

Project Proposal: Automated Intelligent Document Stamping System with Machine Vision Integration

1. Introduction

1.1 Title Page Information

- **Project Title:** Automated Intelligent Document Stamping System with Machine Vision Integration
- **Team Members:**
 - Zhiqiang Qiu (UID: 3220111914)
 - Yanzhen Chen (UID: 3220111908)
 - Xuliang Huang (UID: 3220111926)
 - Jiaheng Zeng (UID: 3220111929)
- **Course:** ECE 445 / ME 470, Spring 2026
- **Project Faculty:** Prof. Arne Fliflet, Prof. Huan Hu, Prof. Timothy Lee, Prof. Blake Johnson, Prof. Yu Lin
- **ZJUI Professor:** Fangwei Shao
- **Suggested TA:** Yu Le

1.2 Objective and Background

- **Goals:** This project aims to design and build a mechatronic system capable of automating the manual process of stamping multi-page documents. This addresses the problem of repetitive, time-consuming manual labor for administrative staff.
- **Functions:** Like a printer, the system uses a pickup roller to feed single sheets into the stamping stage. It integrates a Vision-Language Model (VLM) and a camera to detect appropriate stamping locations—either finding open spaces (Mode A) or locating specific keywords with a relative offset (Mode B). An X-Y positioning arm moves the stamp head, and a Z-axis actuator applies the appropriate pressure to stamp the document. Finally, an output roller pushes the sheet to the exit tray.
- **Benefits:** The goal is to liberate ZJUI administrative staff from repetitive stamping tasks, significantly saving their time and reducing human error.
- **Features:** Unlike traditional automated machines that rely on pre-programmed fixed coordinates, this system innovatively integrates a VLM and machine vision for "content-aware" stamping, allowing it to adapt to various document layouts

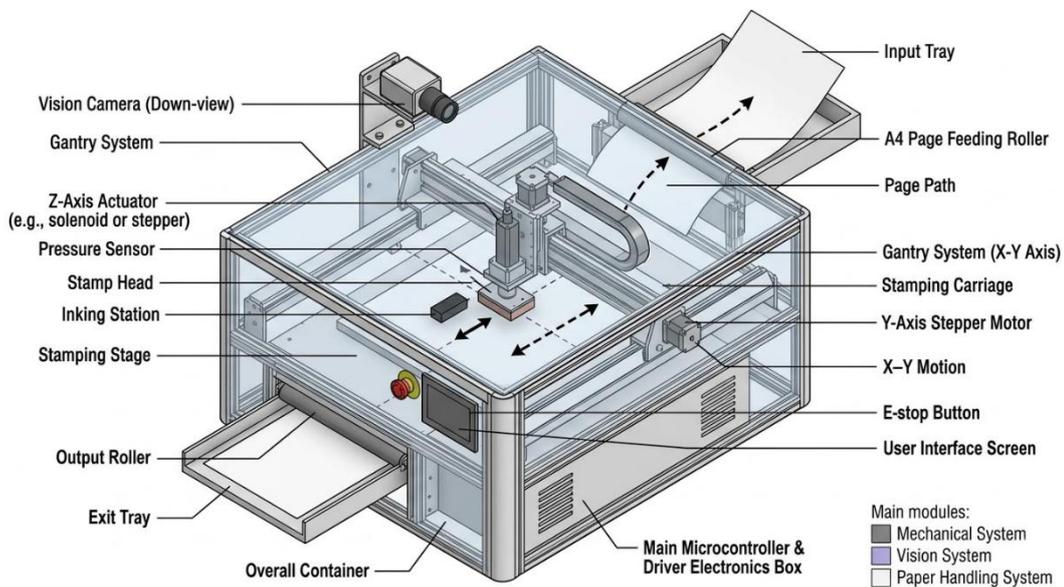
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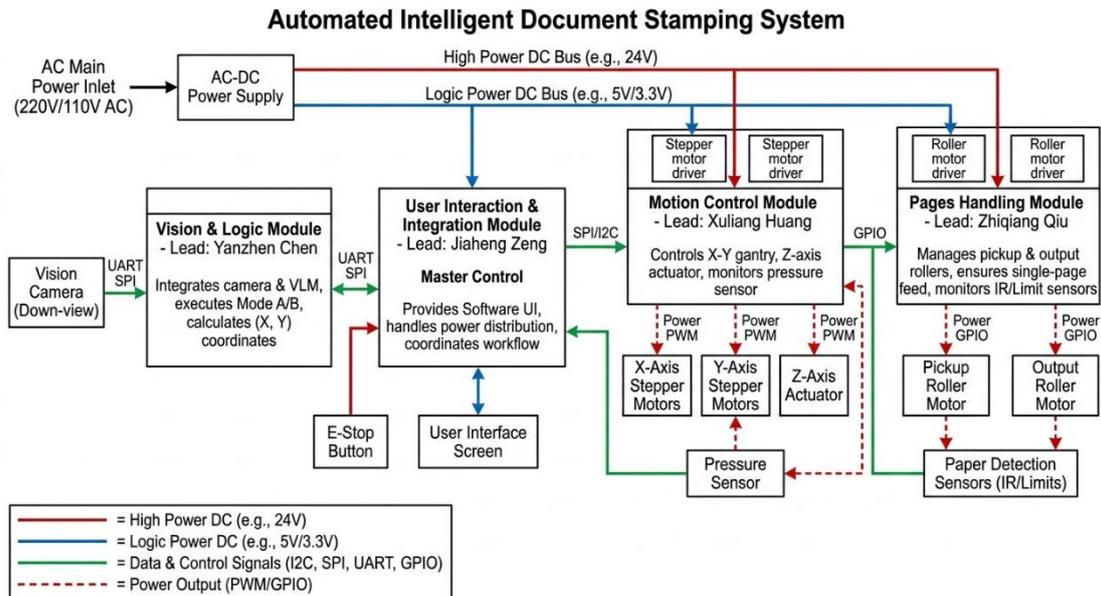
1.3 High-Level Requirements (HLRs)

