Project Proposal

ECE 445 Senior Design

Eco-Trim: Smart Scratch Pad Recovery System

Zhizheng Ju (zju4)
Tianyi Xu (tianyi25)
Lehan Pan (lehanp2)
Zihan Wang (zihan20)

Advisor: Yu Lin

March 24, 2026

Contents

1. Introduction

1.1 Problem

University libraries and study spaces generate massive paper waste from partially used notes, single-sided printouts, and draft materials. Although many of these pages still contain significant blank regions, they are usually discarded because manually locating reusable areas is inconvenient.

Existing solutions do not address this problem effectively. Standard paper shredders destroy the entire sheet, including usable blank regions, while industrial recycling processes require wet pulping, de-inking, and centralized infrastructure that are too resource-intensive for local deployment. Therefore, there is a need for a compact automated system that can locally reclaim usable blank areas from discarded paper stacks and convert them into scratch pads without chemical reprocessing.

1.2 Solution

Our proposed solution, Eco-Trim, is an automated mechatronic system that recovers reusable blank sections from discarded paper using a dry, localized process. Instead of fully recycling paper into pulp, Eco-Trim accepts a stack of partially used sheets, feeds them one at a time, optically detects printed versus blank regions, and automatically trims usable sections into uniform scratch pads. The system is activated by a single push of a button, satisfying the one-button activation requirement while minimizing user effort.

The system depends on real-time sensing, embedded control, and safe power actuation. A custom PCB will integrate the microcontroller, optical sensing circuitry, and interface electronics. The microcontroller will run a finite state machine (FSM) to coordinate paper feeding, optical scanning, motion control, and fault handling. Opto-isolated motor drivers and hardware safety interlocks will be used to control high-torque actuators while ensuring safe operation in a public environment.

1.3 Visual Aid

Figure 1 illustrates the overall concept of Eco-Trim. A user inserts a stack of discarded paper and presses a single start button. The machine then feeds sheets individually, scans them using optical contrast sensing, determines whether sufficient blank area exists, and trims reusable sections into small scratch pads. Safety interlocks monitor enclosure access and user proximity throughout operation.

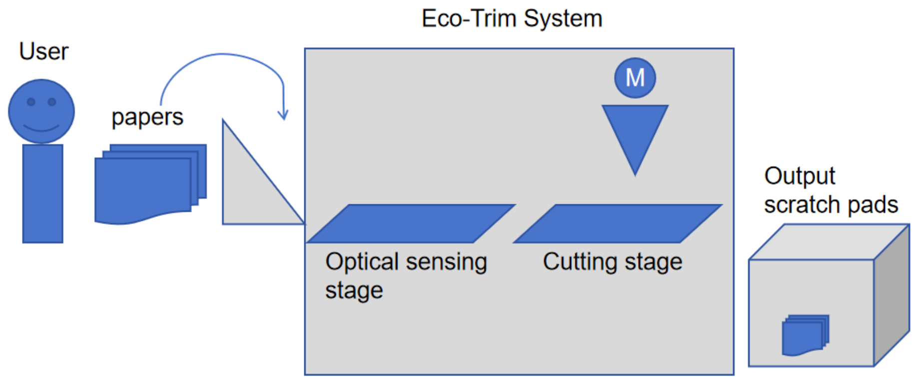

Figure 1: High-level visual representation of Eco-Trim.

1.4 High-level Requirements

The project must satisfy the following high-level requirements:

1. The system shall continuously feed at least 5 individual sheets from an input stack without mechanical jamming or repeated multi-sheet feeding during normal operation.
2. The sensing and control system shall correctly distinguish printed regions from blank regions and trigger the appropriate cutting decision based on optical contrast measurements.
3. The cutting mechanism shall automatically trim the paper into uniform scratch pads with clean edges and without visible tearing under normal operating conditions.
4. The hardware safety interlock system shall physically disconnect motor power within 100 ms whenever the enclosure is opened or the IR light curtain is breached.

2. Design

2.1 Block Diagram

Figure 2 shows the structure and function of the main parts of the system.

