ECE 445: SENIOR DESIGN LABORATORY
PROJECT PROPOSAL

Intelligent Shared Item Cabinet

Team #23

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1 Introduction

1.1 Objectives and Background

1.1.1 Goal

- Provide a 24/7 self-service solution for borrowing small tools in a residential college environment.

1.1.2 Functions

- Store various items in individual compartments securely.
- Enable students to borrow and return items by tapping their campus card.
- Use sensors and a camera to verify that the returned item matches the one borrowed.
- Log all borrowing records in a database for easy tracking and management.

1.1.3 Benefits

- **Convenience:** Students can borrow tools at any time.
- **Time-Saving:** Save time for students waiting and registering.
- **Accountability:** Keeps track of who borrowed each item, minimizing losses.
- **Reduced Staff Burden:** Less need for manual checkouts and returns at the front desk.

1.1.4 Features

- **24/7 Availability:** Always accessible, meeting immediate tool needs.
- **Easy Authentication:** Uses existing campus card systems for quick and familiar user access.
- **Automated Item Detection:** Ensures that the returned item matches what was borrowed.

1.2 High-Level Requirements List

- The cabinet must unlock a compartment within 2 seconds after scanning a valid campus card.
- The item verification module must correctly identify returned items at least 95% of the time.
- The system must log every borrow and return event in the database with 100% reliability.

2 Design and Requirements

2.1 Block Diagram

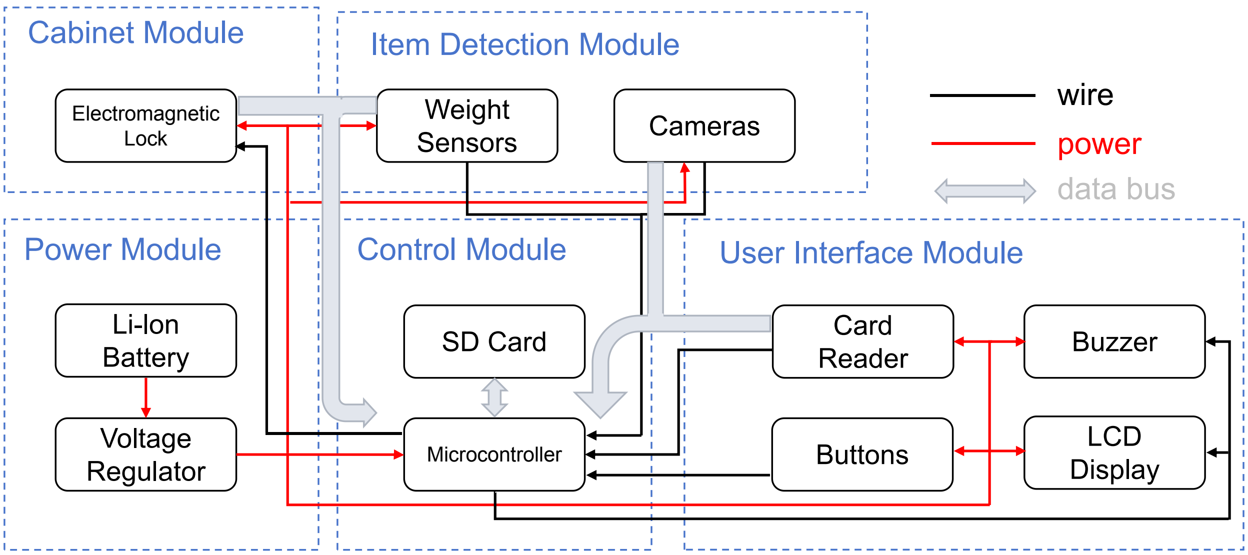

Figure 1: Block Diagram.

2.2 Block Description

2.2.1 Cabinet Module

The cabinet module stores items in individual compartments safely. It monitors door status in real time and includes a manual release mechanism for emergency access.

1) **Electromagnetic Lock**

   – The magnetic lock(e.g., SARY XG-07A) operates at DC 12V/2A and has a service life exceeding 300,000 cycles. It includes an internal detection switch for real-time door status feedback and a manual release mechanism for emergency access.[1]

   – *Requirement 1:* The lock must fully unlock within 2 seconds after receiving a signal from the control module.

   – *Requirement 2:* The lock must provide a reliable door status feedback signal, maintaining at least 90% accuracy under normal operating conditions.

2.2.2 Power Module

The power module provides a stable supply to all electronics, ensuring that the system operates reliably and continuously even during fluctuations or temporary outages.

1) **Li-Ion Battery**

- A rechargeable Li-Ion battery pack (e.g., nominal 7.4V, 2200 mAh) supplies backup power to the system. This component ensures that the system can run without interruptions, even during outages, and switch mode smoothly between AC power and battery backup.
- *Requirement 1:* Ensure to power the entire system for at least 8 hours under typical load (300–500 mA desirable current consumption) conditions through off-grid operation.
- *Requirement 2:* Must include sophisticated protection circuitry, essential for over-voltage, under-voltage, and over-current protection, along as temperature monitoring to prevent damage from abnormal conditions to ensure safe operation.

