ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Cyber Guandan AR Tabletop with Real-Time Visual Assistance and Action Monitoring

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Abstract

This report presents the final design of Cyber Guandan AR Tabletop with Real-Time Visual Assistance and Action Monitoring, a cyber-physical assistant for the Chinese card game Guandan. The final prototype combines an automatic four-direction card dealer with a camera-based software assistant. The dealer uses an ESP32-based integrated printed circuit board (PCB), a bottom-mounted N20-10D feed motor, a TT 1:48 turntable motor, a Hall sensor, a push button, and 3D-printed transmission parts to distribute two decks of cards to four players. The software assistant uses a camera to recognize a player's visible hand cards and a rule engine to recommend legal Guandan plays. During the semester, the design was refined from recognizing each card during mechanical transfer to a more practical system that separates reliable dealing from tabletop visual assistance. Final bench tests showed stable Hall homing, repeatable 108-card dealing in normal and pseudo-random modes, and reliable hand recognition when the camera was placed correctly. The resulting system demonstrates a compact tabletop platform that automates card distribution and augments physical play with real-time digital assistance.

Contents

1 Introduction

Guandan is a four-player climbing card game played with two standard decks, for a total of 108 cards [1]. Each player receives 27 cards at the beginning of a round. Manual dealing is repetitive and can introduce uneven piles, dropped cards, or delays before the actual game begins. Players who are learning Guandan also need help understanding which combinations are legal and which cards can beat the previous play.

The purpose of this project is to build a tabletop assistance system that reduces the manual burden of starting and playing a Guandan round. The final system has two coupled parts. The first part is a physical automatic dealer that distributes cards toward four player positions. The second part is a camera-based assistance program that recognizes the player's hand cards and recommends legal plays through a local web interface.

The project title, Cyber Guandan AR Tabletop with Real-Time Visual Assistance and Action Monitoring, is interpreted as a cyber-physical tabletop augmentation. The term "AR Tabletop" does not refer to a headset-based augmented reality display. Instead, the physical table is augmented by automatic card dealing and by a digital visual layer that reads the player's hand state and provides game assistance. The "Action Monitoring" portion of the final implementation refers to monitoring the current hand state, previous play, and possible legal actions in the assistance software, rather than tracking every card as it leaves the mechanical dealer.

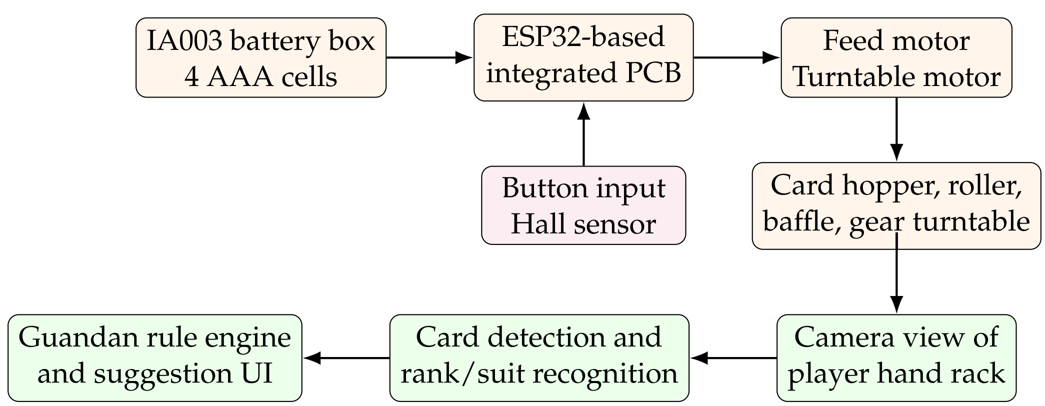

Figure 1: Overall cyber-physical system block diagram. The final system combines automatic four-direction dealing with camera-based hand recognition and Guandan play assistance.

As shown in Figure 1, the hardware and software are intentionally separated at the functional level. The embedded controller handles deterministic actuation, homing, and button input. The computer vision software runs on a computer connected to a camera, where it has enough processing power and screen space for recognition, user controls, and play suggestions. This division made the project more achievable while still preserving the original assistance goal.

2 Design Evolution and Requirements

2.1 Scope Refinement

The original design document proposed recognizing each card while it was being dealt, recording the four output piles, and displaying the largest card in each pile. During prototyping and weekly meetings, the team found that this approach placed a high mechanical precision requirement on the dealer. A transfer-recognition channel would need consistent card speed, card angle, lighting, camera placement, and spacing between consecutive cards. Since the team did not include a dedicated mechanical engineering member, building a sufficiently precise transfer path while also completing a reliable dealer created high integration risk.

The final design therefore refined the scope. The mechanical system focuses on reliable card feeding and four-direction distribution. The vision system moved from the transfer path to the player hand rack, where the cards are relatively static and the camera can observe the card faces directly. This change keeps the project aligned with the original visual assistance theme while reducing the dependence on a tightly controlled mechanical recognition channel. Table 1 summarizes the major block-level changes.

Table 1: Main design changes from the original design document to the final prototype.

Original design direction	Final design direction	Reason for change
Recognize each card during mechanical transfer	Recognize the player's visible hand cards after dealing	Lower mechanical precision requirement and better match the assistance goal
Servo guide chute for distribution	Gear-driven rotating dealer body	Simpler four-direction motion with fewer unused actuators
Raspberry Pi and Arduino Mega control structure	ESP32-based integrated PCB plus external computer for vision	Matches the actual hardware platform and separates motor control from image processing
Hardware level buttons and local pile display	Web-based level, previous-play input, and recommended play display	More flexible interface for Guandan decisions
Maximum-card calculation for four piles	Rule-based legal play recommendation and hand-state monitoring	More useful to a player during a real game

2.2 High-Level Requirements

The final system requirements are listed in Table 2. Following the instructor guidance for projects with major design changes, these high-level requirements were updated to match the final prototype instead of being forced to follow the earlier transfer-recognition concept from the design document.

