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ATM (Smart ATM System)

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Disclaimer

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Abstract

The development of automated cash handling systems has become increasingly important due to the growing demand for secure, efficient, and cost-effective currency exchange solutions. This project presents the design and implementation of an automated ATM prototype dedicated to intelligent cash exchange operations, supporting both accumulation and change-dispensing modes for paper currency and metallic coins.

The system integrates multiple engineering domains including embedded control, pneumatic routing, dual-stepper arc positioning, servo-based coin gating, computer vision-based banknote recognition, pulse-based coin validation, and wireless inventory synchronization. Banknotes inserted by the user are captured and validated using a Raspberry Pi image processing subsystem equipped with controlled LED illumination and a servo-driven presentation mechanism. Validated currency is accumulated digitally before confirmation.

For dispensing operations, a dual NEMA23 stepper-driven arc positioning mechanism aligns a vacuum suction assembly with the required banknote denomination. Selective airflow routing is achieved using normally-closed solenoid valves connected to a centralized vacuum system. Metallic coins are dispensed through servo-controlled 3D-printed gate mechanisms.

The system supports hybrid transactions, allowing combinations of paper currency and coins within a single exchange session. Real-time inventory levels are synchronized automatically with a wireless administrator application via ESP8266 communication.

Unlike commercial banking ATMs, this prototype focuses on intelligent denomination exchange and accumulation within a compact and educational mechatronic platform, demonstrating the integration of embedded systems, pneumatics, motion control, computer vision, and wireless monitoring into a unified architecture.

1. Introduction

Automation technologies have significantly transformed financial transaction systems and cash-handling mechanisms. While commercial Automated Teller Machines (ATMs) provide full banking services, there remains a need for specialized automated systems capable of intelligent currency exchange, accumulation, and multi-denomination dispensing in smaller-scale environments.

This project focuses on the design and implementation of an ATM prototype dedicated to advanced denomination exchange operations. The system supports multiple transaction modes including coin-to-coin exchange, paper-to-paper accumulation, hybrid accumulation (paper and coins), and selective multi-denomination change dispensing.

The ATM integrates embedded control systems, dual-stepper arc motion mechanisms, pneumatic vacuum routing, servo-controlled coin release systems, computer vision-based banknote validation, and wireless inventory monitoring. The result is a fully integrated mechatronic cash exchange platform.

1.1 Problem Statement

In many commercial environments, there is a frequent need for automated currency exchange systems that can break larger banknotes into smaller denominations efficiently and accurately. Existing ATM systems are often too expensive and unnecessarily complex for such single-purpose applications. Furthermore, simple change machines typically lack intelligent denomination recognition, optimized dispensing algorithms, and remote monitoring capabilities.

The problem addressed in this project is the absence of a compact, cost-effective ATM prototype capable of automatically validating inserted banknotes, calculating optimized change combinations based on available inventory, and dispensing multiple denominations (banknotes and optionally coins) while maintaining accurate real-time inventory tracking.

1.2 Objective

The main objective of this project is to design and implement a functional ATM prototype capable of:

- Recognize inserted banknotes using Raspberry Pi image processing
- Detect metallic coin denominations using pulse-based validation
- Support coin-to-coin and paper-to-paper accumulation
- Enable hybrid accumulation of paper and coins
- Provide selectable multi-denomination change options
- Implement a dual-stepper arc positioning mechanism for banknote alignment
- Utilize a pneumatic vacuum routing system for selective extraction
- Dispense metallic coins through servo-controlled gate mechanisms
- Automatically synchronize inventory levels with a wireless administrator application
- Maintain mechanical accuracy using a homing limit switch mechanism

The system aims to demonstrate practical integration of embedded systems, mechanical automation, and intelligent cash management techniques.

1.3 Scope of Work

1. Mechanical Structure and Custom Fabrication
Design and assemble the ATM mechanical frame including storage compartments and dispensing modules. Three custom 3D-printed components were developed for the coin routing and gating mechanism.
2. Dual-Stepper Arc Positioning System
Implement a synchronized two-stepper motor mechanism using NEMA23 motors and TB6600 drivers to achieve controlled semi-circular positioning of the suction assembly.
3. Pneumatic Vacuum Routing System
Design an on-demand vacuum-based banknote extraction system using a centralized pump and normally-closed solenoid valves for selective airflow routing.
4. Banknote Imaging and Validation Module
Integrate Raspberry Pi with a camera, LED illumination system, and servo-driven presentation mechanism for reliable banknote recognition.

