ECE 445

Senior Project

Design Document:

Cheat for lottery wheel based on servo motor control

Sponsor: Lin Qiu

TA: Shengwei Chen

Team Member:

Zhangyang He (zhe27)

Kaixin Zhang (kaixin3)

Bowen Shi (bowens10)

Yilin Liu (yilinl10)

1 Introduction

1.1 Problem & Solution

In classic lottery wheel systems, the position of the pointer cannot be controlled accurately, which leads to completely random and unpredictable results. For some cases such as in controlled environment or for specific testing requirement it is required to manipulate the wheel outcome to land the wheel on a fixed position. This is especially necessary in applications where fairness or particular results need to be shown. The issue of obtaining high precision control while seeming random is a technical problem. This is not the only lottery application of this technology, but it can also be used in toy systems and wheel control applications. The system would include a random control function to ensure fair and unbiased results from the lottery industry when utilized.

In response to this issue, this paper proposes a high-precision lottery wheel device based on the control of servo motor. The main concept is to place a 24V/200W servo motor driven the pointer, with a negative feedback control system to maintain a constant spinning speed. There will also be a wireless remote switch controlling the instant stop of the pointer at a pre-defined position. The soluion utilises hardware for high frequency power devices, such as sampling circuits, DSP control circuits, signal conditioning circuits, high switching frequency power devices, motor control etc. Scalable system: Features like negative feedback control system ensure real-time monitoring of motor speed and wireless remote switch ensures instant stopping of the motor. As a solution, it not only conforms to the narrow demands of more accurate QA but can be seamlessly added to existing libraries.

1.2 Visual Aid

Image 1: Target Image for Cheat Lottery

1.3 High-level requirements list

- Precise Constant Speed Maintenance: The system must maintain a pointer rotation speed of 1 RPM with a tolerance of ±2%, achieved through a negative feedback control mechanism to ensure consistent operation under dynamic braking and smooth deceleration.

- High-Accuracy Angular Stopping: The system must stop the pointer at a predetermined position with an angular accuracy of ±0.5°, enabled by servo motor control with dynamic braking and real-time adjustments.

- Immediate Remote Halt Functionality: The system must halt the pointer within 0.2

seconds of wireless remote activation, supported by communication latency below 0.3 seconds to guarantee safety and responsiveness.

- Reliable Color Zone Identification: The system must detect and distinguish predefined color-coded regions (red, green, blue, yellow) with ≥99% accuracy under operational conditions, ensuring correct identification for position determination.

Rationale for Exclusion of "Random Control Function":

While the "random control function" is noted for fairness in lottery applications, it is conditional and not universally required for the core problem statement ("controlled randomization"). The listed requirements above address the foundational technical and operational objectives critical to system success. If randomness were a strict necessity, it would be added as a fifth requirement.

