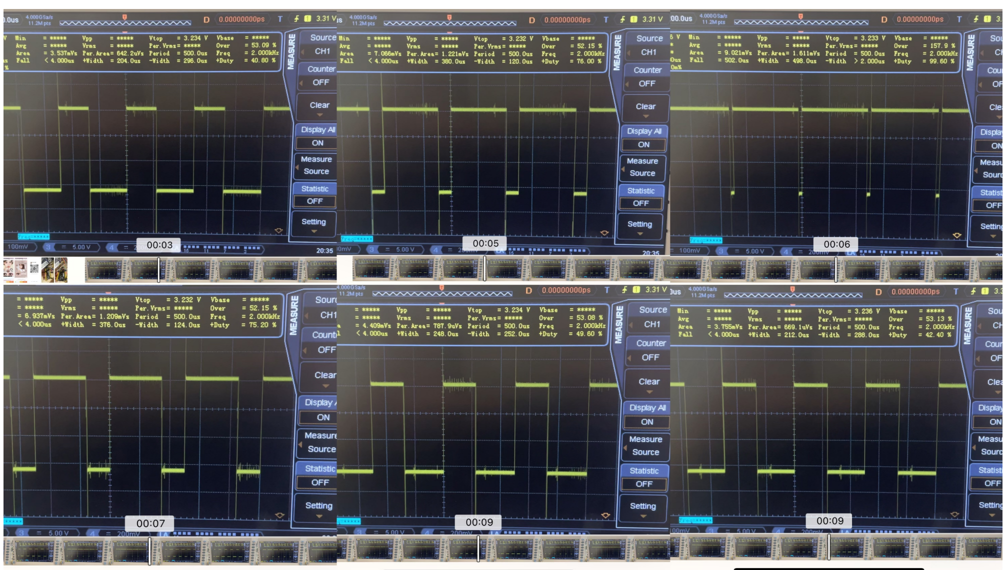


Figure 6: PWM Signal Output on Oscilloscope with Time Label

To assess GPIO response time, we connected direction control pins on the L298N driver to the STM32F407 GPIO output pins. The motor controlled by the L298N driver run in a specific direction as expected. Table 3 shows the relationship between input signal and motor direction.

IN1	IN2	IN3	IN4	Motor Performance
HIGH	LOW	X	X	Motor A: clockwise
LOW	HIGH	X	X	MOtor A: counter-clockwise
X	X	HIGH	LOW	Motor B: clockwise
X	X	LOW	HIGH	MOtor B: counter-clockwise

Table 3: Motor Direction Controlled by L298N

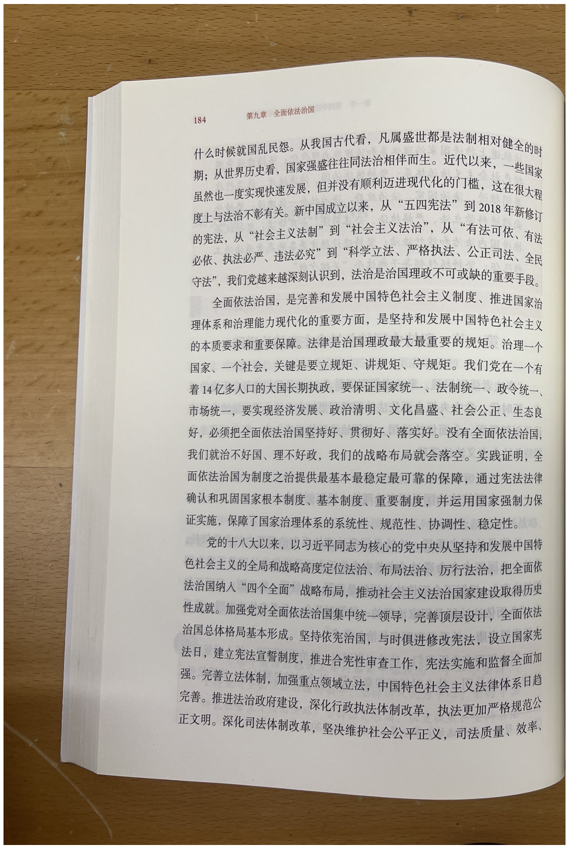
Measurements indicate that the motor driver responded approximately 4.5 ms after a GPIO edge trigger, meeting the system's real-time requirement of 5 ms.