5. **Pulse-Based Coin Detection**
Integrate a coin acceptor module that identifies metallic coin denominations using pulse-counting logic.
6. **Embedded Control Architecture**
Develop Arduino-based control logic to manage motors, valves, vacuum pump, coin gates, and transaction flow.
7. **Hybrid Accumulation and Exchange Logic**
Implement transaction logic supporting coin-to-coin, paper-to-paper, and hybrid accumulation scenarios.
8. **Wireless Inventory Synchronization**
Develop real-time communication with an administrator application using ESP8266 to automatically update stored denomination quantities.

1.4 Significance

The significance of this project lies in its ability to integrate multiple engineering domains into a single ATM prototype. The system combines:

- Mechatronic motion control
- Pneumatic routing mechanisms
- Computer vision-based currency validation
- Pulse-based digital coin recognition
- Hybrid denomination exchange logic
- Real-time wireless inventory management
- Embedded microcontroller coordination

Unlike conventional ATM prototypes that focus solely on dispensing, this system supports multi-mode currency exchange with intelligent denomination selection and inventory-aware validation.

The project serves as a scalable educational platform demonstrating advanced integration of embedded systems, automation, pneumatics, motion control, and intelligent transaction management.

2. Constraints and Earlier Coursework

2.1 Constraints

During the development of the ATM prototype, several engineering constraints influenced system design decisions:

1. **Mechanical Alignment Precision**
The dual-stepper arc motion system required careful calibration to ensure consistent positioning relative to suction channels.
2. **Pneumatic Stability**
Selective airflow routing through normally-closed solenoid valves required precise timing to prevent unintended multi-channel suction.
3. **Image Processing Reliability**
Lighting conditions and camera positioning directly affected banknote recognition performance.
4. **Time-Based Extraction Control**
Since the dispensing system relies on calibrated timing rather than feedback sensors, extensive testing was required to ensure consistent extraction durations.
5. **Power Distribution Management**
Simultaneous operation of multiple drivers, motors, solenoids, and embedded boards required stable multi-voltage supply distribution.

2.2 Earlier Coursework

1. **Electronics and Electronics labs:** The Electronics and Electronics labs course provided the foundational knowledge required for designing stable and reliable electrical subsystems within the ATM. Concepts such as voltage regulation, transistor switching, power supply filtering, motor driving circuits, and load handling were directly applied in integrating solenoid valves, DC motors, stepper motor drivers, and embedded controllers.

2. **Microcontroller Programming:** This course also was extremely important because it made us understand how microcontrollers work and how they should be dealt with and interface them with other components.
3. **Image Processing Fundamentals:** The Image Processing Fundamentals course provided the theoretical and practical background necessary for implementing banknote recognition using Raspberry Pi. Concepts such as image acquisition, preprocessing, grayscale conversion, thresholding, feature extraction, and pattern recognition were applied in validating inserted paper currency.
4. **Software Courses:** Supported modular system design, wireless communication architecture, and administrative monitoring interface development.

These courses provided the technical foundation necessary for implementing the ATM system.

3. Literature Review

Automated Teller Machines have traditionally been designed to provide full banking services. These systems rely on complex proprietary modules for currency validation and dispensing.

Research prototypes have explored embedded control for cash-handling systems; however, many low-cost implementations lack intelligent banknote recognition or integrated inventory management.

Recent advancements in single-board computers such as Raspberry Pi have enabled the application of image processing techniques in currency validation. Additionally, embedded motor drivers and solenoid-based routing mechanisms are widely used in vending and automated dispensing systems.

The ATM prototype developed in this project distinguishes itself by integrating:

- Dual-stepper arc-based mechanical positioning
- On-demand pneumatic vacuum routing
- Servo-controlled coin gating
- Pulse-based metallic coin validation
- Hybrid accumulation logic

- Wireless inventory synchronization

within a unified embedded control architecture suitable for academic applications.

4. Methodology

4.1 System Structure

The ATM prototype was designed as a fully integrated mechatronic system combining structural fabrication, motion control, pneumatic routing, embedded processing, and wireless monitoring.