Table 2: Final high-level requirements.

ID	Requirement	Verification summary
HLR 1	The dealer shall distribute 108 cards to four player positions, with 27 cards per player in normal mode.	Full-deck dealing trials and pile count checks.
HLR 2	The dealer shall support pseudo-random dealing while still ending with 27 cards per player.	Long-press and serial-command tests in pseudo-random mode.
HLR 3	The turntable shall home repeatably using the Hall sensor before and after dealing.	Repeated homing trials with no timeout.
HLR 4	A short button press shall start normal dealing, and a press of at least 1 s shall start pseudo-random dealing.	Button classification trials.
HLR 5	The camera assistance system shall recognize the visible player hand cards when the camera is placed normally.	Hand-rack recognition trials using the final user interface.
HLR 6	The software shall recommend legal Guandan responses from the recognized hand, selected level, previous player's cards, and previous-play combination type.	Scripted rule scenarios and user-interface tests.

3 System Design

3.1 System Overview

The system has three major blocks: the mechanical dealer, the embedded controller, and the camera assistance software. The mechanical dealer stores the deck, feeds one card at a time, and rotates the upper structure toward four directions. The embedded controller drives the two motors and uses the Hall sensor for homing. The software assistant reads a camera frame of the player's hand rack, recognizes cards, and applies Guandan rules to recommend an action.

Figure 2 shows the assembled dealer. The card stack sits in a 3D-printed holder at an angle of approximately 12°. This angle helps the bottom card contact the feed roller while keeping the stack guided by the side walls. A DIY baffle at the front blocks the cards above the bottom card, so the roller primarily moves only the bottom card out of the stack.

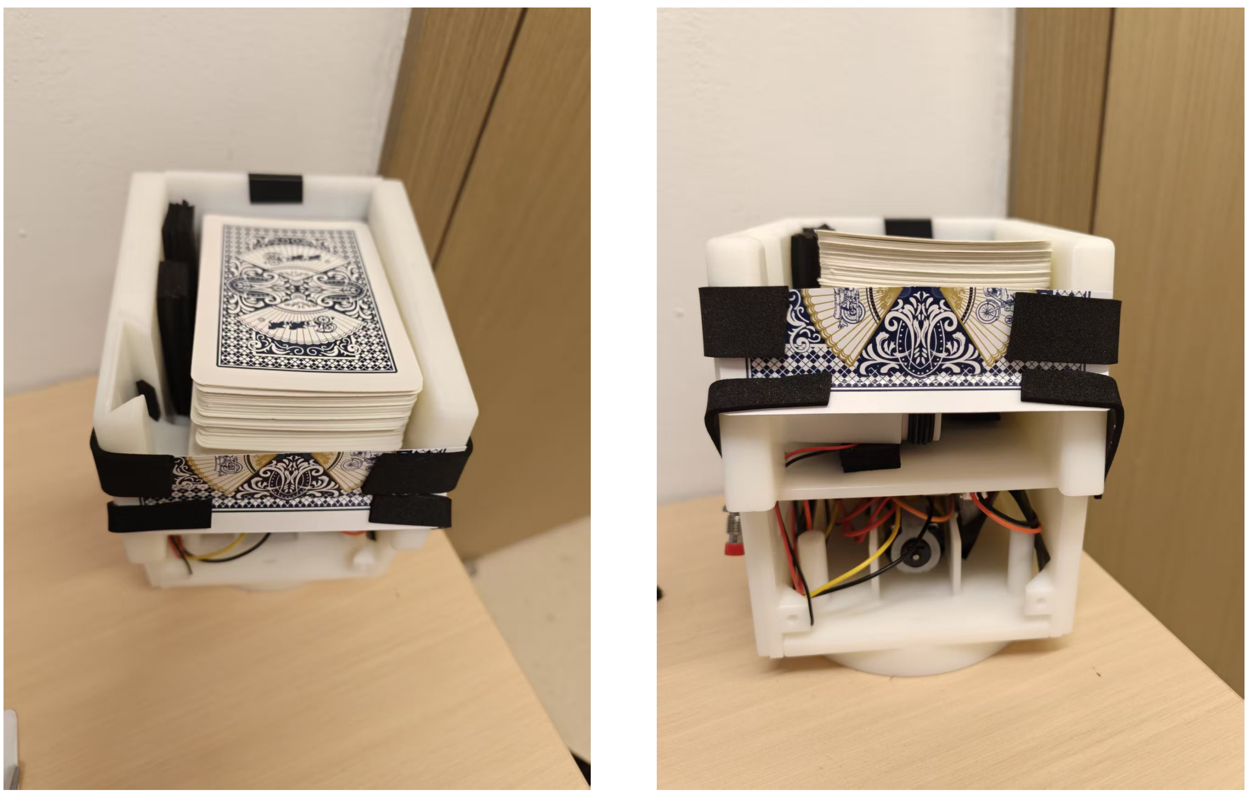

Figure 2: Final automatic dealer prototype. The left image shows the tilted card stack and front output direction. The right image shows the assembled four-direction dealer from the front.

3.2 Mechanical Card Feeding

The feed mechanism uses an N20-10D direct-shaft motor rated at 400 rpm. A 7 mm roller is mounted on the motor shaft, and five O-rings are installed on the roller to increase friction against the bottom card. Unlike the original vertical transfer-channel design, the final design places the feed motor below the card stack. The motor pushes the bottom card upward and outward, while the DIY baffle holds the cards above it.

The firmware drives the feed motor using a reverse-then-forward sequence. The reverse pulse slightly relaxes the card stack and reduces the chance that the next card is dragged forward with the bottom card. The final timing values are 430 ms reverse, 50 ms pause, and 320 ms forward. The feed timing can also be adjusted through the serial command interface. Figure 3 shows the final bottom-feed arrangement.

