Table Tennis Fault Serve Detection

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1. Introduction

1.1 Objective

In table tennis, the service is the most crucial part of every point. It dictates the style and pace of play for the point. In doubles, service becomes even more restrictive where the player can only serve from the right half of his side to the diagonally opposite side of the opponent. Often players try to “jam” the opponent with a serve along the centerline of the table. However, with the speed of the ball and heavy spin generated, it is very difficult for the umpire to determine if a serve was “in” or “out” since he or she is sitting at the side of the table. With organizations like the National Collegiate Table Tennis Association (NCTTA), a doubles match is used as a tiebreaker between two teams who had split results in the singles stage. In such high-stakes matches, even one mistaken call can affect which teams move on in competition.

Our goal for this semester is to design a table tennis fault serve detector. The detection system must be integrated into the table and must not interfere with gameplay. This means that all equipment must be confined to either the area underneath the net or underneath the table. An ultrasonic sensor will be used to detect the presence of the ball in a “questionable” region. This will trigger a microcontroller to save the most recent frames received from the camera. We will determine a result using computer vision ball tracking. The result will then be wirelessly transmitted to a display with the umpire so that it does not distract the players.

1.2 Background

Currently, there are no devices on the market that detect the validity of the serve for specifically table tennis. However, there are systems, such as Hawk-Eye, used in many sports including tennis and cricket to track the position of the ball. Hawk-Eye technology combines the views from at least six cameras to produce a 3D perspective of the ball’s trajectory [1]. Although Hawk-Eye is highly accurate, it would not be practical to implement such a system in table tennis. These systems are very expensive, and at times, there are several table tennis games occurring at once. This would result in the need for many systems. By developing a cost effective, compact serve detector, implementation of such systems in table tennis would be more feasible.

1.3 Requirements

- Requirement 1: The device must be fully integrated into the table equipped with a wireless result display to the umpire to minimize any hindrance to the game.
- Requirement 2: The system must be able to operate for at least 45 minutes.
- Requirement 3: Maintain reasonable accuracy for detection of serve (percentage accuracy to be determined based on calculations)

2 Design

2.1 Block Diagram

The block diagram for our implementation is shown in Figure 1. The main components of our design include the sensor system, control unit, wireless display, and power supply. The power to the different components, via a cable, will be supplied from batteries fixed under the table. The ultrasonic sensor will detect the presence of the table tennis ball as it enters its field of view. The ultrasonic sensor will be connected to the camera which will start recording right away for a predefined period.

This collected data will be fed into the microcontroller performing computer vision to determine the location of the ball, eventually deciding whether the serve was valid. Through the Bluetooth module, the result will be sent wirelessly to the LED display near the umpire.