The system was divided into the following mechanical subsystems:

- External structural housing
- Banknote storage slots
- Coin routing and servo mounting base
- Dual-stepper arc positioning mechanism

Each subsystem was designed individually and later integrated into a unified mechanical architecture.

4.1.1 External Structure and Material Composition

The external enclosure of the ATM was constructed using wooden panels forming the primary structural body of the system. Wood was selected due to ease of machining, availability, and suitability for prototyping.

To withstand mechanical stress generated by the dual NEMA23 motors and vacuum system, internal metal reinforcements were installed. These reinforcements improve rigidity and reduce vibration during arc motion and suction operations.

The external structure provides:

- Mechanical stability
- Protection of internal components

- Isolation between user interface and internal mechanisms

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4.1.2 3D Printed Banknote Storage Slots

The banknote storage slots were fully designed and fabricated using 3D printing technology. Each slot was engineered to:

- Maintain vertical stacking alignment
- Prevent lateral displacement of banknotes
- Ensure consistent exposure of the top banknote for suction extraction

The geometry includes:

- Guided side walls
- Bottom support plate
- Upper clearance gap for suction alignment

The dimensional tolerances were adjusted to balance:

- Friction reduction
- Stack stability
- Prevention of double-note lifting

The printed slots also ensure separation between denominations, minimizing cross-channel mechanical interference.

Material used: PLA .

Printing provided modularity, allowing independent replacement of each denomination slot if needed.

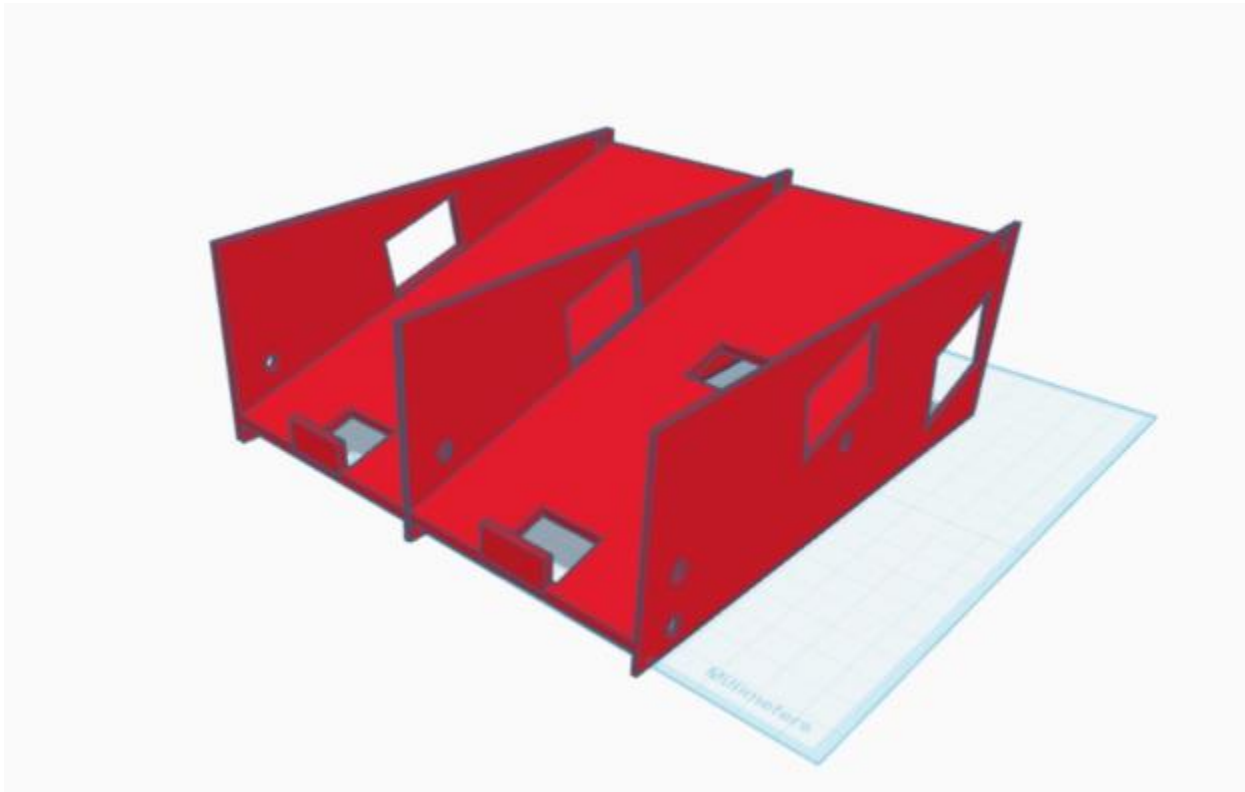


Figure 1(3D Printed Banknote Storage Slots)

