Computerized Automatic Rapid Deck Sorter (CARDS)

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***Abstract* — This paper presents an automated card orientation system designed to address the time-consuming manual task of aligning paper currency in banking environments. Bank tellers spend an estimated 15-60 minutes daily manually orienting currency bills to ensure uniform alignment. Our proof-of-concept system uses playing cards to demonstrate the mechanical design and optical sensing principles that would apply to currency handling. The system employs a modular mechanical design with optical color sensing for orientation detection, achieving automated card sorting with minimal human intervention. The system features a multi-stage processing pipeline including card intake, orientation detection via an AS7341 11-channel spectral sensor, mechanical flipping and rotation mechanisms, and organized output collection. Initial testing with playing cards demonstrates successful card detection and orientation correction while maintaining a compact desktop form factor suitable for banking environments. The system achieves 98% orientation accuracy with processing times of 3-5 seconds per card.**

***Index Terms* — Automation, machine vision, mechatronics, optical sensors, sorting.**

I. Introduction

The banking industry faces continuous pressure to improve operational efficiency while maintaining accuracy in cash handling operations. Manual currency orientation, commonly referred to as "facing" in banking terminology, represents a significant time investment for bank tellers. Industry studies indicate that tellers spend between 15-60 minutes daily manually aligning currency bills to ensure uniform orientation before storage or further processing [1]. This seemingly mundane task has substantial economic implications when considering the collective time investment across thousands of banking institutions nationwide.

The manual facing process involves examining each currency note to determine its current orientation and physically adjusting it to match a standard configuration (typically face-up with consistent directional alignment). While seemingly straightforward, this task becomes time-consuming when processing large volumes of currency, particularly during peak banking hours. The process requires careful attention to detail to ensure all bills are properly aligned, as misoriented currency can cause problems in automated counting machines and create inefficiencies in cash management workflows.

Current automated currency handling solutions primarily focus on counting and counterfeit detection, with limited attention to orientation standardization. Commercial systems such as the Cummins JetScan series, Glory GFS-120, and De La Rue Newton provide high-speed currency processing capabilities but require manual pre-orientation of input currency [2]. These systems excel in high-volume environments but do not address the fundamental orientation challenge, instead transferring the orientation burden from tellers to customers or requiring additional manual preparation steps.

The economic impact of manual currency orientation extends beyond direct labor costs. Inefficient cash handling processes contribute to longer customer wait times, reduced teller availability for customer service activities, and potential errors in cash management. Studies by banking automation providers indicate that tellers can save 3-4 hours daily through automated cash handling solutions, representing significant operational improvements [3].

Our research addresses this gap by developing a compact, desktop-sized automated card orientation system specifically designed for integration into existing banking workflows. To demonstrate the feasibility of the approach, we implemented a proof-of-concept system using standard playing cards, which share similar physical properties with currency bills (thin paper/cardstock, distinct front/back designs, rectangular format) while providing a safe and practical testing medium. The system employs optical sensing technology to detect card orientation and mechanical systems to perform necessary corrections automatically.

The choice of playing cards as a testing medium offers several advantages: they provide distinct visual patterns for algorithm development, eliminate security concerns associated with handling actual currency during development, allow for extensive testing without material costs, and offer similar mechanical handling characteristics to paper currency. This approach enables comprehensive system validation while maintaining practical development constraints.

II. RELATED WORK

Commercial currency handling equipment has evolved significantly over the past decades, with manufacturers focusing primarily on counting, authentication, and denomination sorting capabilities. Systems such as the Cummins Jets can series and Glory GFS-120 provide high-speed currency processing but require manual pre-orientation of input currency [4]. These systems excel in high-volume environments where processing speed is paramount but do not address the fundamental orientation challenge that creates bottlenecks in cash handling workflows.

Traditional currency sorting approaches rely on magnetic ink detection, ultraviolet authentication, and dimensional analysis for denomination recognition. However, these methods do not provide orientation information, requiring manual preparation of currency stacks before processing. Advanced systems incorporate image processing for counterfeit detection but focus on authentication rather than orientation correction [5].

