Comparative Study of Contact and Non-Contact Sensing Architectures for Stewart Platform Stabilization with Adaptive RL Control

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***Abstract*—The stabilization of unstable non-linear systems, specifically the **Ball and Plate System**, is a benchmark problem in control theory. This research evaluates the efficacy of three distinct sensing architectures applied to a Stewart Platform: (1) Resistive Touch Screens (Contact-based), (2) Computer Vision (External Optical), and (3) a proposed high-frequency Infrared (IR) Phototransistor Array (Internal Optical). Experimental analysis reveals that while contact-based methods are cost-effective, they introduce significant mechanical damping (friction) that masks true system dynamics. Conversely, external vision systems eliminate friction but incur computational latency (> 30ms). This paper demonstrates that the proposed IR Phototransistor Array offers a superior trade-off, achieving sub-millisecond response times with zero mechanical impedance. Furthermore, we propose a transition from classical PID control to Deep Reinforcement Learning (DRL) to autonomously compensate for environmental disturbances without manual tuning.**

***Index Terms*—Ball and Plate System, Stewart Platform, Phototransistor Array, PID Control, Deep Reinforcement Learning, Sensor Fusion.**

I. Introduction

The Stewart Platform is a parallel manipulator known for its high rigidity and precision. When applied to the **Ball and Plate System**, the objective is to control the position of a free-rolling ball on a flat plate by adjusting the platform's tilt angles. The core challenge lies in the latency-sensitive feedback loop: the system must detect the ball's position and actuate the servos faster than the ball's gravitational acceleration.

II. System Architectures Analysis

This study contrasts three sensing methodologies based on response time, friction coefficients, and hardware complexity.

A. Architecture I: Resistive Touch Interface

This method utilizes a 4-wire resistive overlay mounted on the top plate.

- **Mechanism:** The ball's weight collapses the spacer between two conductive layers, creating a voltage divider. The analog voltage is mapped to Cartesian (X, Y) coordinates.

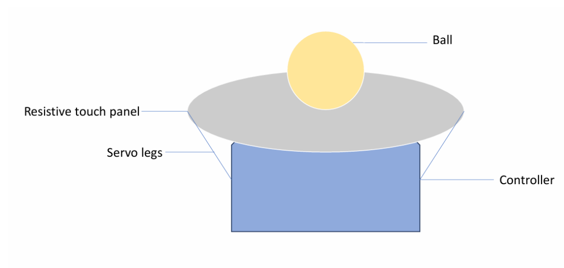

Fig. 1. Architecture I: Contact-Based Sensing. The ball rests directly on a resistive touch panel. Friction from the panel aids stability but reduces mechanical purity.

- **Critical Analysis:** While mathematically simple, this method suffers from hysteresis and wear. Crucially, the friction between the ball and screen acts as a passive damper, absorbing small errors.

B. Architecture II: External Computer Vision

A simplified vision system using a standard CMOS camera overhead (e.g., Webcam or Raspberry Pi Camera).

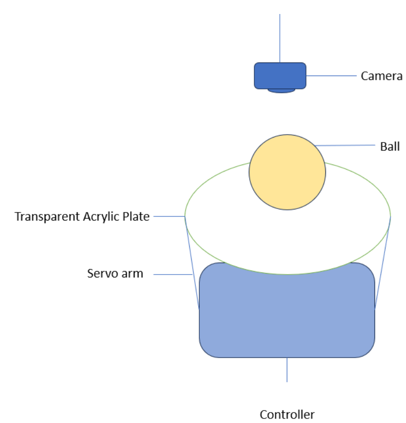

Fig. 2. Architecture II: External Optical Sensing. An overhead camera provides frictionless tracking, but introduces significant latency (lag) into the control loop.

- **Mechanism:** An algorithm (e.g., HSV color thresholding) isolates the ball's centroid from the video feed.
- **Critical Analysis:** This approach achieves true frictionless sensing. However, the total system latency (exposure time + transmission + processing) often exceeds 40ms, causing oscillation or "jitter" during high-speed movements.