3.2 Photocopying Module

3.2.1 Image Processor

To verify the performance of the image processor, we conducted tests on key functional requirements, focusing on processing time, dewarping accuracy, and overall content clarity. For processing speed, we measured the time required to process 10 pages. The average total processing time was recorded as 37.15 seconds, yielding an average of 3.715 seconds per page, which meets the design requirement of $\leq$ 5 seconds per page.

To evaluate dewarping accuracy, we scanned a book page placed over a 7.5 mm grid and used OpenCV's HoughLines to analyze page curvature and skew. The resulting dewarped images showed a deviation within $\pm$ 7.5 mm and a skew of less than $2°$. Figure 7 and Figure 8 show the original image and the dewarped result with grid of a sample page. The final output was visually inspected, and the text remained clear and easily readable. Therefore, the processed content meets usability standards.



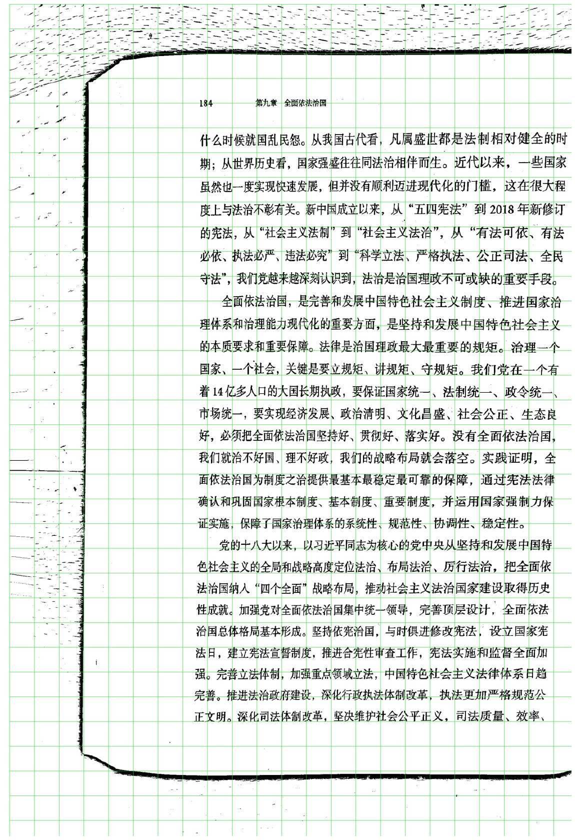
184 第九章 全面依法治国

什么时候就国乱民怨。从我国古代看，凡属盛世都是法制相对健全的时期；从世界历史看，国家强盛往往同法治相伴而生。近代以来，一些国家虽然也一度实现快速发展，但并没有顺利迈进现代化的门槛，这在很大程度上与法治不彰有关。新中国成立以来，从“五四宪法”到 2018 年新修订的宪法，从“社会主义法制”到“社会主义法治”，从“有法可依、有法必依、执法必严、违法必究”到“科学立法、严格执法、公正司法、全民守法”，我们党越来越深刻认识到，法治是治国理政不可或缺的重要手段。