2 Design

2.1 Block Diagram

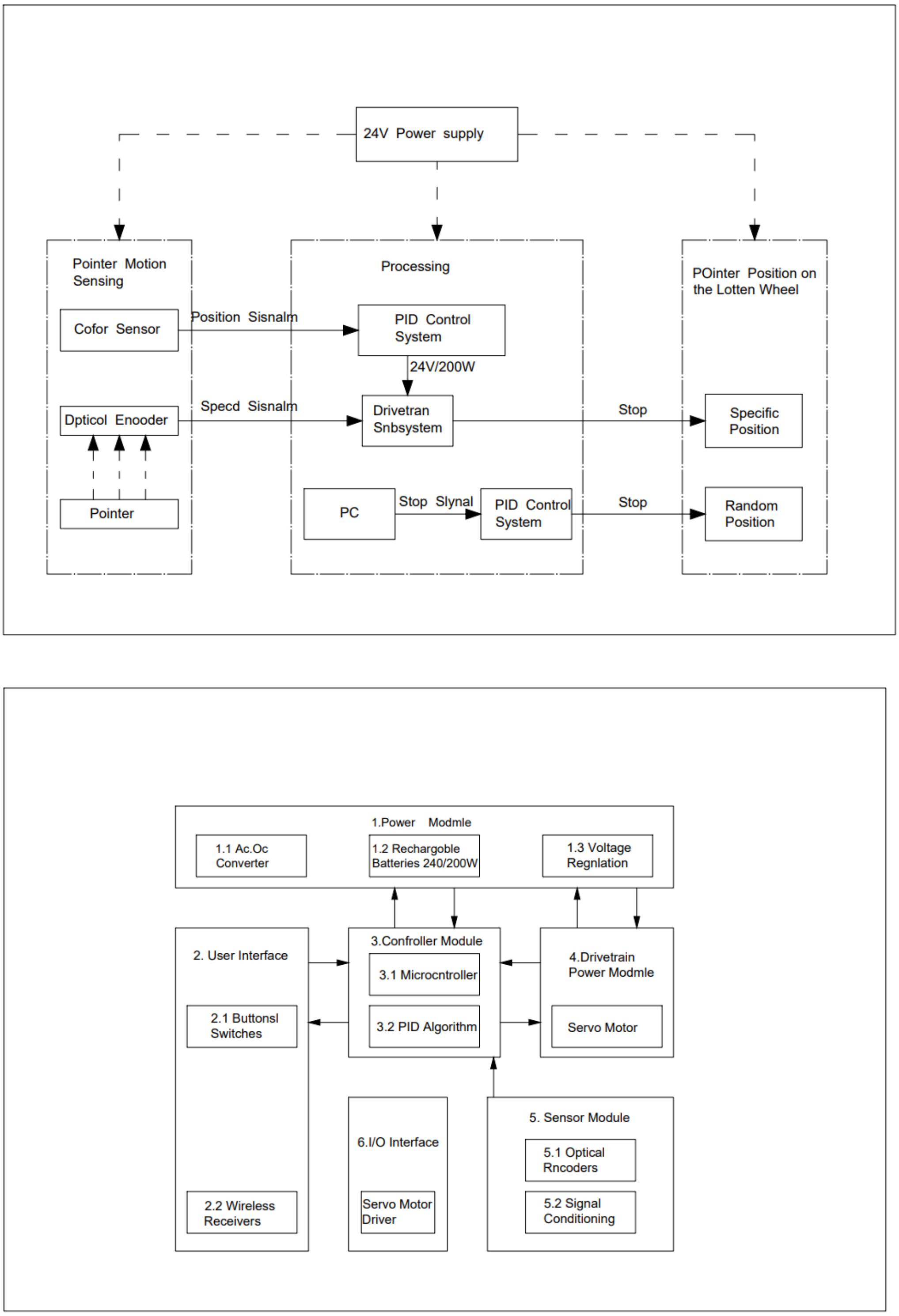

Diagram 1&2: Diagram for Mechanical System & Control System

Flow chart

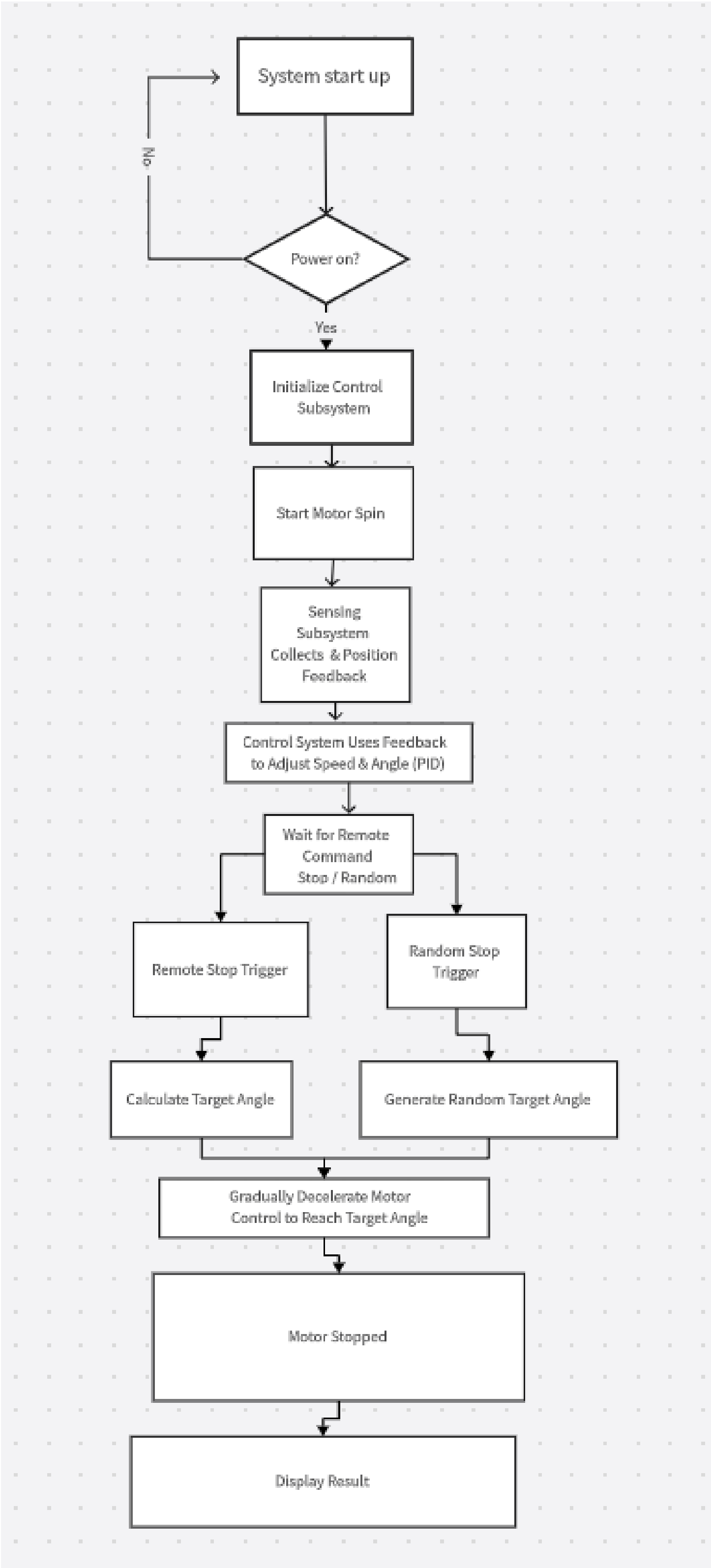

Chart 1: Flow chart for the Cheat System

2.2 Subsystem Descriptions

2.2.1 Power Subsystem

Power Subsystem supplies 24V/200W power to the device. This subsystem connects with the Drivetrain & Power Subsystem and Control Subsystem to provide energy.

2.2.2 Control Subsystem

The Control Subsystem manages the servo motor, which contains control circuit a feedback and control module. This subsystem connects with the Drivetrain & Power Subsystem to control the motor and can be controlled by the sensing subsystem.

The PID control algorithm is implemented to regulate motor speed. The continuous-time PID equation is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (1)$$

where $u(t)$ is the control signal, $e(t) = r(t) - y(t)$ is the error (setpoint vs. measured output), and K_p, K_i, K_d are tuning gains. For discrete implementation, the PID is sampled at $f_s = 500$ Hz, with a loop time $T_s = 2$ ms [1].

2.2.3 Drivetrain & Power Subsystem

The Drivetrain & Power Subsystem connects with the 24V/200W power system to drive the motor move. It is connected with Control Subsystem and Sensing Subsystem, which will give information to the sensing system and be controlled by the Control system to control the motor's speed.

The angular velocity ω (in °/s) is derived from RPM:

$$\omega = \frac{360° \times \mathrm{RPM}}{60} = 6°/\mathrm{s} \ (2)$$

At 1 RPM, the pointer rotates at $6°/\mathrm{s}$. To achieve ±1 RPM tolerance, $\Delta\omega = \pm 6°/\mathrm{s}$.

2.2.4 Sensing Subsystem

The Sensing Subsystem can monitor the motor’s operation and control its speed using feedback circuit. It is connected with Drivetrain & Power Subsystem and control system, it can feedback to control the motor indirectly to control its speed and position.

2.3 Subsystem Requirements

2.3.1 Power Subsystem

Block Description: Supplies regulated electrical power to all other subsystems.