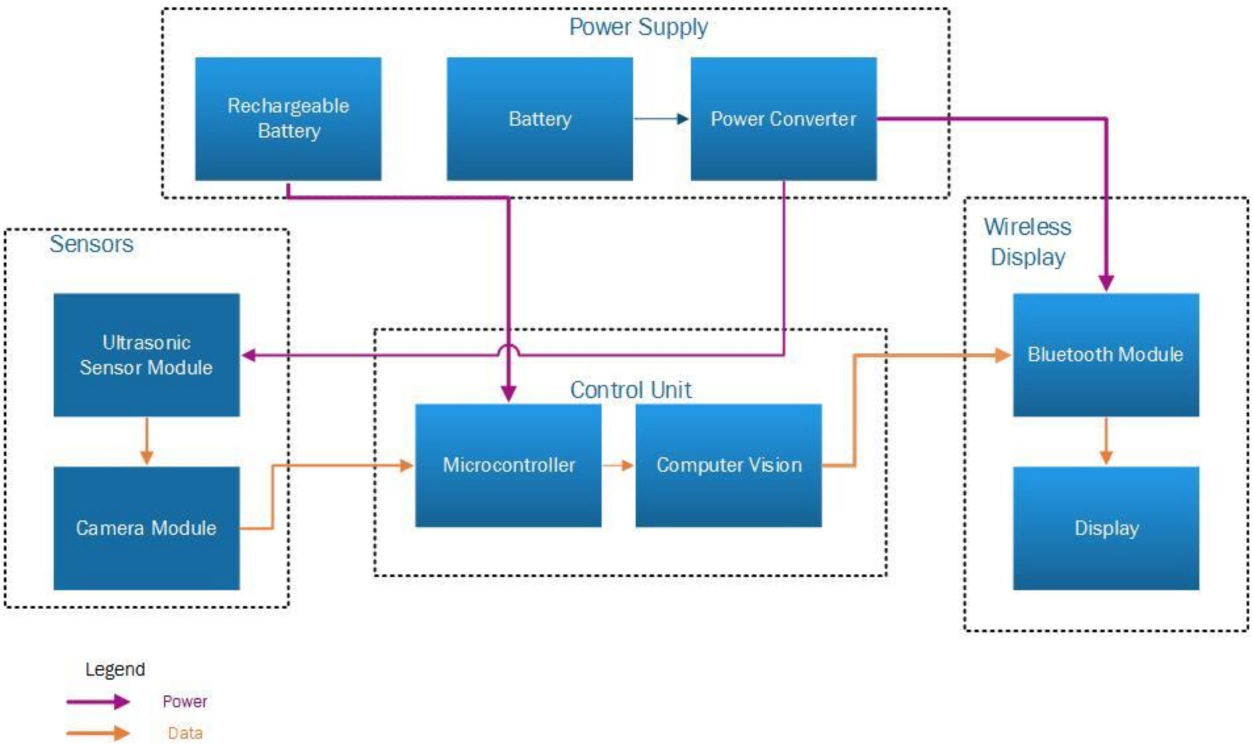

Figure 1: Block diagram

2.2 Physical Design

The ultrasonic sensor and camera modules will need to be placed in the net directly aligned with the center line. As it can be seen in Figure 2, the camera is placed directly above the ultrasonic sensor. This will allow the ultrasonic sensor to detect the ball the moment it hits the table. Since the net is only 6 inches high, the camera and ultrasonic sensor should have negligible effect on the players' vision. The wireless display will be located away from the table as to not interfere with the game.