4.1.3 3D Printed Coin Routing and Servo Mounting Base

The metallic coin dispensing system is mounted on a custom 3D-printed base designed to integrate:

- Vertical coin stacking channels
- Servo motor mounting brackets
- Gear transmission mechanism
- Coin release gates

Each coin denomination is stored in a dedicated cylindrical channel. At the bottom of each channel, a servo-controlled gate regulates single-coin release.

The servo motors (SG90) are mounted directly onto reinforced printed brackets. Attached 3D-printed gears translate servo rotation (0° – 180°) into mechanical gate movement.

The design ensures:

4.1.5 3D Printed Dual-Stepper Arc Positioning Arm

The arc positioning system consists of a dual-arm structure fabricated using 3D printing. Each arm is mechanically linked to a NEMA23 stepper motor.

The two arms are synchronized and connected through a central shaft that carries four vacuum suction tubes. This shaft serves as:

- Structural connector
- Suction tube support

The arc motion geometry was designed to:

- Provide semi-circular displacement
- Cover all denomination slot positions
- Maintain tube-to-slot perpendicular alignment

Mechanical considerations included:

- Load distribution between motors
- Shaft torsional stability
- Minimizing backlash
- Smooth angular displacement

The dual-motor configuration prevents asymmetric torque stress and improves motion accuracy compared to a single-motor design.

3D Printed Dual-Stepper Arc Positioning Assembly

4.1.6 Limit Switch Homing Mechanism

A mechanical limit switch is mounted at the edge of the 3D printed frame to define the home position of the arc assembly.

The switch is directly connected to the Arduino Mega and ground. During initialization, the stepper motors rotate until the limit switch is triggered, resetting the internal position reference.

This ensures:

- Positional accuracy
- Step error correction
- Safe mechanical calibration



4.2 Pneumatic and Motion Control Subsystem

4.2.1 DC Vacuum Pump

The vacuum pump generates negative pressure required for selective banknote extraction. It is powered by the 12V rail and controlled through an L298N driver.

The pump operates in on-demand mode and activates only during extraction sequences. Once the corresponding solenoid valve opens, negative pressure lifts the top banknote and guides it directly toward the output slot through the aligned suction path.

After successful extraction, the solenoid valve closes and the vacuum pump deactivates.

This direct vacuum-based extraction approach simplifies the mechanical design by eliminating the need for additional roller-based transfer mechanisms.



Figure 3(Dc Vaccum Pump)

4.2.2 Solenoid Valves (12V Normally Closed)

Four normally-closed 12V solenoid valves are used to route vacuum pressure selectively.

Each valve controls one denomination channel. Two L298N drivers control these valves (two valves per driver).

Normally-closed configuration ensures suction isolation when idle.



4.2.3 Pneumatic Routing Tubes

The vacuum routing system consists of:

- 10 mm main tube connected to pump
- Four 6 mm secondary tubes connected to solenoids
- Individual suction tubes aligned with banknote slots

This hierarchical routing ensures isolated airflow control and controlled extraction.



Figure 4(Pneumatic Routing Layout)

4.3 Motion Control Subsystem

4.3.1 NEMA23 Stepper Motors

Two NEMA23 stepper motors provide high torque arc motion control. They are mounted symmetrically to balance load.