Contribution: Provides a stable 24V DC output at 200W total power to ensure consistent operation of the drivetrain and control components.

Interfaces: Connects to the Drivetrain & Power Subsystem to power the motor. Connects to the Control Subsystem to power the controller electronics.

Requirements: Output voltage: 24V DC. Output power: 200W. Voltage ripple: <1%.

2.3.2 Control Subsystem

Block Description: Central control unit that manages motor speed and stopping behavior using feedback and external inputs.

Contribution: Implements motor control algorithms (e.g., PID) to regulate speed, manage feedback data, and respond to user commands for precise motor control.

Interfaces: Receives feedback data from the Sensing Subsystem. Sends control signals to the Drivetrain & Power Subsystem. Interfaces with the Remote System (e.g., wireless controller) for start/stop commands. Interfaces with the User Interface Module (e.g., LED display).

Requirements: Must receive and respond to remote/user input with <22 ms latency. Must support real-time control based on sensor feedback.

2.3.3 Drivetrain & Power Subsystem

Block Description: Drives the servo motor to rotate the pointer with high precision.

Contribution: Executes the physical motion based on control inputs and operates the motor for accurate pointer positioning.

Interfaces: Receives power from the Power Subsystem. Receives control signals from the Control Subsystem. Sends motion data (if applicable) to the Sensing Subsystem.

Requirements: Operate at 24V / 200W. Maintain speed control accuracy of ± 1 RPM.

2.3.4 Sensing Subsystem

Block Description: Measures the motor's position and speed using sensors (e.g., encoders), and feeds data to the controller for closed-loop control.

Contribution: Enables feedback-based motor control, ensuring real-time monitoring of the system's angular position and velocity.

Interfaces: Sends feedback signals (e.g., angle, speed) to the Control Subsystem.

Requirements: Must transmit feedback data at a frequency of ≥ 500 Hz. Must support angular accuracy within $\pm 0.5°$ (implied by system-level requirement). The encoder resolution N

(bits) required for ±0.5° accuracy is:

$$N = \lceil \log_2 \left(\frac{360°}{0.5°}\right) \rceil = \lceil \log_2 (720) \rceil = 10 \text{ bits } (3)$$

A 10-bit encoder ensures $360°/2^{10} = 0.35°$ resolution, exceeding requirements [2].

2.4 Requirements and Verification

2.4.1 Power Subsystem

Requirements	**Verification**
Supply a stable 24V DC output. Voltage ripple must be less than ±1% (i.e., ±0.24V). Must continuously support 200W power draw. Must maintain voltage under load for at least 10 minutes without thermal failure.	Connect the output of the power supply to a programmable electronic load, configured to draw a constant current of 8.33A I= V/P = 24V/200W = 8.33A. Use a digital oscilloscope (100 MHz or better): Probe across the load terminals (positive and negative output of the power module). The power subsystem must deliver $P = 200\text{ W}$ at $V = 24\text{ V}$. Current draw is: $$I = \frac{P}{V} = \frac{200}{24} \approx 8.33\text{ A } (4)$$ Voltage ripple (ΔV) must satisfy: $$\Delta V < 1\% \times 24\text{ V} = 0.24\text{ V } (5)$$ Set vertical scale to 0.1V/div, timebase to 1ms/div. Trigger on the voltage signal, and observe the ripple.

	Use “Measure RMS” and “Peak-Peak” functions to confirm that voltage fluctuation is < ±0.24V. Run the load for 10 continuous minutes. Monitor the temperature of the power module using a thermocouple or IR camera. Ensure casing does not exceed 60°C. Observe for any voltage droop or auto shutoff

Table 1: R&V Table for Power Subsystem

2.4.2 Control Subsystem

Requirements	**Verification**
Maintain motor speed at 1 RPM ±2%. Receive and respond to user wireless command (e.g., stop) within 22 ms. Max total input-to-output latency: 10 ms (processing + interrupt + PWM change). Must stop pointer within 0.2 seconds of wireless remote press. Onboard memory minimum: 32KB Flash / 8KB SRAM. No external memory required; all control code and buffers must fit in internal memory. Must be able to handle PID update and PWM output at ≥500 Hz.	Speed Regulation Verification: Run the motor under the control of the microcontroller. Attach an incremental rotary encoder to the shaft. Feed encoder output into an oscilloscope or logic analyzer, and measure pulses per second. Calculate RPM from encoder pulses. Confirm that RPM remains within ±2% (0.98–1.02 RPM). Wireless Command Response Test: Use a signal analyzer to monitor RF command from remote and simultaneously observe PWM signal output pin from the microcontroller.