全面依法治国，是完善和发展中国特色社会主义制度、推进国家治理体系和治理能力现代化的重要方面，是坚持和发展中国特色社会主义的本质要求和重要保障。法律是治国理政最大最重要的规矩。治理一个国家、一个社会，关键是要立规矩、讲规矩、守规矩。我们党在一个有着 14 亿多人口的大国长期执政，要保证国家统一、法制统一、政令统一、市场统一，要实现经济发展、政治清明、文化昌盛、社会公正、生态良好，必须把全面依法治国坚持好、贯彻好、落实好。没有全面依法治国，我们就治不好国、理不好政，我们的战略布局就会落空。实践证明，全面依法治国为制度之治提供最基本最稳定最可靠的保障，通过宪法法律确认和巩固国家根本制度、基本制度、重要制度，并运用国家强制力保证实施，保障了国家治理体系的系统性、规范性、协调性、稳定性。

党的十八大以来，以习近平同志为核心的党中央从坚持和发展中国特色社会主义的全局和战略高度定位法治、布局法治、厉行法治，把全面依法治国纳入“四个全面”战略布局，推动社会主义法治国家建设取得历史性成就。加强党对全面依法治国集中统一领导，完善顶层设计，全面依法治国总体格局基本形成。坚持依宪治国，与时俱进修改宪法，设立国家宪法日，建立宪法宣誓制度，推进合宪性审查工作，宪法实施和监督全面加强。完善立法体制，加强重点领域立法，中国特色社会主义法律体系日趋完善。推进法治政府建设，深化行政执法体制改革，执法更加严格规范公正文明。深化司法体制改革，坚决维护社会公平正义，司法质量、效率、

Figure 7: Original Page



184 第九章 全面依法治国

什么时候就国乱民怨。从我国古代看，凡属盛世都是法制相对健全的时期；从世界历史看，国家强盛往往同法治相伴而生。近代以来，一些国家虽然也一度实现快速发展，但并没有顺利迈进现代化的门槛，这在很大程度上与法治不彰有关。新中国成立以来，从“五四宪法”到 2018 年新修订的宪法，从“社会主义法制”到“社会主义法治”，从“有法可依、有法必依、执法必严、违法必究”到“科学立法、严格执法、公正司法、全民守法”，我们党越来越深刻认识到，法治是治国理政不可或缺的重要手段。

全面依法治国，是完善和发展中国特色社会主义制度、推进国家治理体系和治理能力现代化的重要方面，是坚持和发展中国特色社会主义的本质要求和重要保障。法律是治国理政最大最重要的规矩。治理一个国家、一个社会，关键是要立规矩、讲规矩、守规矩。我们党在一个有着 14 亿多人口的大国长期执政，要保证国家统一、法制统一、政令统一、市场统一，要实现经济发展、政治清明、文化昌盛、社会公正、生态良好，必须把全面依法治国坚持好、贯彻好、落实好。没有全面依法治国，我们就治不好国、理不好政，我们的战略布局就会落空。实践证明，全面依法治国为制度之治提供最基本最稳定最可靠的保障，通过宪法法律确认和巩固国家根本制度、基本制度、重要制度，并运用国家强制力保证实施，保障了国家治理体系的系统性、规范性、协调性、稳定性。

党的十八大以来，以习近平同志为核心的党中央从坚持和发展中国特色社会主义的全局和战略高度定位法治、布局法治、厉行法治，把全面依法治国纳入“四个全面”战略布局，推动社会主义法治国家建设取得历史性成就。加强党对全面依法治国集中统一领导，完善顶层设计，全面依法治国总体格局基本形成。坚持依宪治国，与时俱进修改宪法，设立国家宪法日，建立宪法宣誓制度，推进合宪性审查工作，宪法实施和监督全面加强。完善立法体制，加强重点领域立法，中国特色社会主义法律体系日趋完善。推进法治政府建设，深化行政执法体制改革，执法更加严格规范公正文明。深化司法体制改革，坚决维护社会公平正义，司法质量、效率、

Figure 8: Dewarped Page with Grid

3.2.2 Camera

A batch test of 50 consecutive image capture and transmission cycles was conducted under standard operating conditions using the 3264×2448 resolution camera. The success criteria included correct frame reception, checksum validation, and the generation of usable high-resolution image content. The system achieved a success rate of 98% (49 out of 50 cycles completed without error), with the single failure caused by an invalid file name during the image-saving process. In addition to confirming stable operation, we verified that all successfully saved images retained the full 3264×2448 resolution, ensuring that the level of detail required for clear text recognition across two book pages was consistently maintained. This confirms the robustness of the camera and communication subsystem under repeated use, which is essential for reliable, high-fidelity page scanning.