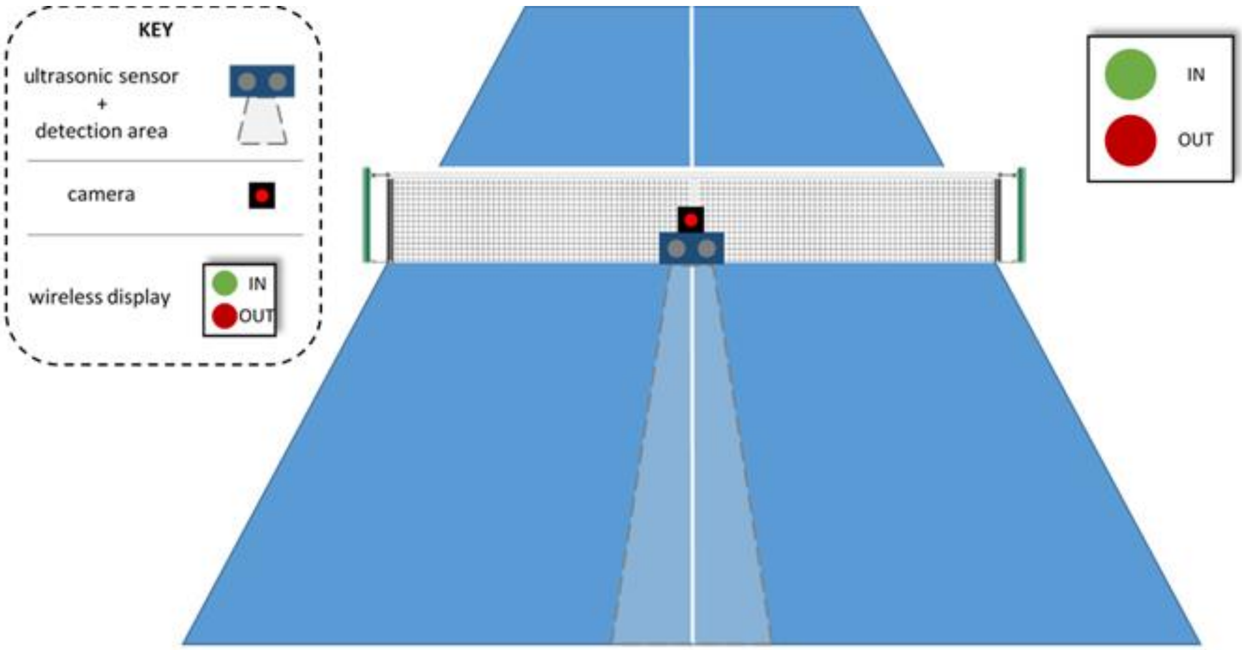

Figure 2: Physical design

2.3 Sensors

2.3.1 Ultrasonic Sensor

The ultrasonic sensor will have a detection range along the center white line. As an object enters the range, the ultrasonic sensor will trigger the camera to start recording.

Requirement 1: Sensor must detect if ball bounces within 2 inches on each side of the center line.

2.3.2 Camera

The camera will be continuously filming along the center line of the table and sending these images to the microcontroller. Resolution will be dependent on the processing capabilities of the microcontroller. In order to function properly, the camera must have: 1) a minimum frame rate and 2) a minimum viewing angle. Both of these are dependent on some measurements we still need to take, but sample calculations are shown below.

Assumptions:

- Camera views only up to a height of 6.0 inches
- Net height is 6.0 inches
- Air resistance is neglected because it would only slow the ball down

For a ball that barely passes over the net (height y=0.1524m or 6.0 inches)

$$\Delta y = \frac{1}{2}a_y t^2 - v_{0,y}t$$
$$-0.1524 = \frac{1}{2}(-9.8)t^2 - 0t$$
$$t = 0.1764\, seconds$$

For a ball that passes high over the net (height y=0.3048m or 12.0 inches)

$$\Delta y = \frac{1}{2}a_y t^2 - v_{0,y}t$$
$$-0.3048 = \frac{1}{2}(-9.8)t^2 - 0t$$
$$t = 0.2494\ seconds$$

Fall time for the last 6.0 inches of ball falling:

$$0.2494 - 0.1764 = 0.0735\ seconds$$

Required frame rate to capture this bounce at least twice on decent:

$$r_{min} = \frac{2}{0.0735} = 27.21\ frames/second$$

Requirement 1: Must be at least 30 frames per second.

2.4 Control Unit

2.4.1 Microcontroller

The camera and ultrasonic sensor will feed into the microcontroller. The microcontroller will save the last X[1] frames using a buffer. When the ultrasonic sensor detects the ball, the current set of frames will be saved for analysis by the computer vision software. There will also be a "reset" option to allow the system to start looking for the next serve.

Requirement 1: Must be able to save the frames containing the bounce of the ball based on sensor input.
Requirement 2: Have an option to clear buffer to be ready for the next serve.

2.4.2 Computer Vision Software

This software will take the X[1] frames from the camera and determine between which frames the ball bounced. From this we can determine the ball's most likely location of contact with the table. By also observing the location of the line in the image, we can determine if the ball was "in" or "out".

Requirement 1: Must distinguish the table tennis ball from the background/table.
Requirement 2: Track the movement of the ball and determine the frame(s) the bounce occurs.
Requirement 3: Determine if ball is "in" or "out".