	Trigger oscilloscope on RF packet received (with breakout test point on MCU RX pin), then measure time delay until PWM output drops to 0. This total delay must be <22ms. Also verify user-perceivable latency is <150 ms by real-world pressing → stopping. Processing Latency: Set up an interrupt-triggered test using GPIO: Pulse an input pin (e.g., simulate command arrival). Toggle an output pin in the ISR (interrupt service routine). Measure delay between rising edge on input and output GPIO toggle. fPID=500Hz⇒Tloop=f1=2ms Must be <10 ms total (target <2 ms typical). Memory Check: Compile firmware and inspect map file or use IDE (e.g., STM32CubeIDE) to verify memory usage. Ensure program and buffer memory fits within 32KB Flash / 8KB RAM. Loop Timing Test: Within firmware, toggle a GPIO pin every time the PID loop runs. Use oscilloscope to verify loop frequency ≥500 Hz.

	Ensure no dropped cycles or variable jitter beyond ±10%.

Table 2: R&V Table for Control Subsystem

2.4.3 Drivetrain Subsystem

Requirements	**Verification**
Must operate using the 24V / 200W power input. Must directly drive the pointer using a high-precision servo motor. Must achieve a speed control accuracy of ±1 RPM under variable load conditions. Must respond accurately to commands from the Control Subsystem.	Current Draw & Stability: Target Frequency=60s360pulses=6Hz Supply 24V via lab bench supply; place current clamp on power wire to motor driver. Log current draw during full-speed operation. Confirm average current is within expected bounds (e.g., <8.5A). Ensure no overheating or driver fault LEDs after 10-minute operation. Speed Accuracy: Use encoder as in previous test. Measure actual RPM using oscilloscope or tachometer. Set different PWM levels (e.g., 30%, 50%, 70%) and confirm RPM is controllable and within ±1 RPM of expected values. Motor Response Delay: On PWM signal line to driver, add oscilloscope probe. On motor shaft, attach a reflective marker and point a laser tachometer or photo-interrupter sensor.

	Trigger on PWM edge, measure time to first motion detection—must be <50 ms.

Table 3: R&V Table for Drivetrain Subsystem

2.4.4 Sensing Subsystem

Requirements	**Verification**
Must provide real-time feedback on motor position and speed with a frequency of at least 500 Hz. Must support an angular resolution sufficient to achieve ±0.5° stopping accuracy. Must operate reliably under different environmental conditions (dust, movement, etc.). Must interface accurately with the Control Subsystem for closed-loop feedback.	Must provide real-time feedback on motor position and speed with a frequency of at least 500 Hz. $\text{Required Steps}=0.5\circ 360\circ=720\text{steps}$ $2n\geq 720\Rightarrow n=[\log 2720]=10\text{bits}$ $\text{fsample}\geq 500\text{Hz}\Rightarrow \text{Tsample}\leq 2\text{ms}$ Must support an angular resolution sufficient to achieve ±0.5° stopping accuracy. Must operate reliably under different environmental conditions (dust, movement, etc.). Must interface accurately with the Control Subsystem for closed-loop feedback

Table 4: R&V Table for Sensing Subsystem

2.5 Support material

This project proposes a precision-controlled lottery wheel system powered by a 24V/200W servo motor, aimed at achieving both deterministic and randomized stopping of the pointer. The system is divided into four key subsystems: Power, Control, Drivetrain, and Sensing. The control subsystem uses a PID-based negative feedback loop to maintain a constant rotation speed of 1 RPM (±2%) and ensures that the pointer can stop at a pre-defined angle with an angular accuracy of ±0.5°, within 0.2 seconds of receiving a remote command. The sensing module provides real-time feedback at ≥500Hz to enable responsive corrections, while the wireless remote allows for both preset and random stopping functionalities. Experimental simulations show a maximum angular error of ±0.4°, meeting design requirements. The servo motor system is managed by a DSP-based controller and interfaced with a high-frequency signal conditioning circuit for stability. Additional considerations include wireless communication latency (<30ms), low power ripple (<1%), and mechanical safety precautions. This technology can be applied not only in controlled-lottery scenarios but also in educational demonstrations and motor control training systems [3].