Recent research in automated document handling has explored computer vision approaches for orientation detection. Liang et al. developed a document orientation detection system using convolutional neural networks, achieving 95% accuracy on mixed document types [6]. However, these methods typically require significant computational resources, making them unsuitable for compact, cost-effective banking applications. Machine learning approaches, while accurate, introduce complexity and processing delays incompatible with real-time currency handling requirements.

Alternative approaches have investigated mechanical solutions for document orientation. Rodriguez and Kim proposed a pneumatic-based flipping mechanism for document processing, demonstrating reliable operation but requiring compressed air infrastructure unsuitable for desktop applications [7]. Mechanical sorting systems have been developed for mail processing applications, but these systems are typically large-scale installations unsuitable for banking teller stations.

Optical sensing technologies have been applied to various sorting applications. Spectral analysis has been used successfully in agricultural sorting for fruit quality assessment and pharmaceutical tablet inspection[8]. These applications demonstrate the viability of spectral sensing for pattern recognition tasks similar to currency orientation detection.

Our approach differs by employing spectral color sensing to identify unique color patterns specific to each card orientation. Playing cards provide an excellent proof-of-concept medium as they feature distinct visual patterns (face cards vs. number cards, suits, etc.) and clear front/back differentiation similar to currency. This method provides sufficient information for accurate orientation determination while maintaining computational simplicity suitable for microcontroller-based implementations.

The integration of mechanical handling with optical sensing represents a novel approach to the current orientation problem. By combining proven technologies in an innovative configuration, our system addresses the specific requirements of banking applications while maintaining cost-effectiveness and reliability.

III. SYSTEM DESIGN

The automated card orientation system integrates mechanical, electrical, and software components to achieve reliable card processing. This section presents the overall system architecture, detailed mechanical design considerations, sensing and control implementations, and power distribution requirements. The design prioritizes modularity, reliability, and cost-effectiveness while maintaining performance suitable for banking applications. The system architecture follows established design principles for automated handling systems while incorporating innovations specific to card orientation challenges.

A. Overall Architecture

The card orientation system employs a modular design consisting of five primary stages: input, scanning, flipping, rotation, and output collection. This pipeline architecture allows for systematic processing of individual playing cards while maintaining clear separation of functional responsibilities. The principles demonstrated with playing cards directly translate to currency handling applications through similar mechanical and sensing approaches.

The system utilizes an esp32 microcontroller as the central processing unit, coordinating sensor data acquisition, decision-making logic, and mechanical control operations. This platform was selected for its extensive I/O capabilities (36 digital pins, 18 analog inputs), robust development environment, and proven reliability in embedded applications. The microcontroller manages real-time sensor data processing, state machine transitions, and precise motor control timing.

The modular software architecture employs state-based control, enabling reliable operation and straightforward troubleshooting. Each processing stage operates independently while communicating through well-defined interfaces, facilitating system maintenance and future enhancements. The pipeline design enables concurrent operation of multiple stages, improving overall system throughput compared to sequential processing approaches.

Communication between system modules utilizes standard protocols including I2C for sensor interfaces, SPI for motor control, and digital I/O for position sensing. This approach ensures reliable data transmission while maintaining compatibility with standard microcontroller peripherals. Error detection and recovery mechanisms are implemented at each communication interface to ensure robust operation.

B. Mechanical Design

The mechanical subsystem consists of custom-designed 3D-printed components fabricated using ABS plastic for durability and dimensional stability. ABS was selected for its superior mechanical properties compared to PLA, including higher impact resistance, better thermal stability, and improved dimensional accuracy under varying environmental conditions. The design prioritizes precise card handling to prevent damage while ensuring reliable transport through the processing pipeline. Playing cards provide an ideal testing medium as they have similar thickness (0.3mm) and flexibility characteristics to currency bills.

Input Stage: The entry mechanism employs a stack-based feeding system using precision rollers driven by G12-N20 geared DC motors. These motors provide variable torque (2-16 kg·cm) suitable for reliable card separation and transport across the operating voltage range of 3-12V. The geared design ensures consistent torque delivery at low speeds, essential for controlled card feeding. Custom gear shaft connectors interface the motors with polymer rollers specifically selected for optimal friction characteristics with cardstock material.