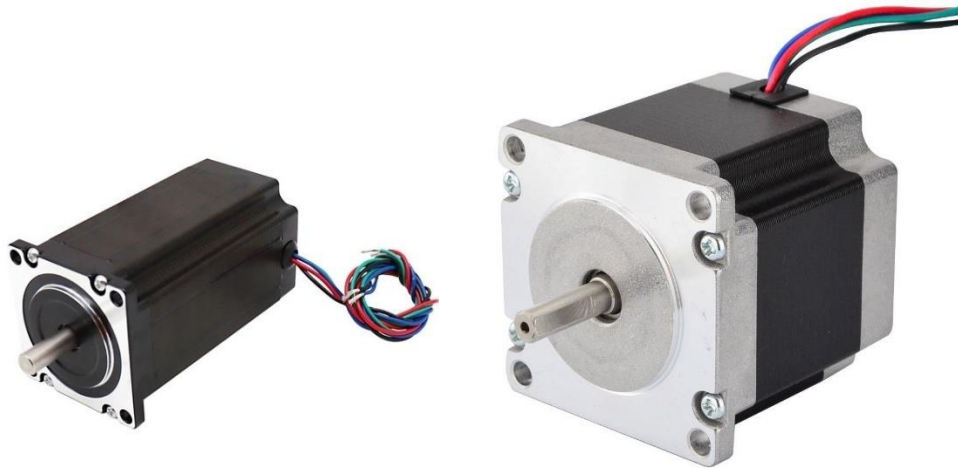


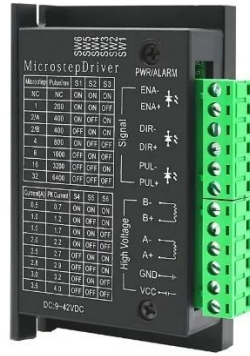
Figure 5(NEMA23 Stepper Motor)

4.3.2 TB6600 Stepper Drivers

Each NEMA23 motor is controlled by a TB6600 driver powered at 12V.

The drivers provide:

- Microstepping
- Current regulation
- Smooth angular motion



4.3.4 Corona DS538HV Servo (Banknote Platform)

The Corona DS538HV servo controls the banknote presentation platform used for image capture positioning.



Figure 8(Corona DS538HV Servo)

4.4 Electronic and Control Subsystem

The electronic subsystem forms the central intelligence layer of the ATM prototype. It coordinates all mechanical, pneumatic, and transactional operations. The subsystem is composed of microcontrollers, motor drivers, sensing modules, user interface devices, and power regulation components.

Each component is described separately below

4.4.1 Arduino Mega 2560

The Arduino Mega 2560 serves as the master controller of the ATM system. The Mega version was selected due to its large number of digital I/O pins and multiple serial communication interfaces, which are necessary for managing the complex hardware architecture of the ATM.

The Arduino Mega is responsible for:

- Controlling dual NEMA23 stepper motors via TB6600 drivers
- Activating three L298N driver modules
- Reading pulse signals from the coin acceptor

- Operating four SG90 servo motors (coin gates)
- Controlling the Corona DS538HV servo (banknote platform)
- Managing vacuum pump activation
- Reading the limit switch homing sensor
- Communicating with Raspberry Pi via wired serial connection
- Communicating with ESP8266 wireless module
- Updating the LCD display
- Reading keypad input

The Arduino executes a state-based control algorithm to manage system transitions between accumulation and dispensing modes.

