

Automatic Sorting Robotic Arm for Table Tennis Balls

Project Proposal

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Problem

Table tennis balls exhibit varying sizes, weight, color, material composition, and surface markings due to evolving manufacturing standards and regulations.

The current ITTF ruling specifies that a standard ball legal for play must meet the following requirements:

- 40 mm in diameter
- 2.7 g in weight
- ABS plastic construction
- White or orange matte appearance

Prior to the regulation changes in October 2000, table tennis balls legal for play were:

- 38 mm in diameter
- 2.5 g in weight
- Made of celluloid, a highly flammable and lightweight synthetic plastic

These changes were implemented to slow down the game and improve visibility for spectators and television audiences.

Notably, some differences among table tennis balls are visually difficult to distinguish, which complicates manual sorting. In training, storage, and equipment management contexts, these variations can lead to inefficiencies and classification errors when sorting is performed manually.

Solution Overview

This project addresses the problem by designing and developing an automated robotic system capable of accurately identifying and sorting table tennis balls based on their physical and visual characteristics.

The system will measure key attributes of each ball, including:

- Diameter
- Weight

- Color
- Logo presence

These measurements are processed by an embedded controller to classify each ball and actuate a robotic arm to place it into the appropriate category.

The system architecture combines:

- Mechanical design
- Multimodal sensing
- Embedded processing
- Controlled actuation

Compared to manual sorting, the proposed solution improves accuracy, consistency, and efficiency while reducing human effort. In contrast to vision-only systems, the use of multiple sensing modalities enables more robust and reliable classification, particularly in cases where visual ambiguity or environmental variability may degrade performance.

Solution Components

Input Box: Passive Storage

- Geometry: sloped walls or funnel shape to keep balls clustered and accessible.
- Surface: low-friction lining to prevent jamming.
- Availability detection: simple IR break-beam or ToF sensor aimed at the pile to corroborate empty detection from vision.

Sensing Platform: Measurement and Fixturing

- Mechanical stabilization: concave cup or V-groove with known geometry that allows for ease of ball placement and pickup and ensures the ball is fixed in place.
- Diameter measurement: ToF sensor, such as VL53L0X, with fixed reference geometry.
- Presence detection: IR break-beam or reflective IR sensor to trigger measurement.
- Design note: platform height and geometry should be consistent with the arm pickup kinematics.

Robotic Arm with Integrated Vision: Feeding, Inspection, and Sorting

Functions combined:

- Pick ball from input box
- Place ball on sensing platform
- Capture image for color and logo inspection
- Pick ball from platform
- Place into correct output bin

Actuation:

- 3–4 DOF servo-based arm with PWM-controlled servos
- Actual model of arm undetermined

End effector:

- Suction gripper using a small vacuum pump and nozzle
- High reliability for smooth, lightweight balls
- May be unreliable if the balls are not clean
- Alternative: compliant finger gripper with rubber padding

Vision module:

- Camera, such as a Raspberry Pi Camera, mounted near the end effector
- Color classification using RGB thresholding
- Logo detection using contrast or contour-based processing

Key implications of using the arm for feeding:

- Requires pose consistency of balls in the input box
- May need simple bin shaping
- Increases cycle time, since feeding is no longer parallelized
- Eliminates the need for feeder actuators, reducing mechanical complexity

Output Boxes: Sorting Bins

- Fixed bin positions mapped to arm coordinates
- Sized to tolerate placement error

Custom PCB Controller

Core Architecture

- Microcontroller: STM32, such as STM32F4 series, for real-time control and integration.
- Vision processing: Raspberry Pi handles image processing and communicates with the PCB via UART or SPI.

PCB-Integrated Subsystems

Subsystem	Planned Design
Sensor interfaces	HX711 circuit for load cell, I2C buses for ToF sensors, and GPIO for IR sensors.
Motor control	PWM outputs for servo control, including arm servos and optional actuators, with power drivers and proper current routing for motors.
Power management	Separate regulated rails: 5–6 V high-current rail for servos and 3.3 V rail for logic and sensors, with decoupling and filtering.
Communication	UART or SPI link to the vision processor.
Protection and layout	Ground plane separation for analog and digital sections, plus noise isolation for weight measurement accuracy.

Criterion for Success

Category	Success Metric	Target
Ball handling and manipulation	The robotic arm shall successfully pick up a table tennis ball from the input box and place it on the sensing platform.	Success rate $\geq 90\%$ over 20 consecutive trials.
Ball handling and manipulation	The arm shall transfer a classified ball from the sensing platform to the correct output bin.	Placement accuracy of ± 2 cm from the target bin center in at least 90% of trials.
Sensing accuracy	The sensing platform shall measure ball weight compared to a calibrated reference scale.	Error $\leq \pm 0.02$ g.
Sensing accuracy	The diameter estimation system shall classify balls as 38 mm vs 40 mm under controlled positioning conditions.	Accuracy $\geq 95\%$.
Vision accuracy	The vision system shall correctly classify ball color as white vs orange under consistent lighting conditions.	Accuracy $\geq 95\%$.
Vision accuracy	Logo presence detection shall be evaluated while acknowledging higher variability.	Accuracy $\geq 85\%$.
System reliability	The full system shall complete consecutive sorting cycles.	At least 30 consecutive cycles with no more than 2 total classification or actuation failures.
System reliability	The system shall recover from a failed grasp or missed detection without manual reset.	Recovery in $\geq 80\%$ of failure cases.