The estimated unloaded roller surface speed is calculated with Equation 1:

$$v = \frac{\pi d n}{60}, \tag{1}$$

where d is the roller diameter and n is the motor speed in revolutions per minute. With $d = 7$ mm and $n = 400$ rpm, the ideal surface speed is approximately 147 mm/s. A 320 ms forward pulse therefore gives about 47 mm of ideal roller surface travel. Because the bottom card only needs to be advanced far enough to leave the stack and continue sliding out, this timing range was sufficient after prototype tuning.

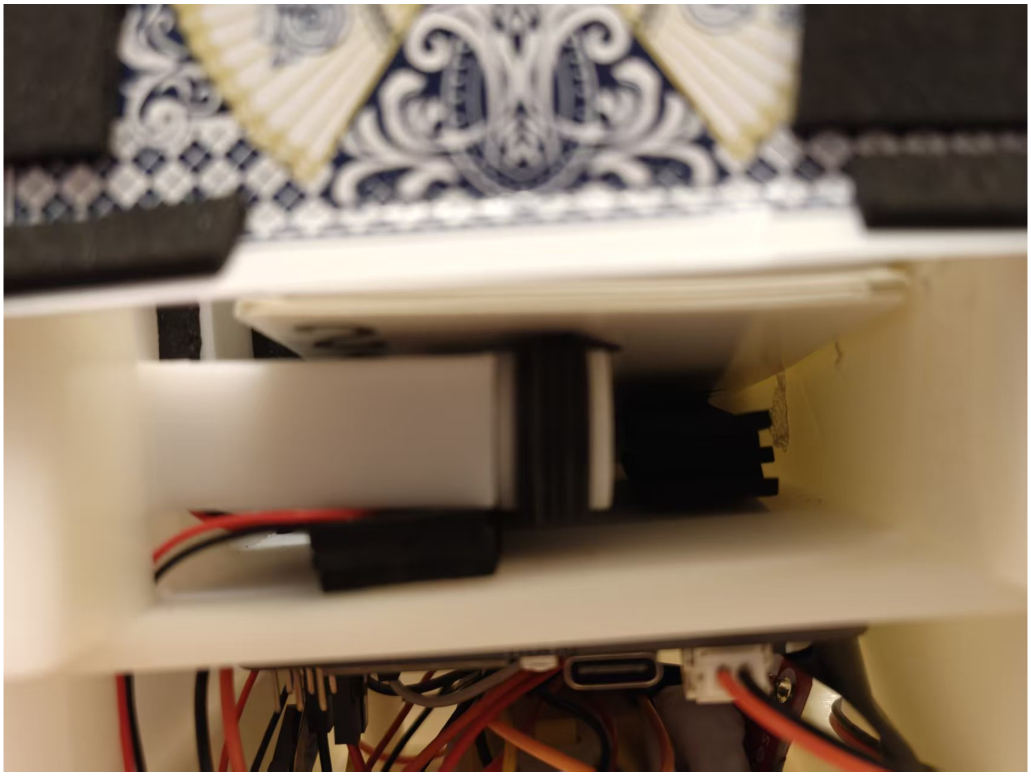

Figure 3: Close-up of the bottom feed structure. The motor-driven roller contacts the bottom card, while the front baffle restrains the cards above it.

3.3 Turntable and Homing Mechanism

Four-direction dealing is produced by rotating the entire upper dealer structure. The turntable motor is a TT 1:48 single-shaft geared motor. A small 3D-printed gear with an approximate diameter of 1 cm is mounted on the motor shaft. This small gear meshes with a fixed 3D-printed base gear with an approximate diameter of 6.5 cm. Because the large gear is fixed to the base, the small gear drives the upper structure around the base gear.

The diameter ratio is approximately given by Equation 2:

$$G = \frac{D_{\text{large}}}{D_{\text{small}}} = \frac{6.5}{1.0} \approx 6.5. \tag{2}$$

This ratio increases the motor shaft rotation needed for a full turntable revolution, which improves controllability for four-player indexing. The Hall sensor is mounted on the rotating upper structure near the lower surface, and a magnet is fixed to the non-rotating base gear. When the sensor passes the magnet, the controller detects the home direction. This prevents cumulative timing error from growing across a long dealing run. Figure 4 shows the physical gear and Hall-sensor implementation.

