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Research Article

Embedded Ball Launcher with Trajectory Path Analysis for Empowering Junior Table Tennis Players

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ABSTRACT

One of the most popular sports in Asia is Table Tennis, it requires close supervision from a coach to assess the player's strengths and weaknesses. To address this need, a personal Table Tennis trainer in the form of a pitcher machine has been developed. The machine analyzes the player's practical performance by examining the trajectory path of the ball. The system incorporates a camera that tracks the movement of the table tennis ball. Images captured by the camera are processed using OpenCV software, enabling the prediction of the ball's flying trajectory based on its X and Y coordinates. This analysis allows for an evaluation of the player's performance in different directions. By utilizing a smartphone, the pitcher machine can be adjusted to target the direction where the player's performance is weak, thereby providing additional practice in that specific area. Although the proposed system does not currently include spinning serves, it offers a suitable platform for early-stage table tennis training. Experimental results demonstrate the system's ability to perform acceptable performance analysis in complex and cluttered environments.

1. Introduction

Table Tennis, a beloved physical activity enjoyed by many, involves two or four players taking turns hitting a ball. Just like any other sport, coaching plays a crucial role in a player's performance, both before and during competitions. Researchers have conducted several studies to improve the performance of ping pong players. They have integrated sensors and devices to analyze various aspects of athletes' performance, such as gender, fitness, blood lactate level and mental health [1], [2], [3], [4], [5], [6]. Additionally, thanks to rapid advancements in technology and robotics, table tennis robots have been created. These robots are designed to generate and optimize the ball's trajectory over time [2], [7], [8], [9]. An exciting development in this field is the introduction of an aggressive trajectory generator, controlled by sensors, in [10]. Researchers have also explored the prediction of a spinning ball's trajectory in [11] to understand its physical behavior. Various other methods for predicting and generating trajectories have been discussed and proposed [12], [13], [14]. In this particular paper, we propose, design, and create a table tennis launcher and performance analyzer. Our motivation behind this work is to enhance the training experience for solo ping pong players by analyzing the trajectory path and helping them practice more in the direction where they struggle. Moreover, the proposed Embedded Ball Launcher offers a training experience that can be personalized by players and coaches. They have the ability to adjust launch parameters such as ball speed, spin, and trajectory, allowing them to create training scenarios that are specifically designed for their skill levels and training goals. The system can also be programmed to simulate different opponents, match

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conditions, and playing styles, providing a versatile and dynamic training environment. Finally, a bright future for the ping pong ball launchers and trajectory path analyzers can be predicted by implementing the real time feedback and coaching during the training sessions, utilizing Virtual Reality (VR) and Augmented Reality (AR), and the integration of the smart portable ball launchers with smart watches or any other wearable devices.

2. Hardware Architecture and Experimental Setup

Computer stereovision system. Stereovision system is the extraction of 3D data from computerized pictures, for example, those got by a CCD (Charged Couple Device) camera. By looking at data about a scene from two vantage focuses, 3D data can be separated by analysing the general places of articles in the two boards. CCDs are sensors utilized in advanced cameras and camcorders to record still and moving pictures. The CCD catches light and changes over it to computerized information that is recorded by the camera. Thus, a CCD is frequently viewed as the computerized adaptation of film. The proposed embedded Table Tennis ball launcher with trajectory path analyser design is based on the operation of a ball launcher attached at the end of the table tennis table and the camera attached to the laptop beside the table for path analysis. The various hardware elements of a ping pong ball pitching machine collaborate to launch the ball with precision and desired attributes. The specific components employed in this project are ball hopper stores that supply the balls to the machine. Stepper motor is also employed to ensure accurate control over speed and position. Finally, the control system of the pitching machine that consists of microcontrollers, circuit boards, and related electronics. The entire launching system is supported by a sturdy wooden frame stand, which acts as the backbone of the system and ensures stability. One of the key components is the actuator mechanism, responsible for accurately shooting one ball at a time when triggered. To achieve this, the ball container used is a modified basket made from plastic. This basket has a disc with half-circle-shaped holders for the balls, which is attached to a motor. The motor and disc combination allows the launcher to rotate a full 360 degrees. A hole is specially created at the bottom of the basket for a long handlebar to be attached. Additionally, a second handlebar, shorter than the first one, with some flexibility is connected to the longer handlebar, making it easier to reach and maneuver. As the motor turns, the propeller-shaped disk holding the balls rotates, positioning them on the shooting track. The speed of the motor can be controlled to adjust the shooting speed. The ping pong balls travel from the propeller-shaped disc in the hopper to the first horizontal track. To provide shooting in different directions, a second track is connected to the first track at a 30-degree angle. The prototype's side, front, and top views can be seen in Fig.1.