3.3 Control & Interface Module

3.3.1 UART Transmission

To verify the accuracy of UART-based data transmission via CH340, we measured the total transmission time for message sending and receiving by recoding a video when running the Python test script as shwon in figure 9. At a baud rate of 115200 bps, an 80-char message was transmitted in 0.04 seconds. When we tested the UART sending function, from the terminal window, we observed no mismatches between the message sent by STM32F407 and the message received by PC. When we tested the UART receiving function, from the terminal window, we observed no mismatches between the message sent by PC and the message reflected from STM32F407. This indicates reliable transmission with no loss or corruption of byte.

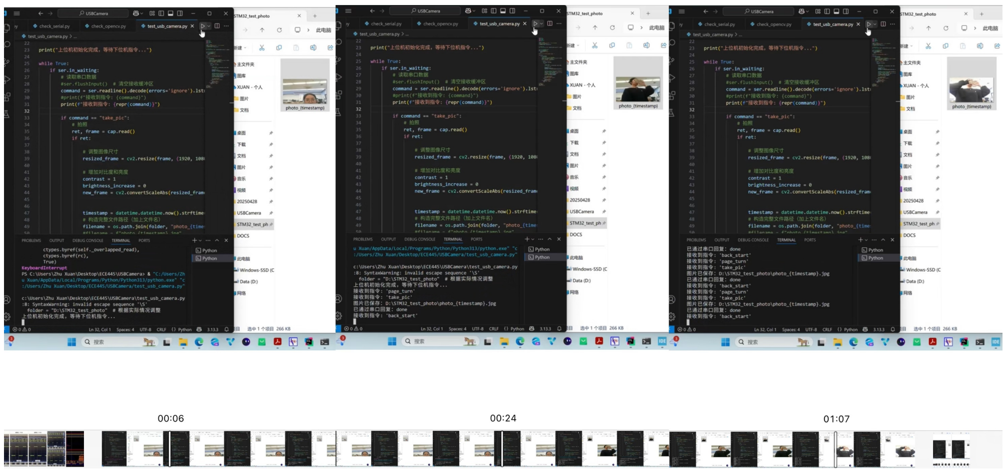


Figure 9: Terminal Window of UART Test with Time Label

3.3.2 Emergency Stop

The emergency stop mechanism can be triggered by recieving a specific ”STOP” message configured for EXTI from PC by clicking the UI botton. We meatured the time interval between the UI button press and the execution of the interrupt service routine by recording a video. When the emergency stop button was activated, all active PWM outputs controlling the page separating and page turning motors were immediately disabled. The response time was consistently within 8 ms, which is well below the 10 ms safety threshold.

Following emergency stop activation, the system entered a locked safety mode. Attempts to resume operation without pressing a manual reset button on the STM32F407 board were intentionally blocked by firmware-level state control.

3.3.3 User Interface

The user interface was tested to ensure it meets key functional requirements, including real-time system status updates and responsive image processing upon user input. During testing, the UI reliably reflected changes in system status, such as image capture initiation and processing completion, through dynamic text and visual indicators. The ”Run Image Processor” button consistently triggered the image processing pipeline when pressed, with no missed or delayed responses observed across multiple trials. These results confirm that the UI successfully provides feedback to the user and allows effective control of the system, fulfilling its role as an accessible and functional front end for the image processing workflow. Figure 10 and figure 11 demonstrate the user interface of two system states—Ready and Scanning respectively.