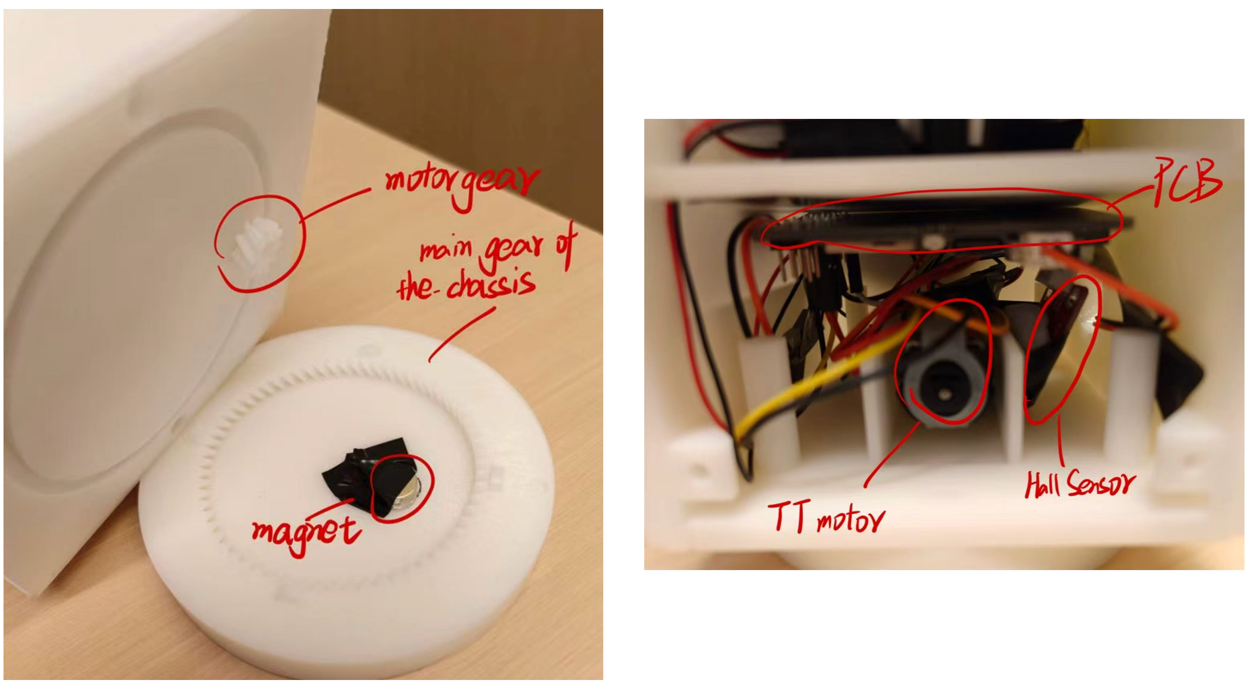

Figure 4: Turntable and control hardware. The Hall sensor rotates with the upper assembly, while the magnet is fixed on the base gear.

3.4 Embedded Hardware and Firmware

The final embedded platform is not a separate ESP32 development board. It is an integrated PCB that includes an ESP32-compatible controller and motor-driving capability.

The ESP32 family provides the microcontroller foundation for GPIO control, serial debugging, and the Arduino-based firmware workflow [2]. Power is supplied by a Bambu Lab IA003 battery box with four AAA cells connected in series. The board drives two DC motor ports and reads one button and one Hall sensor.

The relevant firmware pin assignments are:

- Start button: GPIO13, configured as an input with internal pull-up.
- Turntable motor: GPIO16 and GPIO32.
- Card-feed motor: GPIO26 and GPIO27.
- Hall sensor output: GPIO22.
- Hall sensor power: GPIO21, driven high by the controller.

The firmware build disables the unused front-panel display and unused gate servo through compile-time flags. This reflects the final hardware: the servo is not installed, and the final user input is the single start button plus serial debug commands.

The button handler debounces the input and measures press duration. A short press starts normal round-robin dealing. A press of at least 1 s starts the pseudo-random mode. The pseudo-random mode first builds a full balanced random target-player sequence. During sequence construction, the firmware uses remaining-card weighting with feasibility checks and a squared remaining-card bias, rejects choices that would make the final distribution impossible, and limits consecutive cards to the same player to a configurable burst value. The default burst value is three, and the generated sequence still preserves the required final card count for each player.

3.5 Camera Assistance Software

The software assistant runs on a computer and is launched through the project Python command-line interface. The user interface is served as a local web page. The user can choose the camera, select the current level rank, enter the previous player's cards, choose the previous-play combination type, and start the assistance service. The recognition pipeline uses common computer-vision tooling, including OpenCV-style image acquisition and processing [3] and YOLO-family model components for detection/classification experiments [4].

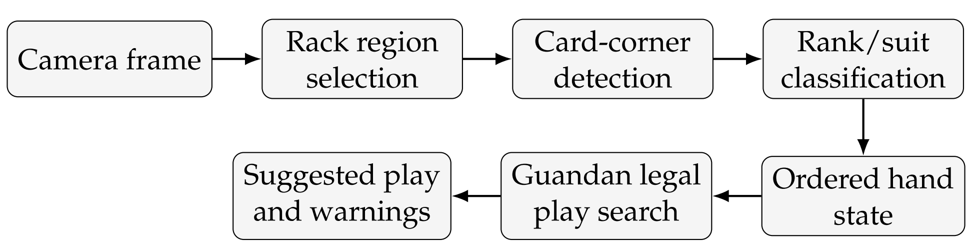

Figure 5: Camera assistance pipeline used by the software subsystem.

Figure 5 summarizes the software pipeline. The camera frame is cropped to the hand-rack region, card corners are detected, and rank/suit information is classified for each visible card. The cards are then ordered by rack position. The Guandan rule engine searches for legal responses based on the selected level rank, the previous player's cards, and the selected previous-play combination type. The interface highlights recommended cards by rack position so that the player can find them quickly.

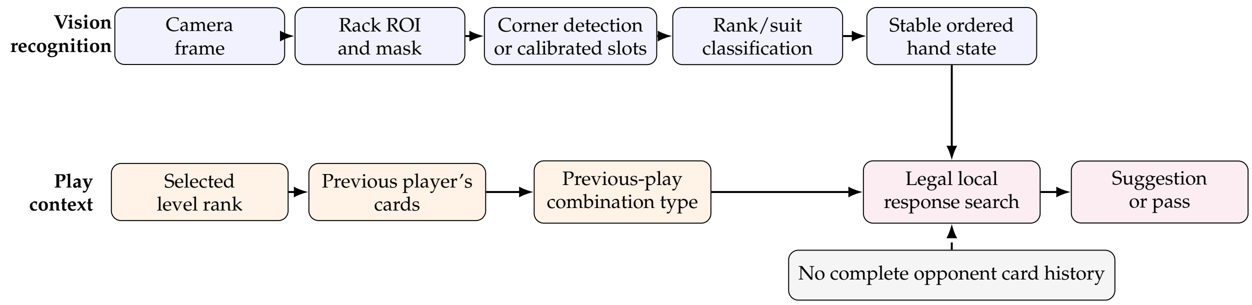

Figure 6: Detailed recognition and local recommendation flow. The rule engine receives the recognized hand and previous-play context, but it does not observe the full opponent card history.