C. Architecture III: IR Phototransistor Array (Proposed)

The proposed design features a custom PCB matrix of IR Emitters and Phototransistors embedded beneath a diffused acrylic plate.

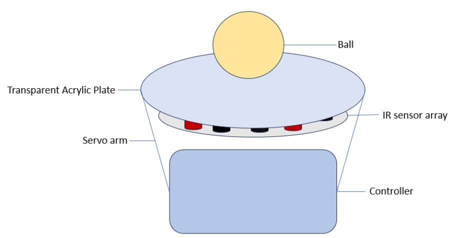

Fig. 3. Architecture III (Proposed): Internal Optical Sensing. The IR array embedded below the semi-transparent plate provides microsecond-level response times.

- **Mechanism:** As illustrated in Fig. 4, the system uses pairs of IR emitters and receivers. The emitters project IR light upwards. When the ball traverses the plate, it reflects varying intensities of IR light back to the phototransistors.
- **Calculation:** The position is derived via a weighted centroid calculation:

$$Pos_{ball} = \frac{\sum(V_{sensor_i} \times Pos_{sensor_i})}{\sum V_{sensor_i}} \quad (1)$$

- **Performance:** This architecture yields a response time of $< 10\mu s$ (limited only by the ADC sampling rate). It is immune to the friction of touch screens and the latency of cameras, making it the optimal choice for high-speed balancing.

III. Control Strategy Optimization

A. Baseline: PID Control

The standard implementation utilizes a Proportional-Integral-Derivative (PID) loop.

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (2)$$

While effective for small deviations, PID requires precise manual tuning and struggles if the ball's mass changes.

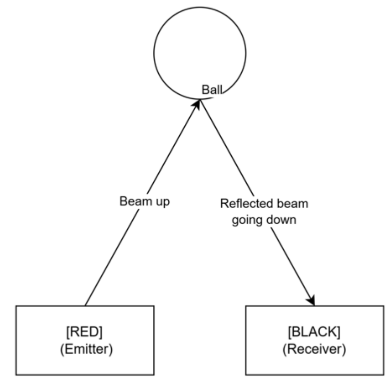

Fig. 4. Sensing Principle of Proposed Architecture. The IR Emitter (Red) projects a beam upwards. The Ball reflects the beam down to the Receiver (Black), creating an analog signal proportional to proximity.

B. Proposed: Reinforcement Learning (RL)

To enhance robustness, we propose replacing the static PID block with a Deep Reinforcement Learning (DRL) agent.

- **Framework:** The problem is modeled as a Markov Decision Process (MDP).
- **Advantage:** Unlike PID, the RL agent learns to anticipate the ball's momentum through training, creating an adaptive control policy.

IV. Comparative Analysis

Table I summarizes the performance metrics based on experimental observations.

TABLE I
Comparison of Sensing Architectures

Feature	Touch Screen	Camera Vision	IR Array (Ours)
Sensing Type	Contact	Optical (Ext)	Optical (Int)
Complexity	Low	Medium	High
Response Time	Fast	Slower	**Very Fast**
Friction	High	None	**None**

V. Conclusion

This study implemented and compared three sensing architectures for a **Ball and Plate System**. The Resistive Touch Screen provided a stable but friction-heavy solution. The Computer Vision approach offered frictionless movement but was limited by latency. The proposed IR Phototransistor Array proved to be the superior architecture. Furthermore, the theoretical integration of Reinforcement Learning suggests a path toward fully autonomous calibration.

REFERENCES

[1] "Comparative Study & Implementation of Ball Balancing Robot Architectures," Technical Project Report, 2024.
[2] K. Ogata, *Modern Control Engineering*. Prentice Hall, 2010.
[3] R. S. Sutton and A. G. Barto, *Reinforcement Learning: An Introduction*. MIT Press, 2018.