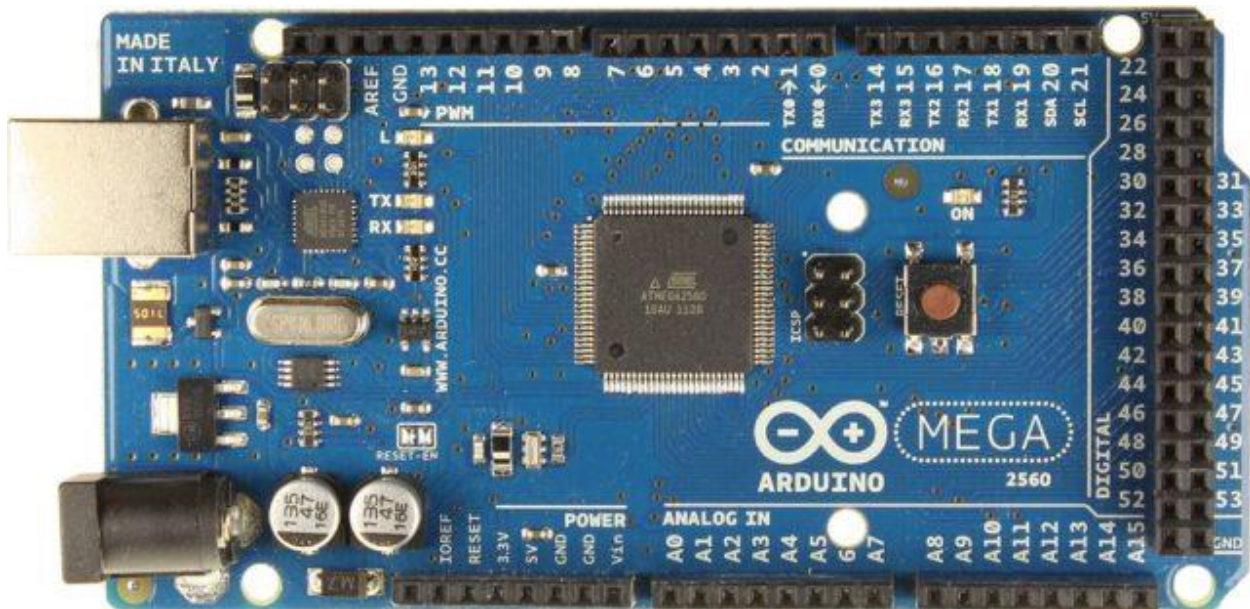


Figure 9(Arduino Mega 2560)

4.4.2 L298N Driver Modules (3 Units)

Three L298N motor driver modules are used within the ATM.

Two L298N modules control the four 12V normally-closed solenoid valves responsible for selective vacuum routing.

The third L298N module controls the DC vacuum pump motor.

This configuration allows controlled switching of inductive loads while maintaining electrical isolation between high-power and low-voltage subsystems.

The L298N drivers provide:

- Voltage isolation
- Adequate current handling capacity
- Reliable switching of inductive loads

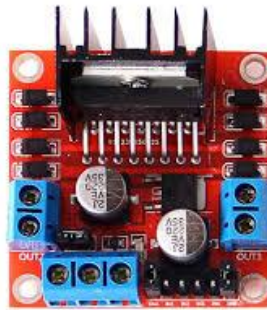


Figure 10(l298n driver motor)

4.4.3 Coin Acceptor Module

The coin acceptor module is used to validate metallic coin denominations during insertion. It operates using pulse-based digital signaling.

The module is powered from the main power supply and provides one digital data output connected directly to the Arduino Mega.

Pulse mapping configuration:

- 1 Shekel → 1 Pulse
- 2 Shekels → 2 Pulses
- 5 Shekels → 5 Pulses
- 10 Shekels → 6 Pulses

The Arduino counts pulses within a defined time interval and converts the pulse count into monetary value.

This digital approach simplifies denomination detection and avoids complex analog measurement circuits.



Figure 11(Coin Acceptor)

4.4.4 Raspberry Pi

The Raspberry Pi subsystem performs paper currency validation using image processing techniques.

It is connected to:

- A camera module positioned above the banknote insertion area
- An LED strip providing controlled illumination
- A local display screen
- The Arduino Mega via serial communication

When a banknote is inserted, the Arduino triggers the presentation servo, positioning the note under the camera. The LED illumination activates to ensure consistent lighting conditions.

The Raspberry Pi captures the image, performs denomination recognition, and transmits the detected value to the Arduino.

This subsystem ensures reliable paper currency validation before storage or exchange.



Figure 12(Raspberry Pi)

4.4.5 ESP8266 Wireless Communication Module

The ESP8266 module enables wireless communication between the ATM and the mobile administrator application.

The module:

- Operates as a wireless access point
- Receives updated inventory values from Arduino
- Transmits real-time stock levels to the mobile application
- Allows administrative monitoring and manual inventory adjustment

The ESP8266 is powered using the 3.3V rail from the power supply.

This module ensures real-time synchronization between physical inventory and digital records.



Figure 13(ESP8266)

4.4.6 LCD 2004 I2C Display

The LCD 20×4 I2C display provides user interaction feedback.

It displays:

- Main menu
- Target denomination
- Accumulated sum
- Error messages
- Inventory availability
- Confirmation prompts

The I2C interface reduces wiring complexity by using only two communication lines with the Arduino Mega.



Figure 14(LCD 2004)

4.4.7 Keypad 4×4 User Interface

The 4×4 keypad serves as the primary user input interface.

It allows users to:

- Select operation mode
- Choose target denomination

- Confirm transactions
- Cancel operations

The keypad is directly connected to the Arduino Mega digital input pins.