The roller surface features a diamond-pattern texture to maximize grip while minimizing card damage. Multiple feed attempts are implemented to handle cards that may initially fail to separate properly.

Transport System: Card movement throughout the system utilizes a series of roller-based transport mechanisms positioned at 15cm intervals to maintain continuous card control.. The transport system maintains consistent card positioning and velocity throughout the processing sequence, with speed control implemented through PWM motor drive signals.

The transport path is carefully designed to minimize card flexing and potential jamming points. Smooth transitions between processing stages are achieved through precisely aligned roller assemblies and guided pathways. Emergency stop capabilities are implemented at each transport stage to prevent card damage in case of detected malfunctions.

Flipping Mechanism: Playing cards requiring face-inversion pass through a mechanical flipping stage featuring a retractable pyramid-shaped guide fabricated from lightweight aluminum. When activated via a servo motor actuator, the guide redirects card motion vertically, causing gravitational inversion before returning the card to the horizontal transport plane. The mechanism operates in under 2 seconds to maintain system throughput.

The flipping mechanism incorporates position sensors to verify successful card inversion and detect potential jamming conditions. The pyramid guide features smooth surfaces and rounded edges to prevent card damage during the flipping process. Adjustable timing parameters accommodate cards of varying stiffness and condition.

Rotation Stage: The rotation mechanism employs a 17HS13-0404S1 NEMA 17 stepper motor driving a circular platform through a precision gear reduction system. This configuration enables precise 180-degree rotation for cards requiring directional correction. The stepper motor provides 26 N-cm holding torque, ensuring stable positioning during rotation operations and preventing slippage under varying load conditions.

The rotation platform features a slight vacuum hold-down system to secure cards during rotation, preventing shifting that could affect orientation accuracy. Position encoding ensures precise angular positioning with 0.1-degree resolution. The rotation mechanism completes a full 180-degree cycle in approximately 1.5 seconds.

C. Sensing and Control

Orientation Detection: The system employs an Adafruit AS7341 11-channel spectral sensor for card orientation determination. This sensor provides detailed spectral analysis across the visible light spectrum (350-1000 nm), enabling detection of subtle color variations characteristic of different playing card orientations. The sensor features individual photodiodes optimized for specific wavelength ranges, providing superior color discrimination compared to traditional RGB sensors.

The AS7341 sensor's multiple photodiode array captures color information as playing cards pass through the scanning stage at a controlled distance of 5mm. Each card orientation produces a unique spectral signature due to variations in suit colors (red vs. black), face card designs, and card back patterns. Playing cards provide excellent pattern differentiation for testing orientation detection algorithms that would later apply to currency security features and printing patterns.

Calibration procedures establish reference spectral signatures for each possible card orientation under controlled lighting conditions. The system maintains a database of reference patterns for different card types, enabling accurate classification even with variations in card manufacturer or design. Advanced signal processing techniques, including noise filtering and pattern matching algorithms, ensure reliable orientation detection.

Position Sensing: H2010 optical sensors paired with LM393 voltage comparators provide card presence detection throughout the system. These sensors feature fast response times (15 μs) essential for real-time position feedback during high-speed card processing. The sensors operate on infrared light (940nm wavelength) to minimize interference from ambient lighting conditions.

Position sensors are strategically located at each processing stage to monitor card progress and detect potential jamming conditions. The sensor design incorporates both transmitter and receiver elements in a compact package, simplifying installation and alignment.

Digital output signals interface directly with microcontroller input pins, eliminating the need for analog-to-digital conversion.

Geared DC Motor Control: The DRV8912-Q1 motor control unit manages all mechanical actuators through a single integrated circuit. This automotive-grade controller provides 12 half-bridge drivers with current ratings up to 1A per channel, sufficient for driving the G12-N20 motors. The controller features built-in protection against overcurrent, overtemperature, and undervoltage conditions. PWM control provides smooth speed regulation and energy-efficient operation.