2) **Voltage Regulator**

- A DC-DC buck converter (e.g., MP1584) steps down the battery voltage to stable 5V and/or 3.3V rails. This component is critical for providing a clean, regulated power supply to sensitive electronics such as the microcontroller, sensors, and user interface circuits.[2]
- *Requirement 1:* Output voltage must remain stable within $\pm 5\%$ with less than 50 mV ripple across the full range of operating loads to ensure reliable performance of all connected devices.
- *Requirement 2:* Must be capable of delivering a maximum current of up to 2 A under load, while maintaining an efficiency of at least 80% to reduce energy loss and heat generation.

2.2.3 Control Module

The control module manages data flow between storage, communication interfaces, and peripheral controls. It ensures real-time processing and reliable control of all connected components.

1) **Microcontroller**

- An STM32 microcontroller (e.g., STM32F4 series) that serves as the system's brain, interfacing with the SD card via SPI, managing communication with the WiFi module over UART, and controlling other peripheral devices.[3]
- *Requirement 1:* Must support simultaneous SPI and UART communications at speeds of at least 2 Mbps each.
- *Requirement 2:* GPIO pins must be able to source or sink a minimum of 10 mA at 3.3 V ($\pm 5\%$) for driving status LEDs and interfacing with buttons.

2) **SD Card**

- A dedicated interface for managing the SD card used for local flash storage and caching data. This component communicates with the microcontroller via the SPI bus and ensures data integrity during read/write operations.

- *Requirement 1:* Must reliably read from and write to the SD card with SPI clock speeds up to 10 MHz.
- *Requirement 2:* Should implement error-checking mechanisms to ensure data integrity and maintain a consistent data cache.

2.2.4 Item Detection Module

The real object identification will take place in the item detection section of the cabinet, combing the sophisticated features of the sensors and computer vision. This module is a vital element for providing an interface free of transaction hassles and the confirmation of reliability and acceptance.

1) **Weight Sensors**

   - High-precision load cells are used to measure the weight of items placed in or removed from the cabinet. Such sensors allow for real-time feedback about item presence and discrepancies detection.
   - *Requirement 1:* Exact accuracy should be accomplished by using a detecting system reaching ± 0.1 gram for small tools (e.g., screwdrivers, wrenches) to be able for reliable identification.
   - *Requirement 2:* 0.5 seconds or less response time must be shown to create quick feedback for the users.

2) **Cameras and Computer Vision**

   - A camera system, designed to include 3D computer vision technology, is employed to capture the physical attributes of items and reveal various anomalies (e.g. item discrepancies). The system makes use of machine learning models trained by means of a dataset obtained from the images of tools to further advance the reliability of recognition accuracy.
   - *Requirement 1:* The camera must identify 1080p as a minimum resolution and 30 frames per second as a normal frame rate for a clear image capture with minimal time lag.
   - *Requirement 2:* The computer vision model must achieve a detection accuracy of 95% or higher under good lighting conditions, while a false positive rate of less than 5% is required.

3) **Voting Controller**

   - The weight sensor data and the data from cameras are merged in order to confirm item identification. The selection technique, designated to resolve these discrepancies (like if the weight sensor records an item while the camera does not), comes into effect.
   - *Requirement 1:* The system should process and validate data within 2 seconds, in order to give instant feedback to users.

– *Requirement 2:* Error log files must be kept for all the conflicts that occur, so that the system can be enhanced and moreover, to ease troubleshooting.

2.2.5 User Interface Module

The user interface module provides a direct interface for user interaction, encompassing authentication, status indication, and feedback through different input/output apparatus.

1) **Card Reader**

   – An RFID / NFC card reader (for example, MFRC522) used to authenticate the user by reading campus cards. It connects to the microcontroller via SPI or UART.[4]

   – *Requirement 1:* Must read and recognize a valid card within 2 seconds, at most, after touch or swipe.

   – *Requirement 2:* The communication interface should support data transfer rates of at least 1 Mbps.

2) **Buttons**

   – Tactile buttons for user input (e.g., confirm, cancel, or emergency functions) connected directly to microcontroller GPIO pins.

   – *Requirement 1:* Must give precisely debounced output in a digital signal for accurate detection of user actions.

   – *Requirement 2:* Give a button that supplies the user with tactile feedback indicating that the button was pressed successfully.

3) **LCD Display**

   – An LCD display with an SPI interface, used for presenting textual information such as system status, instructions, and error messages to the user.

   – *Requirement 1:* Within 100 ms, the system presents an updated content that can respond with visual feedback.

   – *Requirement 2:* Operate at 3.3 V ($\pm 5\%$) and drive SPI clock frequencies up to 10 MHz to ensure smooth and clear display performance.