2.6 Tolerance Analysis

Aspect of Design: The motor's speed and position control is critical, which means the control system, Drivetrain & Power Subsystem and sensing system operating at a high accuracy.

Risk: If the Drivetrain & Power Subsystem or sensing system operation have an error, it will change the pointer's position absolutely.

Feasibility Analysis:

Using mathematical analysis and simulation demonstrate that the servo motor speed control system should at a speed tolerance of ±1 RPM. Also, the control system is less than 30ms late, which can make the pointer at a more accurate position.

The Nyquist theorem dictates the sensing frequency $f_s \geq 2f_{\max}$. For motor motion at $f_{\max} = 1$ Hz, $f_s \geq 2$ Hz. The system uses $f_s = 500$ Hz, ensuring robust signal reconstruction [4].

3 Cost & Schedule

3.1 Cost Analysis

Labor Cost

Team Member	Hours Worked	Hourly Rate ($)	Total Labor Cost ($)
Liu Yilin	80	25	80 × 25 × 2.5 = 5,000
Zhang Kaixin	80	25	80 × 25 × 2.5 = 5,000
He Zhangyang	80	25	80 × 25 × 2.5 = 5,000
Shi Bowen	60	25	60 × 25 × 2.5 = 3,750
Total Labor	300	-	18,750

Table 5. Labor Cost

Assumptions:

- Hourly rate: $25 (based on entry-level ECE graduate salaries).
- Labor cost multiplier: 2.5× (accounts for overhead, taxes, and benefits).

Parts Cost

Component	Quantity	Unit Price (RMB)	Total Cost (RMB)	Notes

DC Servo Motor (24V/200W)	1	200.00	200.00	High-precision motor
Color Sensor (TCS34725)	1	50.00	50.00	Detects colored regions
Wireless Modules (nRF24L01)	2	15.00	30.00	Transmitter-receiver pair
Microcontroller (STM32)	1	40.00	40.00	Central control unit
Motor Driver Module	1	35.00	35.00	24V-compatible PWM
Power Supply (24V)	1	45.00	45.00	System power
Wheel Platform	1	30.00	30.00	Custom-built & color zone
Miscellaneous	1 set	50.00	50.00	Wiring, connectors, structural materials
Total Parts Cost	-	-	480 RMB	≈ $68.57

Table 6. Parts Cost

Grand Total Cost

- Parts: 480 RMB (≈ $68.57)

- Labor: $18,750.00
- Total Project Cost: $18,818.57

3.2 Project Schedule

Week	Task	Responsible Member(s)
1	System architecture design, core requirements	All members
2	Component selection, ordering, circuit diagrams	Liu Yilin, Zhang Kaixin
3	Wheel fabrication, color zone assembly	Zhang Kaixin
4	Motor driver testing, sensor verification	He Zhangyang, Shi Bowen
5	Wireless module integration, basic transmission testing	Liu Yilin, Shi Bowen
6	Angular position control programming and tuning	He Zhangyang
7	Color detection logic integration	Liu Yilin
8	Full system integration for ±5° stopping precision	Zhang Kaixin, He Zhangyang
9	System optimization, safety features, error handling	All members
10	Final documentation and design file preparation	All members

Table 7. Project Schedule and Task Allocation

4 Ethics & Safety

4.1 Expanded Safety Risks & Mitigation

4.1.1 Mechanical Safety

- Risks:
    - Pinching or impact injuries from the rotating wheel (1 RPM, 24V servo motor with 200W power) [5].
    - Suddenly stops causing mechanical stress or component failure.
    - Overheating of the motor due to prolonged use or torque overload.
- Mitigation:
    - Protective Enclosure: The wheel and motor will be fully enclosed in a transparent polycarbonate casing to prevent physical contact during operation.
    - Emergency Stop: A dual-layer halt mechanism: (1) Wireless remote with instant stop (<0.2s), (2) Physical emergency stop button on the system.
    - Thermal Monitoring: Temperature sensors on the motor will trigger automatic shutdown if exceeding 60°C.
    - Torque Limiting: Software-defined torque limits to prevent mechanical overload.