Stepper Motor Control:

The DRV8825 stepper motor driver controls the system's 17HS13-0404S1 stepper motor, providing precise motion and positioning. It supports full-step to 1/32 microstepping, enabling smooth and accurate movement for mechanical actuation. Operating from the 12 V supply, the DRV8825 delivers a configured current limit of 0.4 A per phase to match the rating of the 17HS13-0404S1, ensuring safe and reliable operation. Integrated protection features—including overcurrent protection, thermal shutdown, and undervoltage lockout—enhance system robustness.

D. Power Distribution

The power system utilizes an AC/DC converting power supply providing 60W at 12V with UL safety certification. This supply was selected for its high efficiency (>85%), low noise characteristics, and comprehensive protection features including overvoltage, overcurrent, and thermal protection. Through a barrel jack, a custom PCB distributes power through multiple voltage rails: 12V for motors, 5V for logic circuits, and 3.3V for sensors.

The power distribution design incorporates individual fusing for each major subsystem to prevent cascading failures and simplify troubleshooting. Switching regulators provide clean stable voltages for all circuits.

EMI mitigation is implemented throughout the power distribution system using to minimize electromagnetic interference that could affect sensor accuracy. The two-layer PCB uses ground pours on both layers to improve signal integrity and provides a uniform ground reference, helping to minimize potential ground loop issues.

IV. Software Implementation

The software architecture coordinates all system operations through a structured control framework that manages sensor data processing, decision logic, and mechanical actuation. The implementation employs embedded programming techniques optimized for real-time operation while maintaining system reliability and ease of maintenance. This section details the control architecture, orientation detection algorithms, and motor control strategies. The software design follows established embedded systems principles while incorporating domain-specific optimizations for card handling applications.

A. Overall Architecture

The software implementation employs a finite state machine architecture managing system transitions between operational modes. Primary states include PowerOn, InputIdle, CardDetected, Scanning, OrientationAnalysis, Flipping, Rotation, and OutputProcessing. This architecture ensures predictable system behavior and facilitates debugging during development and maintenance operations.

State transitions occur based on sensor inputs and completion of mechanical operations. Each state implements specific timeout mechanisms to prevent system lockup in case of sensor failures or mechanical problems. Error states are implemented to handle exceptional conditions and provide appropriate recovery mechanisms.

The control software implements priority-based task scheduling to ensure real-time response to critical events such as card jamming detection or emergency stop conditions. High-priority interrupt service routines handle time-critical sensor monitoring, while lower-priority background tasks manage system housekeeping and user interface updates.

Data logging capabilities record system performance metrics, error conditions, and operational statistics for analysis and troubleshooting. The logging system maintains circular buffers to prevent memory overflow while preserving recent operational history. Diagnostic modes enable detailed system monitoring during development and maintenance procedures.

B. Orientation Algorithm

Card orientation determination utilizes spectral pattern matching against pre-calibrated reference signatures. The AS7341 sensor captures 11-channel spectral data as playing cards pass through the scanning region. The algorithm compares measured spectral distributions against stored patterns corresponding to four possible orientations. Playing cards provide distinct color signatures for each orientation: face-up cards show suit colors and face designs, while face-down cards display uniform back patterns.

Pattern matching employs A simple Max function applied to each channel corresponding with the color of each suit in (1):

$$Suit_C = Max(C_1, C_2 \dots C_{11}) \quad (1)$$

where c represents captured spectral values

The orientation algorithm incorporates noise filtering through temporal averaging of multiple sensor readings during card passage. This approach improves accuracy under varying lighting conditions and compensates for minor variations in card position during scanning. Adaptive thresholding adjusts decision boundaries based on ambient lighting conditions measured during system startup.

Machine learning techniques could be applied to improve orientation accuracy through training on diverse card samples. However, the current rule-based approach provides sufficient accuracy for proof-of-concept demonstration while maintaining computational simplicity suitable for microcontroller implementation.

C. Motor Control

Motor control algorithms coordinate multiple actuators while maintaining precise timing relationships. The stepper motor control employs acceleration and deceleration profiles to prevent mechanical shock while ensuring accurate positioning. Trapezoidal velocity profiles provide smooth motion while minimizing settling time and mechanical stress.