Figure 6 expands the recognition and recommendation flow. The recognition subsystem is designed for the final tabletop setup rather than for arbitrary card photos. During normal operation, the camera faces a fixed hand-card rack. The software locates the rack region, masks out the room background, and then uses either a live dynamic corner detector or calibrated slot recognition. The calibrated path maps visible top-left card-corner locations from a reference image onto the current rack position and can absorb small scale or translation changes.

After card-corner regions are selected, each corner is split into rank and suit regions. The rank and suit predictions are combined into card codes, and the cards are sorted by their physical rack positions across the two visible rows. A hand tracker compares repeated frames and only updates the displayed hand state after stable detections, reducing one-frame recognition noise. The same tracker supports action monitoring by checking whether removed cards match the current suggestion.

In the final interface, the selectable options describe the previous-play combination type rather than separate game modes. Supported comparison types include single, pair, triple, full house, straight, consecutive pairs, steel plate, plane, flush straight, bomb, and four jokers. After the user enters the previous player's cards and selects the matching combination type, the system recommends a legal response from the recognized hand or returns pass when no suitable response is available. Figure 7 shows the final user interface.

The recommendation should be interpreted as a legal local suggestion rather than a globally optimal Guandan strategy. The system does not know the full history of cards played by all opponents, the remaining unknown cards, partner strategy, or hidden information outside the current camera view. Therefore, the rule engine bases its decision only on the recognized player hand, the selected level rank, the previous player's cards, and the selected previous-play combination type. Its heuristics prefer valid responses that avoid unnecessarily breaking useful hand structures, but they cannot guarantee the theoretically best play for the whole game.

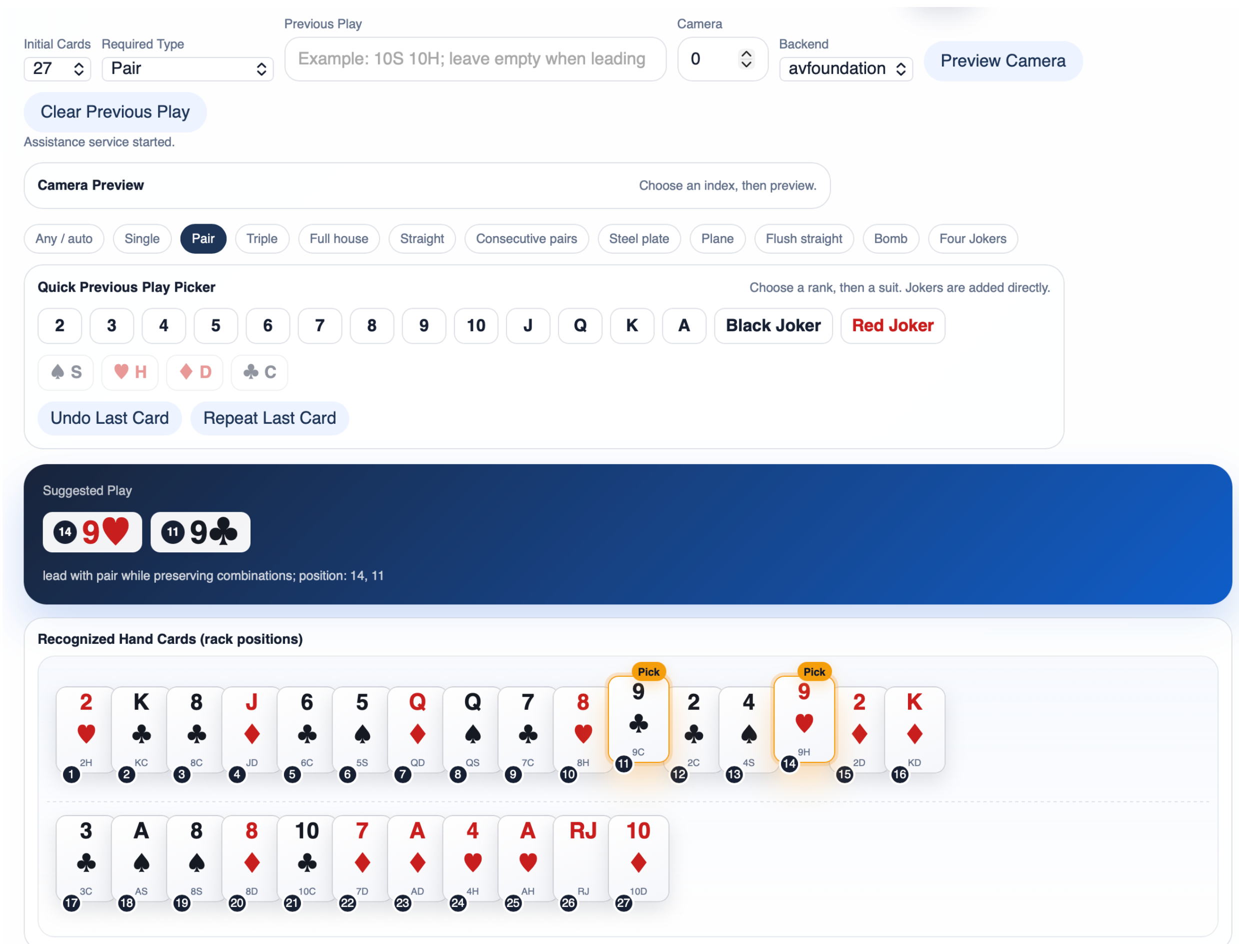

Figure 7: Final Guandan assistance interface. The recognized hand cards are displayed by rack position, and the suggested pair is highlighted for the player.