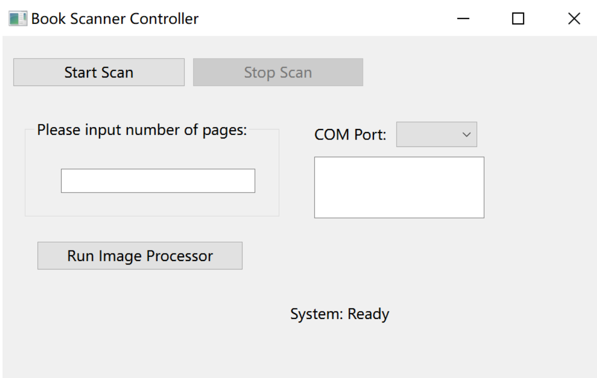


Figure 10: User Interface of Status System Ready

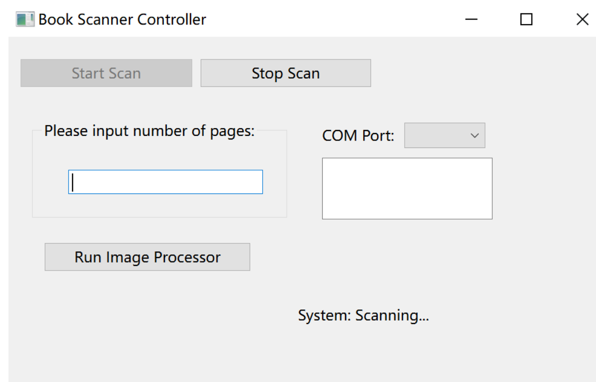


Figure 11: User Interface of Status Scanning

4 Costs

4.1 Parts

The cost of all components is listed in Table 4. Through enumeration and calculation of the components one by one, it can be confirmed that the material cost is well controlled within the budget.

Table 4: 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	ϕ 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**

4.2 Labor

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

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

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.

5 Schedule

Table 5: Weekly Work Report of Team Members

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
3/24/25	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

Continued on next page

Week	**Yingying Gao**	**Yiying Lyu**	**Xuan Zhu**	**Shuchang Dong**
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
4/24/25	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 version of the prototype to test the success rate and efficiency of the page-turning function	Conduct experiments on the second version of the prototype to test the success rate and efficiency of the page-turning function	Optimize and modify the design based on the first version of the PCB and fabricate the second version of the PCB	Conduct experiments on the clarity of 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 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

6 Conclusion

6.1 Accomplishments

Currently, the mechanical structure of this automatic page-turning photocopier is capable of achieving a continuous page-turning action cycle. The success rate of single-page turning per single attempt exceeds 75 %. Meanwhile, the sensor for detecting the success of page turning can identify the lifted page with a 99 % probability and trigger the subsequent page-turning process. In the photocopying stage of the process, the camera can completely cover the entire spread-out page of the book and take pictures for storage. The stored image data will undergo image processing operations such as segmentation, flattening, and clarification in sequence.

6.2 Uncertainties

Under the existing mechanical conditions, for book pages larger than A4 size in a single sheet, a jamming situation may occur during the page-turning process. Moreover, when the pressure between the book and the rollers is too high, multiple pages may be driven in a single page-turning operation. The mechanical structure of the entire instrument needs to be adaptively adjusted according to the size and thickness of different books before starting, so that the designated automatic page-turning and photocopying functions for multiple pages can be completed more smoothly.

6.3 Ethical considerations

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 usage 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 must 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.

6.4 Future Work

In the future, the adaptation work for more types of books with different materials and sizes needs to be improved. In terms of control, the page-turning process should be shortened to reduce the time required for a page-turning cycle. In the aspect of image processing, in addition to clarification and saving, a more intelligent text recognition function should be added. Through these improvements, the automatic page-turning photocopier can adapt to more archival work and provide users with better and more user-friendly services.