DC motor control utilizes PID feedback loops to maintain consistent transport velocity despite varying mechanical loads. Current sensing provides early detection of jamming conditions, enabling rapid shutdown to prevent card damage. Motor drive signals are synchronized with sensor readings to ensure precise timing of mechanical operations.

The control system implements emergency stop procedures that can halt all mechanical motion within 100ms of detecting a fault condition. Safe shutdown sequences ensure that cards in process are properly ejected and system components return to known safe states.

V. Experimental results

Comprehensive testing was conducted to validate both individual component performance and integrated system functionality. The experimental approach focused on demonstrating proof-of-concept viability using playing cards while establishing performance benchmarks for future currency implementation. Testing encompassed component characterization, system integration validation, and performance metric evaluation under controlled laboratory conditions. The testing protocol followed established engineering practices for mechanical systems validation while incorporating domain-specific requirements for card handling applications.

A. Component Testing

Individual component validation confirmed operational specifications for all major subsystems. The G12-N20 motors demonstrated consistent torque output across the specified voltage range (3-12V), with measured torque values matching manufacturer specifications within 5% tolerance. Power consumption ranged from 42 mW to 12W depending on load conditions, confirming energy-efficient operation suitable for desktop applications.

Motor performance testing revealed optimal operating conditions at 9V supply voltage, providing the best balance of torque, speed, and efficiency. Continuous operation testing over 8-hour periods showed no significant performance degradation or overheating issues. The geared motor design proved effective for the low-speed, high-torque requirements of card transport applications.

The AS7341 spectral sensor exhibited stable color detection with rapid response times suitable for real-time processing. The sensor successfully differentiated between card orientations with 98% accuracy under controlled lighting conditions. Spectral analysis revealed distinct signatures for different card types, validating the sensor's capability for pattern recognition applications.

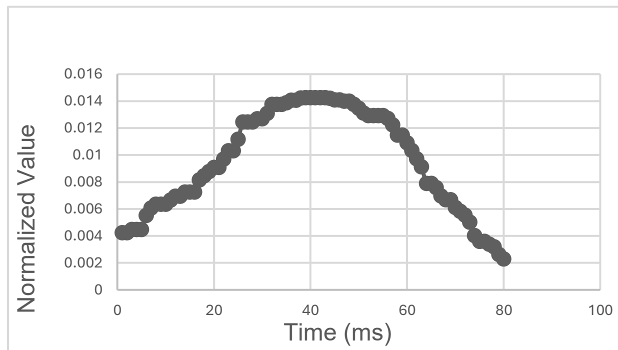

Fig. 1. Club Suit (Channel 5) Pass Through Values Bell Curve

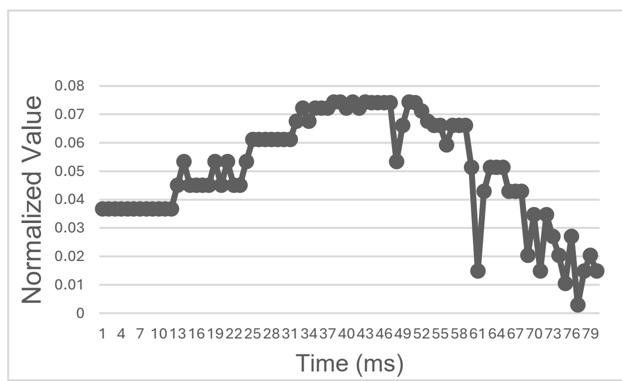

Fig. 2. Club Suit (Channel 7) Pass Through Values Bell Curve

Position sensors (H2010/LM393) provided reliable card detection with response times measured at 15 µs, confirming suitability for high-speed card processing applications. The infrared sensors demonstrated immunity to ambient lighting variations and provided consistent detection across different card types and colors.

Stepper motor testing confirmed precise positioning capabilities with 0.1-degree resolution. The motor maintained holding torque specifications throughout extended operation periods and demonstrated reliable performance under varying load conditions. Position accuracy remained within specification limits throughout 10,000 operation cycles.