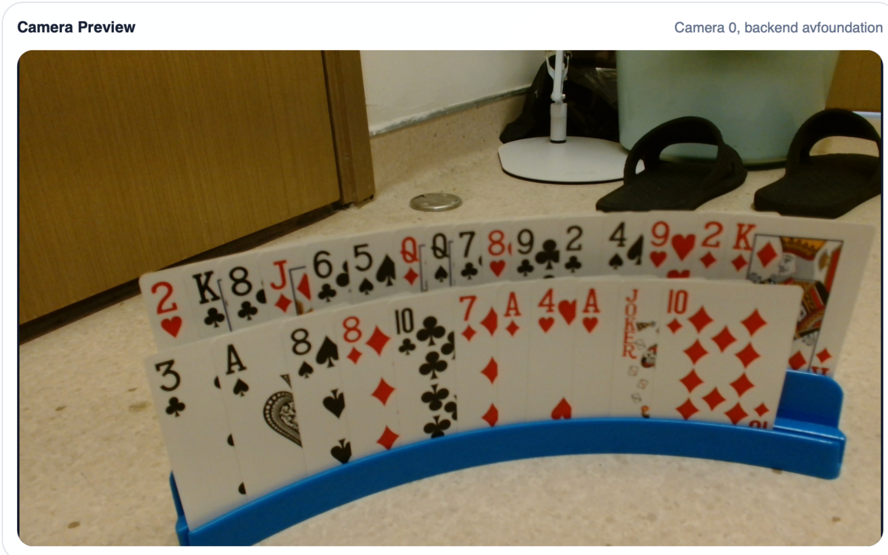

Figure 8: Camera preview for a 27-card hand rack. Reliable recognition requires the camera to be aligned with the card faces and the cards to be visible.

3.6 Tolerance Analysis

The most important mechanical tolerance is the single-card feed condition. A standard playing card is thin, flexible, and slippery, so a hard mechanical gap was not used as the primary separator. Instead, the prototype uses a front baffle that blocks the cards above the bottom card. The O-ring roller applies friction to the bottom card only. The card stack angle of about 12° keeps the bottom card in contact with the roller without producing excessive normal force.

Additional screenshots of selected 3D-printed parts are included in Appendix C.

The 7 mm roller diameter makes the feed sensitive to small timing changes. A forward pulse that is too short leaves the card partially fed. A pulse that is too long can disturb the next card after the bottom card leaves the baffle. The final 320 ms forward timing was selected because it advanced the card reliably in repeated tests. The reverse pulse was kept at 430 ms because it reduced coupled motion in the upper cards before the forward feed.

The turntable tolerance is dominated by open-loop motor timing, gear backlash, and battery voltage variation. These errors would accumulate if the system relied only on timed rotation. The Hall sensor reduces this risk by giving the firmware a repeatable home reference. During each run, the controller measures a full rotation from one home edge to the next and divides the measured time by the number of players. When the home edge appears during runtime, the interval estimate is smoothed and resynchronized. This approach makes the four-direction distribution more robust than a fixed-delay-only design.

4 Verification

4.1 Method

The final prototype was verified at both block and system levels. Hardware tests checked feed reliability, four-direction distribution, Hall homing, and button-mode selection. Software tests checked hand recognition and rule-based recommendations. The detailed requirement and verification table is included in Appendix A; this section summarizes the main results.

4.2 Dealer Verification

Normal dealing was tested with full 108-card runs. Each run used four players and 27 cards per player. The final tuned feed sequence was 430 ms reverse, 50 ms pause, and 320 ms forward. The normal dealing time was 3 min 4 s. Pseudo-random mode used the long-press workflow and completed a full 108-card run in 2 min 48 s with the updated balanced-sequence firmware. Table 3 summarizes the dealer tests.

Table 3: Final dealer verification results.

Test	Trial size	Result	Notes
Normal full-deck dealing	3×108 cards	324/324 correct	Each final pile was 27 cards.
Pseudo-random full-deck dealing	3×108 cards	324/324 assigned	Prebuilt random sequences preserved counts; max run obeyed BURST=3.
Short-press command	20 presses	20/20 normal starts	Presses below 1 s used normal mode.
Long-press command	20 presses	20/20 random starts	Presses at or above 1 s used pseudo-random mode.
Hall homing	20 home runs	20/20 detected	No home timeout occurred.

The tests showed that the final mechanical design met the primary dealing requirement. The most useful tuning change was the reverse-then-forward feed sequence. It reduced the tendency of the next card to move with the bottom card and made the DIY baffle more effective.

4.3 Vision and Assistance Verification

The vision subsystem was tested with the final web interface and a physical 27-card hand rack. Recognition was reliable when the camera was placed normally, the card faces were visible, and the rack was not heavily occluded. The most important practical limitation is camera placement: if the camera angle hides card corners or produces strong blur, recognition quality drops. Table 4 summarizes the software tests.

Table 4: Final camera assistance verification results.

Test	Trial size	Result	Notes
Hand-rack recognition	Six 27-card rack images	162/162 visible cards recognized	Normal camera placement, as in Figure 8.
Recommendation generation	12 scripted hand scenarios	12/12 legal suggestions or pass decisions	Covered singles, pairs, full house, straight, bomb, and four jokers.
Previous-play comparison	10 previous-play cases	10/10 beat or passed previous play correctly	No invalid higher play was selected.
UI card highlighting	10 recommendation states	10/10 matched suggested cards	Highlighted rack positions matched the suggestion.

4.4 Representative Recommendation Tests

Table 5 gives representative cases used to test the rule engine. These examples verify that the system does more than classify cards: it applies the selected level and previous-play context to produce a playable action. These tests check legality and consistency, not global game optimality, because the system does not observe every card that opponents have played.

Table 5: Representative Guandan rule-engine tests.

Hand subset	Previous-play type	Previous play	Expected behavior
9H, 9C, 2H, KC, 8C	Pair	none	Recommend a low pair and preserve stronger singles.
10S, 10H, JD, JC, QD, QS	Pair	9S, 9H	Recommend the smallest pair above the previous pair.
7D, 7H, 7S, 4C, 4D	Full house	none	Return the triple-plus-pair full house.
3C, 4D, 5S, 6H, 7C	Straight	none	Return the increasing straight.
5S, 5H, 5D, 5C	Bomb	previous high pair	Allow bomb over a non-bomb play.
BJ, BJ, RJ, RJ	Four jokers	any lower bomb	Recommend four jokers as the highest control.