*Figure 15(Keypad 4*4)*

4.4.8 Multi-Voltage Power Supply Distribution

The ATM uses a multi-voltage power supply providing:

- 12V → Stepper drivers, solenoid valves, vacuum pump, DC motors
- 5V → Arduino Mega, LCD, SG90 servos
- 3.3V → ESP8266

This separation ensures stable operation and prevents voltage drops during simultaneous motor and solenoid activation.

Proper grounding was implemented to reduce electrical noise interference.



Figure 16(PC Power Supply)

4.4.9 Mobile Administrator Application

A mobile-based administrator interface was developed to provide real-time monitoring of the ATM inventory and operational status. The application communicates wirelessly with the ESP8266 module, which operates as a dedicated access point.

The application consists of a single dashboard interface displaying:

- Total stored monetary value
- Number of active storage slots
- Individual denomination quantities
- Monetary value per denomination
- Real-time connection status (LIVE indicator)

Each denomination is displayed separately with:

- Denomination value
- Quantity (QTY)
- Calculated total value for that denomination
- Editable option for manual adjustment

The application automatically synchronizes inventory data every 5 seconds. Whenever a dispensing operation occurs (either paper currency through vacuum extraction or metallic

coin release via servo gate), the Arduino updates internal counters and transmits the updated values to the ESP8266 module. The mobile application then reflects the updated quantities immediately without manual refresh.

If a denomination reaches zero, it is displayed accordingly in the interface, preventing unavailable combinations from being executed in subsequent transactions.

This administrator interface ensures:

- Real-time stock awareness
- Automatic deduction of dispensed denominations
- Manual stock correction capability
- Remote system monitoring
- Improved operational transparency

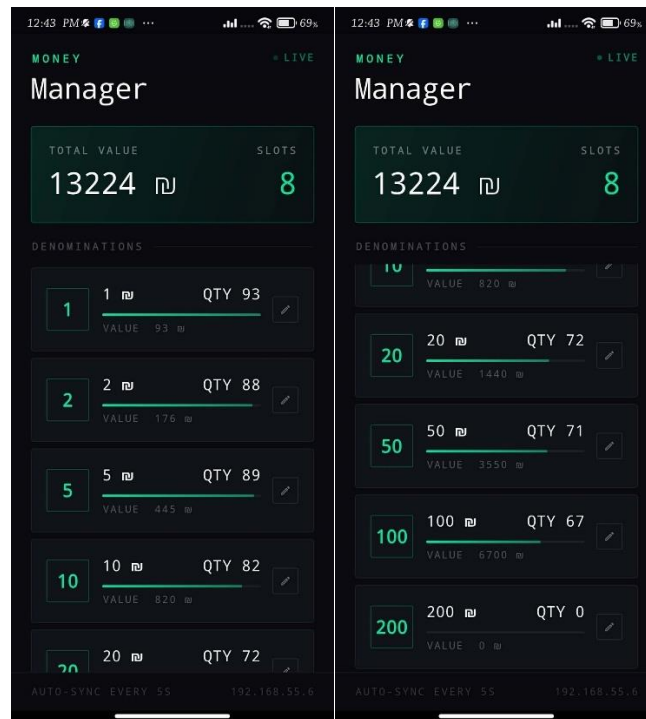


Figure 17(Mobile Administrator Interface)

4.4.10 Wireless Communication Architecture

The ATM system implements a two-layer communication architecture to enable real-time synchronization between the embedded controller and the mobile administrator application.

1. Arduino to ESP8266 Communication (Serial Layer)

Communication between the Arduino Mega 2560 and the ESP8266 module is established through wired serial communication (UART).

The Arduino transmits structured serial messages containing updated inventory values after each transaction. These messages include:

- Denomination identifier
- Updated quantity
- Total stored value

The ESP8266 continuously listens to the serial interface and updates its internal memory variables upon receiving valid data packets.

This wired serial approach ensures:

- Reliable low-latency communication
- Reduced interference compared to wireless internal communication
- Deterministic synchronization between control and networking layers

2. ESP8266 to Mobile Application Communication (Wireless Layer)

The ESP8266 operates as a dedicated WiFi access point, creating a local wireless network. The mobile administrator application connects directly to this access point using the device's IP address.

Inventory data is transmitted wirelessly from the ESP8266 to the mobile application. The application refreshes automatically at fixed intervals (every 5 seconds), ensuring near real-time synchronization.