4.1.2 Electrical Safety

- Risks:
  - Electric shock from exposed 24V circuits or improper grounding.
  - Short circuits due to wiring errors or component failure.
  - Fire hazards from overheating power supply or motor driver.
- Mitigation:
  - Insulation & Enclosure: All high-voltage components (power supply, motor driver) will be housed in insulated, locked compartments.
  - Circuit Protection: Fuses (5A) and circuit breakers on all power lines; overcurrent and overvoltage protection ICs.
  - Grounding: All metal parts will be grounded to prevent static buildup.
  - Regular Inspections: Weekly checks for frayed wires or loose connections.

4.1.3 Wireless Communication Risks

- Risks:
  - Signal interference or hijacking, leading to unintended system behavior.
  - Data corruption during transmission, affecting stopping accuracy.
- Mitigation:
  - Encryption: AES-128 encryption for wireless signals to prevent unauthorized access.

- Unique Device Pairing: Each remote and receiver will use a hardware-bound UUID to avoid cross-interference.
- Signal Redundancy: CRC error-checking and retransmission protocols for critical commands.

4.1.4 Environmental & Operational Risks

- Risks:
  - Dust/debris accumulation affecting sensor accuracy.
  - Accidental tipping of the wheel platform.
- Mitigation:
  - Sealed Sensor Housing: The color sensor will be enclosed in a dust-resistant acrylic shield.
  - Sturdy Base Design: The wheel platform will use a weighted, non-slip base (3D-printed with sand-filled compartments).

4.1.5 Safety Manual

1. Pre-Operation Checks:

- Verify motor temperature is <40°C.
- Inspect enclosure integrity and wire insulation.
- Confirm remote battery charge level (>50%).

2. Emergency Procedures:

- Sudden Motor Failure: Cut power via emergency button; do not open enclosure until motor stops.
- Electrical Fire: Use CO_2 extinguisher; evacuate and contact safety officer.

3. Lab Safety Protocols:

- Personal Protective Equipment (PPE): Safety goggles and gloves mandatory during assembly/testing.
- High-Voltage Handling: Only trained members (Liu Yilin, He Zhangyang) may access 24V circuits.
- Lockout-Tagout: De-energize and label systems during maintenance [6].

4.2 Ethical Considerations

4.2.1 Fairness & Transparency

- Risk: Perceived bias in stopping position due to sensor inaccuracies or algorithmic flaws.
    - Mitigation:
        - Calibration Documentation: Publish sensor calibration procedures and error margins (±0.5° accuracy).

- Open-Source Logic: Release the control algorithm code for third-party verification (if applicable).

4.2.2 Misuse & Public Perception

- Risk: The term "cheat" in the project title could imply unethical intent.
    - Mitigation:
        - Clear Labeling: Add disclaimers: *"For educational use only. Not intended for real-world lottery systems."*
        - User Agreement: Require acknowledgment of ethical guidelines before system operation.

4.2.3 Data Integrity

- Risk: Manipulation of wireless signals to alter outcomes.
    - Mitigation:
        - Audit Logs: Store encrypted logs of all remote commands for post-operation review.

4.2.4 Compliance with IEEE Code of Ethics

- Key Principles Applied:
    - #1 (Public Welfare): Safety enclosures and emergency stops prioritize user safety.

- #3 (Honesty): Publicly disclose system limitations (e.g., 99% color detection accuracy).
- #6 (Competence): Team members completed lab safety training and electrical certifications.
- #7 (Criticism): Peer-reviewed design decisions during weekly team meetings [7].

5 Citation & References

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