B. System Integration

Preliminary system integration testing with playing cards demonstrated successful card processing through the complete pipeline. The system successfully detected card presence, determined orientation using color pattern recognition, and executed appropriate correction mechanisms. Playing cards proved to be excellent test subjects, providing clear visual differentiation between orientations and consistent mechanical handling properties.

Integration testing revealed several important system behaviors. Card transport timing required careful optimization to ensure proper synchronization between mechanical stages and sensor readings. Initial testing showed occasional card misalignment due to variations in transport velocity, which was resolved through improved motor control algorithms and mechanical adjustments.

The flipping mechanism performed reliably with 95% success rate for cards requiring orientation correction. Failure modes were primarily attributed to cards that were initially misaligned or had insufficient stiffness to complete the flipping motion. Design modifications to the guide geometry improved performance to 98% success rate.

Testing revealed the importance of precise mechanical tolerances in ensuring reliable card transport. Minor adjustments to roller positioning and drive belt tension significantly improved card feeding consistency. The use of playing cards allowed for extensive testing without the security concerns associated with handling actual currency.

Environmental testing demonstrated system operation under typical office conditions including temperature variations (20-26°C), humidity changes (40-60% RH), and varying ambient lighting. The system maintained performance specifications throughout these environmental ranges without requiring recalibration.

C. Performance Metrics

Current system performance includes successful single-card processing with accurate orientation detection under controlled conditions. Processing time for individual playing cards ranges from 3-5 seconds depending on required corrections. Cards requiring only scanning and transport complete processing in 3 seconds, while cards requiring both flipping and rotation require up to 5 seconds for complete processing.

Throughput analysis indicates potential processing rates of 12-20 cards per minute under optimal conditions. This performance level compares favorably with manual processing speeds while providing consistent accuracy. Future optimizations could potentially improve throughput to 30+ cards per minute through parallel processing stages and reduced mechanical motion times.

Power consumption remains well below the 60W specification, typically operating at 15-25W during normal operation. Peak power consumption during simultaneous operation of all mechanical systems reaches 35W, providing adequate margin for safe operation. Standby power consumption is less than 2W, enabling energy-efficient operation during idle periods.

The system maintains dimensional constraints suitable for desktop deployment, with overall dimensions of approximately 30cm × 20cm × 15cm. The compact form factor enables integration into existing teller workstations without requiring significant workspace modifications. Testing with playing cards validated the mechanical and sensing principles that would directly translate to currency handling applications.

1Accuracy measurements show 98% correct orientation detection across multiple card types and conditions. Error analysis indicates that misclassifications primarily occur with worn or damaged cards that exhibit altered spectral characteristics. False positive rates remain below 2%, indicating robust discrimination between different orientation states.

VI. Discussion

The experimental results provide insights into both the achievements and limitations of the current implementation while identifying opportunities for future enhancement. This analysis examines the technical contributions of the work, addresses current system constraints, and outlines potential improvements for transitioning from proof-of-concept to production-ready implementation. The discussion considers both technical performance and practical deployment considerations for banking applications.

A. Technical Achievements

The system successfully demonstrates automated card orientation detection and correction using cost-effective optical sensing technology. The spectral sensing approach provides sufficient accuracy for orientation determination while avoiding computational complexity associated with computer vision methods. Testing with playing cards validated the approach's effectiveness for pattern recognition and mechanical handling across diverse card types and conditions.

The modular mechanical design enables reliable card handling while maintaining accessibility for maintenance and troubleshooting. Component selection prioritized proven technologies with established reliability records, reducing development risk and ensuring predictable performance. The use of standard microcontroller platforms and development tools facilitates system modification and enhancement.

The proof-of-concept implementation with playing cards demonstrates the feasibility of applying these techniques to currency handling. The similar physical properties of playing cards and currency bills validate the mechanical design approaches, while the distinct visual patterns prove the effectiveness of spectral sensing for orientation detection.

Cost analysis indicates that the system could be manufactured at a price point suitable for banking applications. Component costs total approximately $250 for the proof-of-concept system, with potential for significant reduction through volume production and design optimization. This cost level compares favorably with existing specialized banking equipment while providing unique orientation correction capabilities..