References

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7 Appendix

Table 6: Requirements and Verification

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 20-cycle tests on more than 2 types of papers and record the success rate. 3. Record full page-turning cycles (separation to completion) which take no more than 16 seconds. Adjust the speed of motors to make efficient page-turning cycle.

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 20 times page turns and record detection results system judges. 2. Conduct multiple times page turning process and use an oscilloscope to capture signal rise/fall times during controlled page interruptions.

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 (0.1-0.6 kg) on book platform for 2 hours. Measure deformation of component which supports the book platform via vernier caliper.

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.

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.

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.

Requirements	Verifications
1. User Input Registration: Accurately detect On/Off and Emergency Stop touches within ≤500ms latency. 2. Latency: Update status information within ≤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.

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.

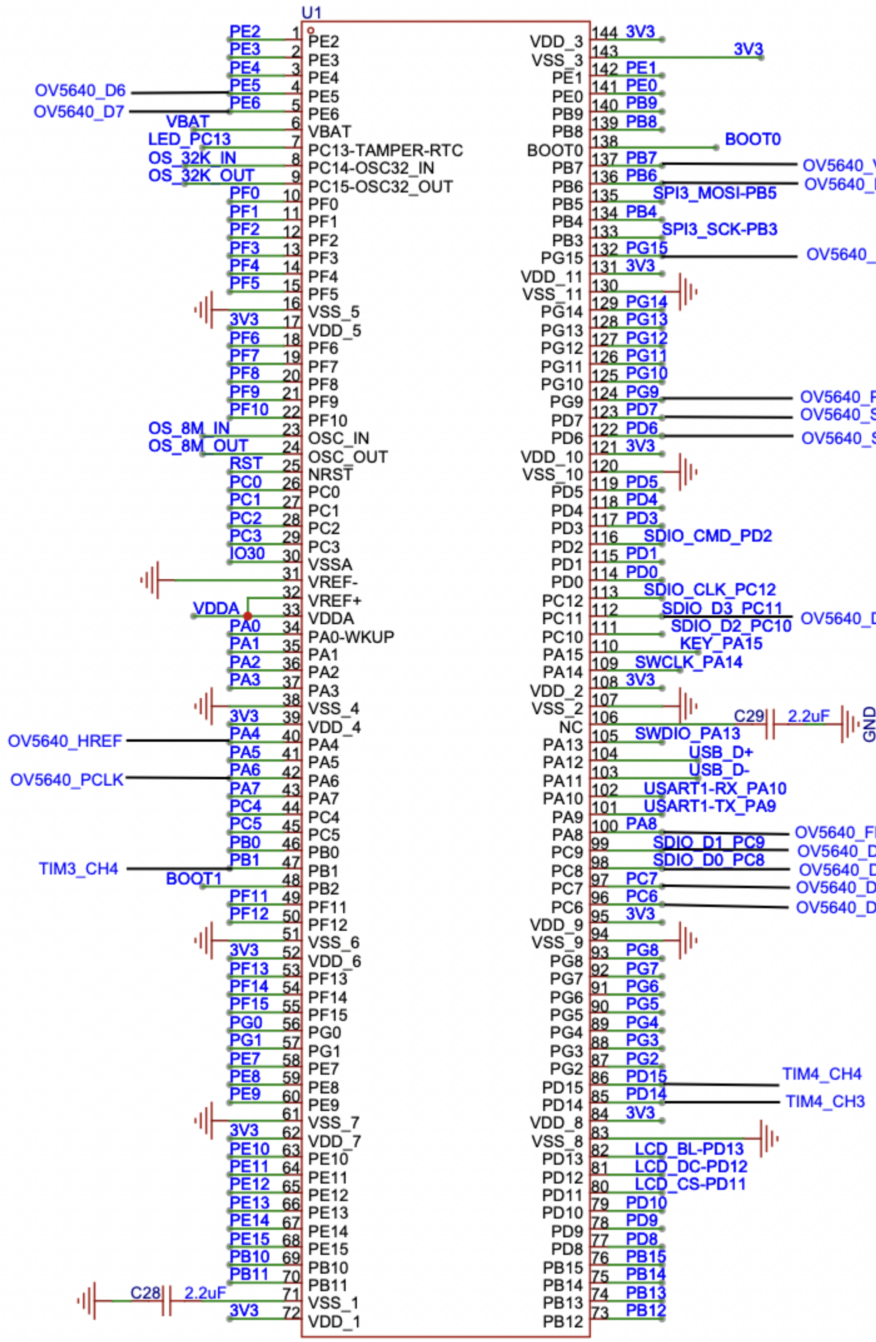

Figure 12: Control Module Schematic

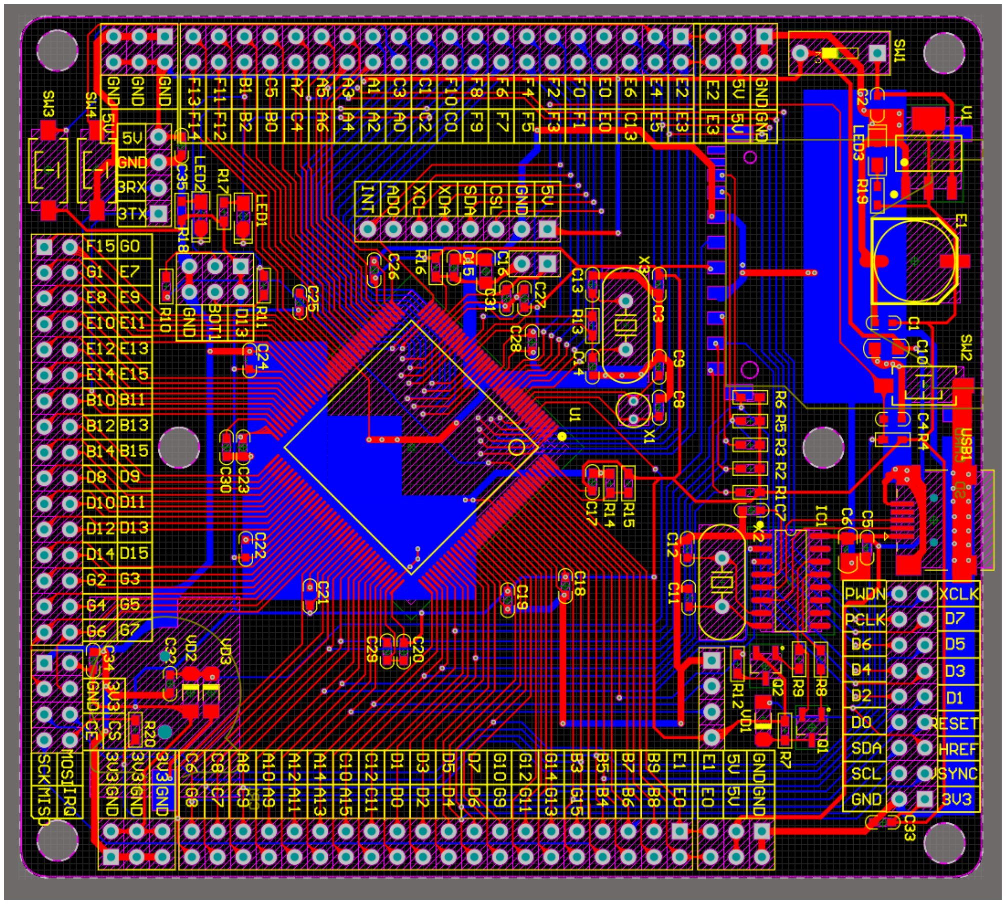

Figure 13: PCB Layout