The wireless communication layer provides:

- Remote monitoring capability
- Real-time inventory updates

- Administrator-level visibility
- Independence from external internet connectivity

4.5 How The System Works

4.5.1 System Startup

1. Power supply energizes all voltage rails.
2. Arduino initializes all actuators and sensors.
3. Stepper motors execute homing sequence.
4. Limit switch defines reference position.
5. LCD displays main menu:
 - BREAK
 - CONSOLIDATING

The system remains idle until a user selection is made.

4.5.2 Accumulation Mode

Coin Accumulation

1. User selects accumulation → coins.
2. Selects target denomination.
3. LCD shows target and sum.
4. Coins inserted via coin acceptor.
5. Pulses counted and sum updated.
 - If sum < target → continue insertion.
 - If sum > target → transaction cancelled.
 - If sum = target → user confirms.
6. Corresponding servo releases higher denomination coin.

7. Inventory updated automatically.

Paper Accumulation

1. User selects accumulation → cash.
2. Banknote inserted.
3. Presentation servo positions note.
4. LED activates.
5. Raspberry Pi captures and validates.
6. LCD displays value.
 - If confirmed → note stored.
 - Sum updated.
7. When sum = target → dispensing initiated.

4.5.3 Dispensing Mode

1. User selects dispensing mode.
2. Selects target amount.
3. System displays predefined combinations.
4. Inventory validated before execution.

After deposit confirmation:

For each required banknote:

1. Stepper motors rotate the arc arm toward the selected denomination slot.
2. The vacuum pump activates.
3. The corresponding normally-closed solenoid valve opens.
4. Negative pressure extracts the top banknote.
5. The banknote is guided directly to the output slot.
6. The solenoid valve closes.

7. The vacuum pump deactivates.
8. Inventory counters are updated automatically.

For metallic coins:

- Corresponding servo rotates.
- Single coin released.
- Inventory decremented.

After completion:

- Stepper returns to home position.
- Limit switch resets position.
- Updated inventory synchronized via ESP8266.

5. Results & Discussion

5.1 Results

The developed ATM prototype successfully performs automated currency exchange operations under different transaction scenarios. The system was able to validate inserted banknotes using image processing, accumulate values accurately, and dispense the selected denominations using the integrated mechanical and pneumatic subsystems.

Additionally, the ATM demonstrated stable operation of the dual-stepper arc positioning mechanism, vacuum-based banknote extraction, and servo-controlled coin release. The real-time inventory tracking system functioned as expected, automatically updating denomination quantities in the administrator mobile application after each dispensing operation.

The prototype achieved reliable performance across accumulation, hybrid exchange, and multi-denomination dispensing modes.

5.2 Discussion

The ATM system integrates mechanical motion control, pneumatic routing, embedded programming, and wireless monitoring into a unified architecture. While the system operates effectively within controlled conditions, it remains a prototype intended for academic demonstration rather than commercial deployment.

The use of calibrated timing instead of physical feedback sensors simplifies the design but may limit long-term industrial reliability. However, the overall integration between hardware and software components demonstrates a practical implementation of intelligent cash-handling logic.

The inclusion of real-time wireless inventory monitoring significantly enhances system usability and administrative control, making the prototype more advanced than traditional simple change machines.

6. Conclusions & Future Work

6.1 Conclusions

In conclusion, the developed ATM prototype successfully demonstrates an intelligent and integrated cash exchange system capable of handling both paper currency and metallic coins. The project achieved its primary objectives of implementing banknote validation using image processing, pulse-based coin detection, controlled denomination accumulation, and multi-denomination dispensing.

The integration between mechanical motion systems, pneumatic vacuum routing, embedded control logic, and wireless inventory monitoring resulted in a functional and reliable prototype. The system proved capable of operating under different transaction scenarios, including coin accumulation, paper accumulation, hybrid exchange, and selective change dispensing.

6.2 Future Work

Although the ATM prototype operates successfully, several improvements could enhance its performance and reliability in future development stages:

- Expanding the image processing algorithm to improve recognition robustness under varying lighting conditions.
- Developing a more advanced mobile application with detailed transaction logs.
- Improving the external enclosure using industrial-grade materials for increased durability

These enhancements would increase system stability, security, and scalability, making the ATM prototype more suitable for extended real-world applications.