4) **Buzzer**

   – A piezo buzzer driven by the PWM-able GPIO pin that gets its control signals from beeping notifications for successful actions or error alerts.

   – *Requirement 1:* Should be able to produce tonal frequencies in the 2–4 kHz region at a volume (e.g., approximately 70dB at distances up to 30 cm).

   – *Requirement 2:* For a given voltage supply (which could be either 3.3 V or 5 V), the current consumption level should be no more than 20 mA.

2.3 Risk Analysis

The system faces possible problems in several modules, bringing up issues and concerns. The power module's Li-Ion battery and voltage regulator have to output stable conditions even if the loads are fluctuating, moreover, the task for this subsystem is to develop complex circuits for protection against over and under voltages, temperature, and over and under current, which are very critical for safety. The system control microcontroller is in charge of the high-rate SPI and UART communication channels (e.g., the SD card is built with 10MHz SPI and the UART operates at 2Mbps), which becomes technically challenging in data transfer and timing. In addition to this, the user interface component demands the card reader, buttons, LCD, and buzzer to be responsive and fast, like unlocking in less than 2 seconds and updating the display in less than 100 ms—this is what we call real-time operation, and it means that anything needs to be done immediately and also correctly. Finally, the integration of mechanical and electronic devices, to which the electromagnetic lock belongs too, requires close attention in terms of design (and even more so in situations where people or infrastructure are at risk).

2.3.1 Greatest Risk Justification

The most challenging part to develop is the Item Detection Module, which involves the smooth merging of sophisticated technologies like weight sensors and a camera system equipped with computer vision skills, which cashes the returned items into the system. This module is inherently challenging because its design calls for highly accurate sensor data, which is extremely complex. The data has to be reconciled in real-time, and this is the most critical point and the system's significant risk factor.

2.3.2 Acceptable tolerances

The acceptable tolerances for this component are quite strict; for instance, the load cells must bear the precision within ± 0.1 gram, while the maximum response time is 0.5 seconds, and the camera system is expected to deliver a resolution of at least 1080p at 30 frames per second. Additionally, the computer vision algorithm must offer a minimum detection accuracy of 0.95, with a false positive rate below 0.05, while the voting controller subsystem has to process and validate sensor data within a two-second interval to facilitate their seamless operation.

2.3.3 Alignment with High-Level Requirements

This high level of performance is directly associated with the requirement that the item verification module confirms returned items at least 0.95 of the time, which derives from the outline of the project, especially the one about addressing the return-to-sender issue. While it is absolutely necessary for the Item Detection System to provide exact tolerances and rapid processing requirements to prevent system failure and user dissatisfaction, it is the deviation from those specifications that could result in mistakes in item verification, thereby ruining the user's trust in the whole intelligent shared item cabinet system.

3 Ethics and Safety

3.1 Ethics

As we are developing the intelligent shared item cabinet, we take a step with the code of ethics, making sure that our project is in compliance with the highest values of integrity, professional behavior, and respect for user privacy. We have such a system that does not impinge upon ethical norms while improving convenience and accountability for a residential college.[5]

In the first instance, we focus on user anonymity by enacting secure data processing. All the lending and returning data are kept within a database that has tight access restrictions, allowing only authorized personnel to access confidential information. The "Campus Card" for access authentication, in which personal data is not exposed unnecessarily, is employed.

To whom it may concern, we are endorsing system transparency. People know how their personal data is handled, and they have the ability to check borrowing records whenever they want. System design incorporates mechanisms that inform users of any errors or inconsistencies in the item-checking process, which builds trust and responsibility.

Initially, we make sure that our project does not end up creating problems. This is a system which is already made to prevent the possibility of items becoming lost or misused, and we have implemented the well-designed error logging system which shall help the system to keep on improving. Through the application of these ethical principles, we are looking at the possibility of building a system that is not only effective but also considerate of users' rights and cultural regulations.

3.2 Safety

Our project will be focused on the safety issues that might occur while performing both the hypothesis testing and execution. According to the lab rules of ECE 445, lab work should not be done alone, which means that at least two students should be present in the lab. Each member has to undergo the mandatory online safety training, and the proof of it must be uploaded to the Blackboard. Besides, any changes involving high voltage or specific battery technologies are recognized as additional risks, thus requiring extra training. [6]

The project combines a spectrum of electrical and mechanical parts, including rechargeable Li-Ion battery with dual-layer protection circuit, a voltage regulator, STM32 microcontroller, and the electromagnetic lock. All the safety of electric voltage is ensured by keeping components within specified voltage limits, which are high enough to withstand external interference, and the overheating of the wires is prevented by the protection device. The physical safety is considered by fastening the locker and blocking the exposed moving parts so that there are no accidental contacts. Through the implementation of these safety protocols, together with the preparation of a complete lab safety manual, our purpose is to ensure the safety of our team as well as the safety of the end users as we will have a dependable and secure system.

References

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