1. The Vision & Logic subsystem must identify the target keyword (Mode B) or a 5x5 cm valid blank space (Mode A) with an accuracy of over 95% within 5 seconds under standard indoor office lighting (300-500 lux).
2. The Motion Control subsystem (X-Y positioning arm and Z-axis actuator) must navigate the stamp to the target coordinates with a physical placement error of no more than ± 5 mm in both X and Y directions, while applying and maintaining a stable Z-axis pressure between 15 N and 25 N during the stamping action.
3. The Pages Handling subsystem must continuously feed and output standard A4 paper (80g/m²) with a jam or multi-feed error rate of less than 2% over 50 consecutive stamping test cycles.

2. Design & Requirements

2.1 Diagrams





2.2 Block Descriptions & Division of Labor

To achieve the system's functionality, we have divided the project into four main logical modules, with specific responsibilities assigned to each team member:

a) Vision & Logic Module - Lead: Yanzhen Chen

- **Description:** Integrates the camera and VLM to capture and process document images. This module executes Mode A (content-aware blank space detection) and Mode B (keyword OCR and offset calculation). It calculates the target physical coordinates (X, Y) for the stamp and transmits them to the main microcontroller.

b) Motion Control Module - Lead: Xuliang Huang

- **Description:** Contains the X-Y axis gantry system, the Z-axis linear actuator, pressure sensors, and corresponding motor drivers. Upon receiving coordinate commands from the control board, it accurately moves the stamp head to the target position. It monitors the Z-axis downward force using the pressure sensor and immediately retracts upon reaching the desired force threshold to ensure clear stamping without damaging the paper.

c) Pages Handling Module - Lead: Zhiqiang Qiu

- **Description:** Manages the physical transportation of the documents. It includes a pickup roller with a separation mechanism (to ensure single-page feeding) and an output roller. It utilizes photoelectric/IR sensors to track the paper's position, prevent jams, and keep the process transparent to the user.

d) **User Interaction & Integration Module - Lead: Jiaheng Zeng**

- **Description:** Provides the software User Interface (UI) where users can view operating instructions, select stamping modes, input target keywords, and monitor progress. This module also handles power distribution, communication buses (SPI/I2C/UART) for the main microcontroller (e.g., Raspberry Pi or STM32), and coordinates the workflow of the other three subsystems.

2.3 Requirements and Verification (R&V) Tables

a) **Vision & Logic Module**

| Requirements | Verification |
|---|--|
| 1. The camera must capture images at a minimum resolution of 1080p (1920x1080) under standard indoor lighting (300 lux) to ensure reliable OCR text recognition. | 1. Place a standard 12pt text document under the camera at 300 lux ambient light, capture an image to verify its 1920x1080 resolution on a PC, and run a standard OCR script to confirm that the text is successfully recognized with 100% accuracy. |
| 2. The VLM/vision algorithm must identify the target keyword (Mode B) and output its correct pixel coordinates to the main MCU within 5 seconds of image capture. | 2. Place 10 sample documents with known keyword locations under the camera, trigger the capture sequence, and use the MCU internal timer to verify that the time from image capture to coordinate output is 5 seconds for all 10 samples. |

b) **Motion Control (Z-Axis Actuator & Pressure Detection)**

| Requirements | Verification |
|---|---|
| 1. Z-Axis vertical travel. The actuator must extend to a defined travel limit to ensure the stamp head makes clear contact with the paper surface without crushing the mechanism. | 1. Command the actuator to extend fully. Use a calibrated caliper or linear encoder to measure the travel distance from the fully retracted position to the fully extended position. Verify it meets the specified stroke length. |
| 2. Controlled descent speed. The actuator must descend at a | 2. Using a high-speed camera or motion sensor, record the downward stroke. Verify |