2.5 Wireless Display

2.5.1 Bluetooth Module

The Bluetooth module will receive a signal from the microcontroller. This signal will then be transmitted to the display.

[1] Value of X to be determined by calculations based on choice of camera and signal delays.

Requirement 1: The Bluetooth module must transmit the signal at least 12 feet away.

2.5.2 Display

The main components of the display for the system will include a receiver and two LEDs. Once a signal is received from the Bluetooth transmitter, either the LED representing "in" or "out" will light up depending on the location the ball bounces.

Requirement 1: The display must clearly show the correct call for the play.
Requirement 2: The display must be reset after each play.

2.6 Power Supply

2.6.1 Battery

The power source for the detection system consists of three batteries. Battery 1 will be a rechargeable power pack for the microcontroller. We chose to use a battery pack because the microcontroller requires much power in order to operate for the specified amount of time. Battery 2 will be used to power the ultrasonic sensor. Voltage for the wireless display will come from a separate source, battery 3. It is important that all batteries will be able to power the components for the appropriate amount of time.

Requirement 1: All batteries must last the length of a best-of-seven game match, which can take up to 45 minutes.

2.6.2 Power Converter

Voltage for the ultrasonic sensor and wireless display may need to be stepped down. As a result, two buck converters will be needed. The buck converters will provide the correct voltage necessary for the components.

Requirement 1: Buck converters need to step down voltages to 3.3V with minimal ripple[2].

2.7 Risk Analysis

In our system, we believe the computer vision aspect poses the most risk to successful completion of the project. Our ability to accurately detect if the ball bounces "in" or "out" is dependent on factors such as resolution and the exact position of the ball for the analyzed frames. Although higher resolution cameras are a better choice for detecting the ball in the frames, they need longer processing times and require more RAM. As a result, a lower resolution camera must be used. We will be able to calculate an appropriate resolution based on our chosen frame rate.

An additional challenge is that the ball position in the frame cannot be controlled. Since the ball may not be captured directly hitting the table, it is important that multiple frames are saved. By using several frames, the motion of the ball will need to be determined. This will give us the ability to approximate the point on the table at which the ball bounces. Combining these different aspects increases the complexity. Therefore, accurate computer vision is essential for successful analysis of the ball.

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[2] *"Minimal" is dependent on the specifications of the ultrasonic sensor we will choose.*

3 Safety and Ethics

It is important that our fault serve detection system complies with the IEEE Code of Ethics not only during the developmental stage but as well as after the design is implemented. There are a couple safety violations that need to be taken into consideration in order to abide by IEEE Code of Ethics, #1 - "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public..." [2]. If voltage or current limits are exceeded for any of the components, there is a possibility of the particular component overheating and/or combusting. If such an occurrence were to happen, the equipment, particularly the net and table, could be damaged. It also poses a risk to anyone near the system at the moment including the players, the umpire, and/or any audience members nearby. To combat this issue, correct calculations for the power supply are essential as well as thorough testing of the system. Another issue could result if the components are not securely fastened. Any loose components could act as projectiles if hit correctly. As a result, all parts of the system will be able to be thoroughly secured.

In order to comply with IEEE Code of Ethics, #3 - "to be honest and realistic in stating claims or estimates based on available data" [2], it must be reiterated that our system will likely not be 100% accurate. The system should not be altered in any way as any changes could affect the accuracy if not recalibrated.

The intended use of our design is for indoor table tennis games. Using the system in an outdoor environment poses the risk of damaging components in the presence of hazardous weather conditions.

References

[1] Wood, Robert. “Hawk-Eye Line-Calling System.” *Hawkeye Tennis Line-Calling System*, Topend Sports Network, 2008, www.topendsports.com/sport/tennis/hawkeye.htm.

[2] “IEEE IEEE Code of Ethics.” *IEEE Code of Ethics*, IEEE, www.ieee.org/about/corporate/governance/p7-8.html.