5 Cost Analysis

5.1 Parts Cost

The prototype was built with a combination of purchased electronic parts, 3D-printed mechanical parts, and common hardware supplies. Table 6 lists the estimated parts cost in Chinese yuan (RMB), because the project parts were purchased in China.

Table 6: Prototype parts cost.

Item	Quantity	Cost (RMB)
ESP32-based integrated motor-control PCB	1	56
N20-10D 400 rpm direct-shaft feed motor	1	27
TT 1:48 single-shaft turntable motor	1	10
Hall sensor module	1	10
Bambu Lab IA003 four-AAA battery box	1	10
AAA batteries	4	20
O-rings for feed roller	5	5
3D-printed parts and fabrication material	1 set	300
Camera for hand-rack recognition	1	300
Wires, screws, adhesive, and miscellaneous hardware	1 set	100
Total		**838**

5.2 Labor Cost

Labor cost was estimated using the ECE 445 guideline formula shown in Equation 3:

$$C_{\text{labor}} = R \times H \times 2.5, \tag{3}$$

where R is the ideal hourly salary and H is the number of hours worked. To keep the cost section in the same currency as the prototype parts table and the course template, Table 7 uses an assumed engineering rate of 200 RMB/h. These values estimate design, fabrication, software development, testing, and report preparation time rather than actual paid wages.

Table 7: Estimated labor cost.

Team member	Hours	Labor cost (RMB)
Fan Zhang	150	75,000
Yushang Yang	145	72,500
Zihan Zhou	140	70,000
Wendao Yao	140	70,000
Total	**575**	**287,500**

6 Ethics, Safety, and Broader Impact

6.1 Ethical Considerations

The project follows the IEEE Code of Ethics by prioritizing public safety, honest reporting, and responsible use of technology [5]. The camera system is designed to recognize playing cards, not people. The camera should be aimed at the card rack or tabletop area rather than at faces or private surroundings. The prototype performs recognition locally and does not require uploading game images to a cloud service.

The software recommendation feature also creates a fairness concern. A Guandan assistant could be inappropriate in a competitive game if other players do not agree to its use. The intended use of this project is demonstration, education, and accessibility support. In a real game setting, all players should know that the assistant is being used.

6.2 Safety

The hardware uses low-voltage battery power from four AAA cells, which reduces electrical shock risk. The main physical risks are pinch points near the roller, the gear transmission, and the rotating upper structure. These areas should be enclosed or handled only when the system is powered off. The firmware includes motor-stop behavior and serial debug commands, but safe operation still depends on keeping fingers and loose wires away from the moving mechanism.

The Hall sensor improves safety and reliability by giving the rotating structure a repeatable home reference. This reduces the chance that the turntable drifts into an unexpected direction after a long dealing run. The mechanical parts are 3D printed, so they should be inspected for cracks or deformation before repeated demonstrations.

6.3 Broader Impact

The project shows how a small cyber-physical system can make a traditional card game easier to set up and learn. Automatic dealing reduces repetitive manual work, and the visual assistant can help new players understand legal combinations. Economically, the final parts cost is low enough for a hobby prototype, although a commercial product would require stronger packaging, better safety guards, and more robust vision testing. Environmentally, the design uses small replaceable batteries and 3D-printed plastic parts; future versions should consider rechargeable power and more durable materials.

7 Conclusion

The final prototype demonstrates the main goals of the project. The hardware dealer can distribute two decks of cards to four positions, return to a Hall-sensor home direction, and switch between normal and pseudo-random dealing using a single button. The mechanical design uses a bottom feed motor, O-ring roller, DIY baffle, tilted card stack, and gear-driven rotating platform to create a compact automatic dealer without the unused servo mechanism from the earlier design.

The software subsystem extends the project from a mechanical dealer into a tabletop assistant. It recognizes a player's hand cards from a camera view and recommends legal Guandan plays through a web interface. This final scope better matches the project title than the earlier maximum-card-display concept because it provides real visual assistance during play.

The main limitation is that both mechanical feeding and camera recognition depend on physical setup. Feed reliability depends on card condition, stack alignment, and baffle position. Recognition depends on camera angle, lighting, and card visibility. The recommendation system is also limited by information: it does not know the complete history of opponents' cards, so its output is a legal local suggestion rather than a guaranteed optimal play. Appendix B summarizes the Guandan rule assumptions used by the software. Future work should add a more rigid enclosure, guarded moving parts, rechargeable power, automatic camera calibration, a larger recorded dataset for recognition accuracy testing, and optional game-history tracking for stronger strategic recommendations.

References

[1] J. McLeod. “Guan Dan,” Accessed: May 14, 2026. [Online]. Available: https://www.pagat.com/climbing/guan_dan.html.

[2] Espressif Systems. “ESP32 Series Datasheet,” Accessed: May 14, 2026. [Online]. Available: https://documentation.espressif.com/esp32_datasheet_en.pdf.

[3] OpenCV. “OpenCV Documentation,” Accessed: May 14, 2026. [Online]. Available: https://docs.opencv.org/.

[4] Ultralytics. “YOLOv8 Documentation,” Accessed: May 14, 2026. [Online]. Available: https://docs.ultralytics.com/models/yolov8/.

[5] IEEE. “IEEE Code of Ethics,” Accessed: May 14, 2026. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.

Appendix A Requirement and Verification Table

Table 8 lists the final high-level requirements, the verification method used for each one, and the final result.

Table 8: Detailed requirement and verification matrix.