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| controlled velocity to prevent ink smearing or mechanical shock upon impact with the paper. | that the descent velocity does not exceed the defined threshold (e.g., 20 mm/s) over 10 consecutive cycles. |
| 3. Pressure detection & force limiting. The system must detect when the stamp head contacts the paper and maintain the required force (e.g., 5-10 N) without exceeding the maximum allowable pressure to prevent damage to the actuator or document. | 3. Place a force gauge (load cell) at the stamping position. Activate the stamping cycle and record the peak force applied to the gauge. Verify the force stays within the defined tolerance range (e.g., $7.5 \text{ N} \pm 2.5 \text{ N}$) for 20 cycles. |

c) Pages Handling (Pickup & Output Rollers)

| Requirements | Verification |
|--|--|
| 1. Single-sheet pickup. Feed exactly 1 sheet per cycle from a stack | 1. Count sheets per cycle. Load 20 sheets, run 10 cycles. Repeat until 200 sheets. Record if 0/2+ sheets moved |
| 2. Repeatable stop position (front edge). Paper front edge must stop consistently | 2. Place a reference line at stop, feed and stop; measure distance error, record 30 samples. |
| 3. Output reliability. Once stamping is done or skipped, sheet must exit fully to tray | 3. Run 200 cycles. record any sheet left halfway or stuck. This can be done together with the first requirement. |

d) User Interaction & Integration

| Requirements | Verification |
|---|---|
| 1. UI Functionality & Mode Selection: The software UI must allow users to view operating instructions, clearly select between | 1. Launch the UI on the screen. Select Mode B and input a test string (e.g., "SIGN HERE"). Use a serial monitor or debugging tool to verify that the main microcontroller |

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|---|--|
| Mode A and Mode B, and input a target keyword for Mode B. | correctly receives the exact string and mode flag. |
| 2. Workflow Coordination & Progress Monitoring: The integration module must coordinate the subsystems and update the UI with real-time system status (e.g., Idle, Feeding, Scanning, Stamping, Error) with minimal latency. | 2. Initiate a standard stamping cycle. Observe the physical machine alongside the UI screen. Use a stopwatch to verify that the UI status updates accurately reflect the physical state changes within 1 second. |
| 3. Communication Bus Reliability: The system must maintain reliable communication via SPI/I2C/UART between the main microcontroller (e.g., Raspberry Pi/STM32) and other modules during a full stamping cycle. | 3. Connect a logic analyzer to the active communication bus. Run 10 continuous stamping cycles and verify that the data logs show 0 framing errors, parity errors, or dropped packets. |
| 4. Power Distribution Stability: The module must distribute stable power to the logic boards and the actuators/motors without significant voltage drops during peak mechanical load. | 4. Connect a multimeter or oscilloscope to the logic and motor power rails. Trigger the Z-axis actuator and X-Y motors simultaneously. Verify that voltage fluctuations remain within $\pm 5\%$ of the nominal values. |

2.4 Tolerance Analysis

- **Critical Risk:** The most critical and challenging aspect of this project is the mapping and tolerance accumulation from visual coordinates (pixels) to physical coordinates (millimeters).
- **Analysis:** Errors are introduced by camera installation angles, lens distortion, and mechanical backlash in the X-Y positioning arm. Suppose the required clearance from the stamp edge to specific text (the keyword) is $D = 10$ mm.
 - Assuming the camera has a field-of-view resolution of 5 px/mm at the height of the A4 paper, the VLM/OCR bounding box center calculation may have an

algorithmic error of ± 2 px (± 0.4 mm).

- The mechanical backlash and belt stretching of the X-Y stepper motors introduce a mechanical tolerance of approximately ± 2 mm.
 - Therefore, the worst-case accumulated error is $E_{\text{total}} \approx 0.4 \text{ mm} + 2 \text{ mm} = 2.4 \text{ mm}$. This is well within our High-Level Requirement (HLR) tolerance of ± 5 mm, theoretically proving that our mechanical and visual architecture can meet the precision requirements for automated stamping.
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3. Ethics and Safety

3.1 Ethics

This project involves scanning and processing administrative or official documents, which raises potential data privacy concerns. In strict alignment with the IEEE Code of Ethics (specifically regarding protecting privacy and personal data), our system will utilize an **Edge Computing** strategy. The document images captured by the camera will be processed entirely locally in the RAM of the microcontroller/Raspberry Pi to calculate coordinates. All image data will be purged immediately from the memory after the stamping cycle is completed. Under no circumstances will sensitive document images be saved to non-volatile memory (e.g., SD cards) or uploaded to external cloud servers.

3.2 Safety

- **Mechanical Safety:** The system incorporates high-torque stepper motors, gears, and pinch rollers, creating potential pinch-point hazards for users' hands. To mitigate this, the entire X-Y moving gantry and feeding area will be enclosed in an acrylic casing. Additionally, a physical **Emergency Stop (E-stop)** button will be installed next to the UI panel to instantly cut power to the motor relays when pressed.
- **Electrical Safety:** The device utilizes 110V/220V AC mains power converted to 12V/24V DC for the motors. All AC connections will be fully insulated, properly grounded, and fused at the power inlet to prevent fire hazards or short circuits caused by electrical overloads.