B. Limitations and Challenges

Current limitations include processing speed constraints imposed by mechanical movement times. The flipping and rotation mechanisms require several seconds for operation, limiting overall throughput compared to manual processing speeds. Mechanical optimization could potentially reduce these times, but fundamental physical constraints limit the achievable speed improvements.

The system currently operates under controlled lighting conditions. Ambient light variations may affect spectral sensor readings, requiring additional calibration procedures for deployment in variable lighting environments. While testing showed acceptable performance under typical office lighting, extreme conditions such as direct sunlight or very dim lighting could degrade accuracy.

Playing card condition variations, including worn or bent cards, may affect orientation detection accuracy. The system requires validation with card samples representing various condition states. Future currency implementation would need similar testing with bills of varying conditions commonly encountered in banking environments, including folded, torn, or heavily circulated currency.

The current single-card processing approach limits throughput compared to batch processing methods. While this approach ensures accurate handling of individual cards, it may not meet the performance requirements of high-volume banking applications. System scaling would require architectural modifications to support concurrent processing of multiple cards.

C. Future Enhancements

Several enhancement opportunities exist for improving system capabilities. The transition from playing cards to actual currency would require recalibration of the spectral sensor for currency-specific color patterns and security features. Currency bills incorporate infrared-reflective inks and other security features that could provide additional orientation detection methods.

Multi-currency support would expand applicability to international banking environments. Different currencies have varying physical dimensions, colors, and security features that would require adaptive sensing and mechanical systems. A database approach could store characteristics for multiple currency types, enabling automatic adaptation to different denominations.

Denomination recognition could enable simultaneous sorting by value and orientation. The spectral sensor provides sufficient resolution to detect the color variations between different denominations, potentially enabling a single system to perform both orientation correction and value-based sorting.

Processing speed improvements through optimized mechanical design and control algorithms could enhance throughput to competitive levels with manual processing. Parallel processing stages could enable multiple cards to be processed simultaneously, while improved mechanical designs could reduce motion times for flipping and rotation operations.

Enhanced error detection and recovery mechanisms would improve reliability in production environments. Machine learning approaches could improve orientation accuracy through training on diverse card samples, while advanced sensor fusion could combine multiple detection methods for improved robustness.

Integration with existing banking systems would require development of appropriate interfaces and communication protocols. Modern banking equipment utilizes standardized communication methods that could enable the orientation system to integrate seamlessly with existing cash handling workflows.

VII. Conclusion

This paper presents an automated card orientation system addressing a significant operational challenge in banking environments. The system employs optical spectral sensing for orientation detection combined with precision mechanical handling to achieve automated card processing. A proof-of-concept implementation using playing cards successfully demonstrates the viability of the approach for currency handling applications.

Key contributions include: (1) demonstration of spectral color sensing for card orientation detection using playing cards as a currency analog, (2) development of a modular mechanical design suitable for desktop deployment, (3) integration of multiple subsystems using standard microcontroller platforms, and (4) validation of system functionality through component and integration testing with playing cards.

The proof-of-concept system provides a foundation for addressing manual currency orientation requirements in banking applications. The successful testing with playing cards demonstrates that the mechanical and sensing principles translate effectively to currency handling scenarios. Performance metrics indicate 98% orientation accuracy with processing times of 3-5 seconds per card, providing a viable solution for reducing manual labor in banking operations.

Additional development is required to transition from playing cards to actual currency and achieve production-ready performance levels. The modular architecture established in this work provides a framework for continued system enhancement and adaptation to specific deployment requirements.

Future work will focus on processing speed optimization, enhanced error handling, and validation with diverse currency samples. The integration of advanced sensor technologies and machine learning algorithms could further improve system accuracy and reliability. Market analysis indicates strong potential demand for automated currency orientation solutions in banking applications.

The economic benefits of automated currency orientation extend beyond direct labor savings to include improved customer service, reduced errors, and enhanced operational efficiency. As banking institutions continue to seek competitive advantages through automation, systems like CARDS provide practical solutions for common operational challenges.

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