ID	Requirement	Verification procedure	Result
HLR 1	Dealer distributes 108 cards evenly to four players in normal mode.	Run three full normal deals, count each output pile, and inspect for double-feed or missed-feed events.	Pass
HLR 2	Dealer supports pseudo-random dealing while preserving final 27-card counts.	Run three full pseudo-random deals from long press or serial command and count each output pile.	Pass
HLR 3	Hall sensor repeatably identifies the home direction.	Run 20 home commands and check that each command detects the magnet before the 15 s timeout.	Pass
HLR 4	Button distinguishes short press from a 1 s long press.	Apply 20 short and 20 long button presses and record the firmware event mode.	Pass
HLR 5	Camera system recognizes visible hand cards under normal placement.	Capture six 27-card rack images through the web interface and compare recognized cards with the physical rack.	Pass
HLR 6	Rule engine recommends legal Guandan actions.	Test scripted cases for singles, pairs, full house, straight, bombs, four jokers, and previous-play comparison.	Pass

Appendix B Guandan Rule Summary

Guandan is played by four players with two standard 54-card decks. The players form two partnerships, and partners sit opposite each other. At the beginning of a round, the 108 cards are distributed evenly so that each player has 27 cards. Players take turns playing legal combinations. A player who wants to beat the previous play usually needs to play a higher combination of the same type, although bombs and four jokers can override many normal plays.

The software assistant uses the selected level rank when comparing cards. In the interface, the user selects the previous-play combination type, such as single, pair, triple, full house, straight, consecutive pairs, steel plate, plane, flush straight, bomb, or four jokers. The rule engine then searches the recognized hand for a legal response to that previous play. Local Guandan rule sets can vary, and the system does not track all cards played by opponents, so the software was designed as a practical local response recommender rather than a complete tournament referee or optimal strategy engine.

Appendix C 3D-Printed Parts

Figures 9 and 10 show selected 3D-printed parts used in the final mechanical assembly.

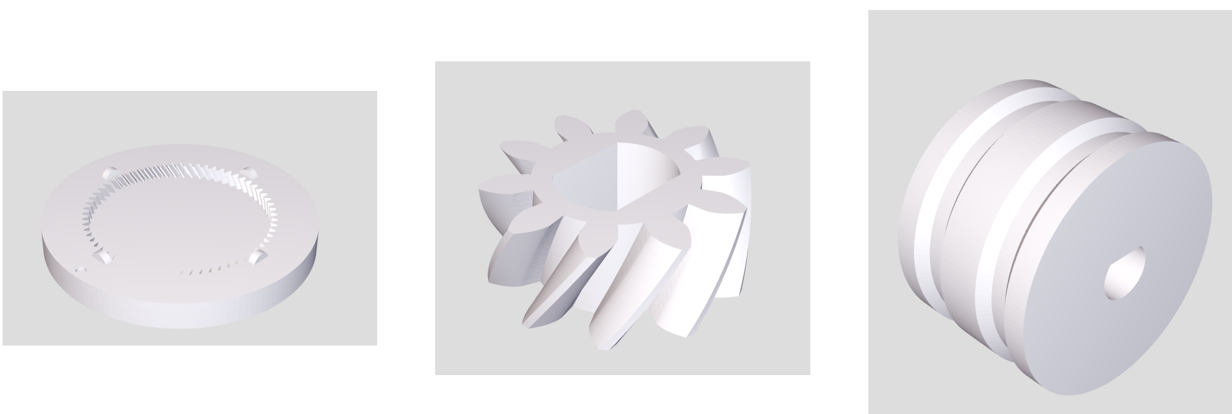

Figure 9: Selected 3D-printed parts: fixed base gear, motor pinion gear, and feed roller.

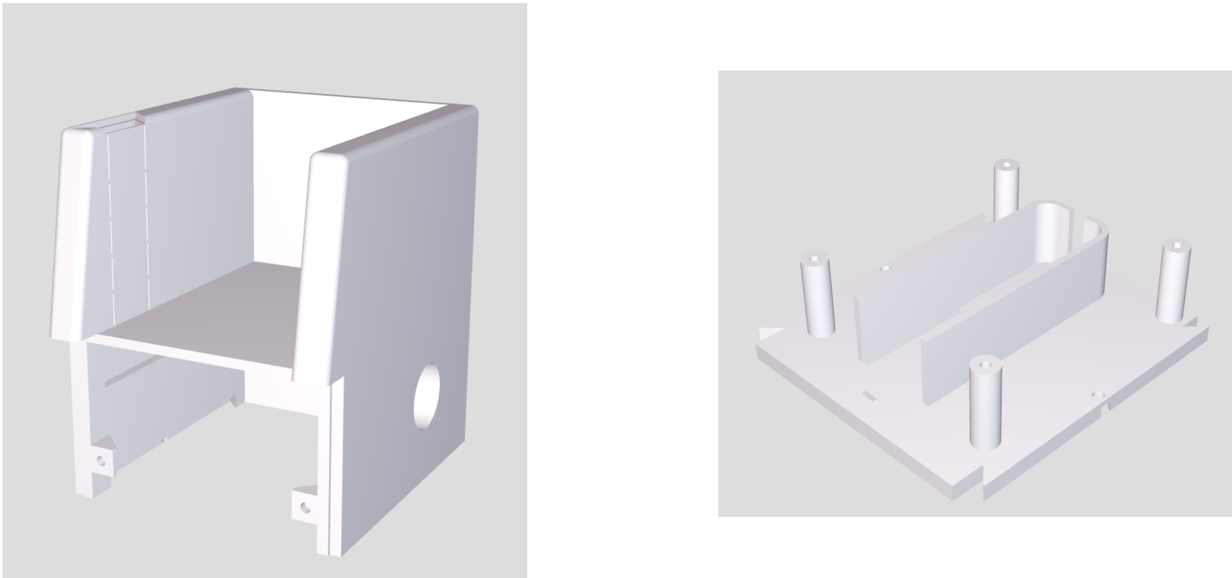

Figure 10: Selected 3D-printed structural parts: moving upper card holder and rotating lower support.