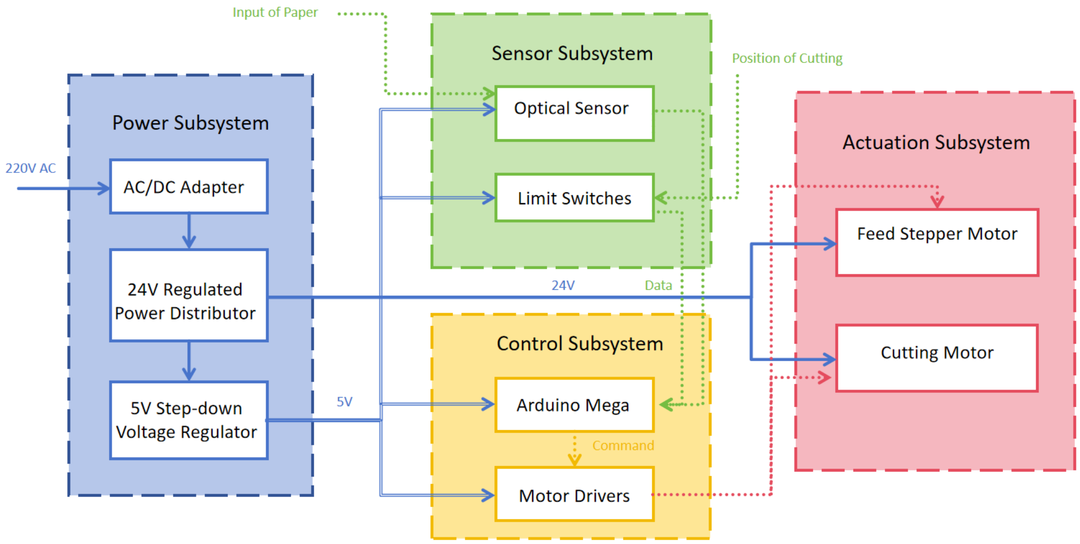

Figure 2: Top-level block diagram of Eco-Trim.

2.2 Subsystem Overview

The Eco-Trim System is divided into four main subsystems:

1. Power Subsystem: Converts wall AC power to 24V DC for the motors and steps down to 5V for the micro-controller and sensors.

2. Sensor Subsystem: Utilizes optical reflective sensors placed at the front to continuously sample the paper's surface. It is responsible for identifying a continuous blank area that meets the minimum length requirement (e.g. ≥ 100 mm).

3. Control Subsystem: Acts as the brain. The distance D between the sensor and the cutting blade is fixed. The micro-controller records the starting position of the blank area. Knowing the paper feed speed v, it calculates the delay time $t = D/v$ or counts the steps of the stepper motor to determine the exact moment to activate the blade.

4. Actuation Subsystem: Consists of a feeding stepper motor to advance the paper and a cutting motor (M) to execute the cutting once the blank area reaches the cutting stage.

2.3 Subsystem Requirements

- **Sensor Subsystem:** Must be able to continuously detect the surface reflectivity at a frequency ≥ 100 Hz to ensure accurate linear scanning along the feed direction. *Requirement drop:* If the sensor fails to distinguish between text and blank areas, the system cannot determine the cut position, rendering it useless.

- **Control Subsystem:** Must accurately count the steps of the feeding stepper motor to track the paper position from the sensor to the blade. *Requirement drop:* If the step count is lost, the cut will occur at the wrong position, destroying potentially reusable paper.
- **Actuation Subsystem:** The cutting blade must provide sufficient force to cut 70-100 g/m^2 paper cleanly in 1.5 seconds.

2.4 Tolerance Analysis

A critical risk to the project is the accuracy of the cutting position. The system relies on fixed distance D and stepper motor counting for localization.

Assume the system uses a stepper motor driving a friction roller of radius $r = 15$ mm. The motor has a step angle of 1.8° (200 steps/rev).

The theoretical distance the paper advances per step is:

$$\Delta d = \frac{2\pi r}{N} = \frac{2\pi \times 15}{200} \approx 0.471 \text{ mm/step}$$

To output a fixed-size scratch pad of 100 mm, the required steps are:

$$Steps = \frac{100}{0.471} \approx 212 \text{ steps}$$

Error Sources:

1. **Mechanical Slip:** Assuming a maximum 1% slip rate during feeding, the maximum error is 100 mm $\times$ 1% = 1 mm.
2. **Truncation Error:** 212 steps equal 99.85 mm, leaving an error of 0.15 mm.

Conclusion: The total expected maximum error is 1 mm (slip)+0.15 mm (truncation) = 1.15 mm. Since 1.15 mm is well within an acceptable tolerance of ± 2 mm for scratch pads, the proposed design using stepper motor step-counting for positioning is highly feasible.

3. Ethics and Safety

Eco-Trim contains moving rollers, a high-torque cutting actuator, and motor power electronics, so user safety is a primary design requirement rather than an afterthought. The machine is intended for public-facing or semi-public environments such as libraries, which means it must remain safe even when users are not technically trained. For this reason, the design includes hardware safety interlocks using enclosure limit switches and IR light curtains. These interlocks physically disconnect motor power within 100 ms if unsafe human access is detected. This hardware-level cutoff is essential because it does not depend solely on correct firmware execution.

From an ethical perspective, the project aims to reduce avoidable paper waste through local reuse rather than chemical recycling. However, the team must communicate the capability of the system honestly. Eco-Trim does not convert waste paper into new blank paper; instead, it salvages reusable blank regions from partially used sheets. Performance claims regarding feed reliability, cut quality, and detection accuracy must therefore be reported truthfully and supported by testing. This approach aligns with the engineer's responsibility to prioritize safety, transparency, and socially beneficial design.