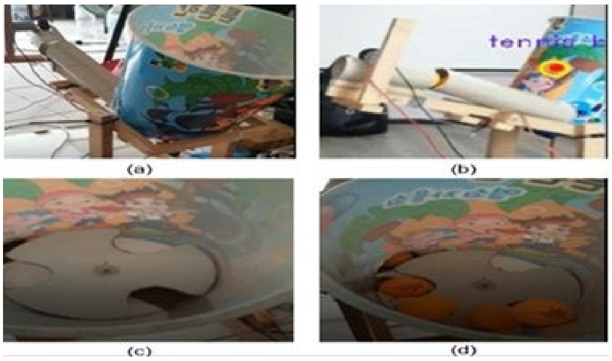

Fig. 1. The (a) Side, (b) Front, (c) Top Views (d) Top View while the Balls are Preparing to launch

In order to adhere to cost limitations and align with the Sustainable Development Goals (SDGs), the proposed prototype utilizes entirely recycled materials. the first and most important step is to find and keep an eye on the ball. To make sure we accurately detect the ball, we need to take some extra steps. One of these steps involves converting the way we represent colors from RGB to HSV. RGB is a color model commonly used in digital displays and cameras, but it doesn't directly match how humans perceive colors. HSV, on the other hand, is a color model that better aligns with human perception. It separates color information from brightness information, making it easier to describe colors in a way that resembles how our eyes see them. By converting the RGB color representation to HSV, we can describe colors in terms of hue, saturation, and value. Hue represents the actual color, saturation represents the intensity or vividness of the color, and value represents the brightness. This allows us to capture the important color characteristics of the ball in a more human-friendly way. To achieve accurate ball detection, we have used either manual tracking or detection-free trackers from the OpenCV library. Manual tracking involves manually following the ball's movement, while detection-free trackers are algorithms that can track objects without explicit detection. Both approaches have been employed to ensure that the ball is effectively identified and tracked throughout the project. When estimating the trajectory of a ping pong ball using OpenCV, there are typically two main steps to follow: ball detection and ball tracking. In ball detection, the system identifies the presence and location of the ball in each frame of the video or image. Then, in ball tracking, the system continuously tracks the ball's movement across subsequent frames, allowing for the estimation of its trajectory over time. The trackbarPos code is employed to filter the desired results. This code facilitates the creation of a trackbar, which provides a user interface element for adjusting the required HSV levels. By using the trackbar, one can easily modify the HSV values to achieve the desired outcome. Fig. 2 shows the outcome of altering the image threshold in runtime from track bar code.

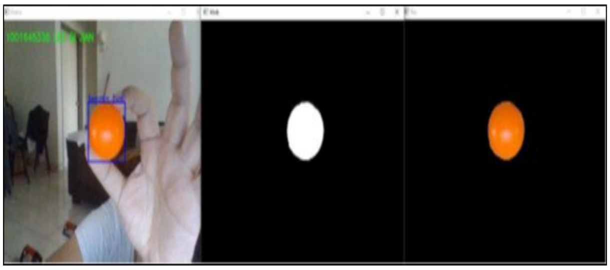

Fig. 2. TrackbarPos HSV Level Adjustment

The general overview of the steps involved in the process of ball tracking is as follows: in the first step, we transform the image into black and white by converting it to grayscale, and implement any required preprocessing methods like blurring or thresholding to improve the identification of outlines. Then we detect all the contours involved in the image for the further use in the image processing which is elimination of those contours that meet the criteria specific to our Ping-Pong ball such as size, circularity, and the color. Once the contours are detected, it's time to calculate the contour area in square pixel. The last step is to monitor the behavior of the Ping-Pong ball through accumulation of collected contour areas.

While color-based object detection offers several benefits, it also has its limitations. One notable limitation is the possibility of background tracking interruption. This occurs when the tracking of the ping pong ball is compromised because the background color closely resembles the color of the ball. Consequently, this interruption can considerably decrease the accuracy of the detection process and consequently have a significant impact on the analysis being performed. Hence, the measurements of the contour area have been set up as shown in Fig. 3.

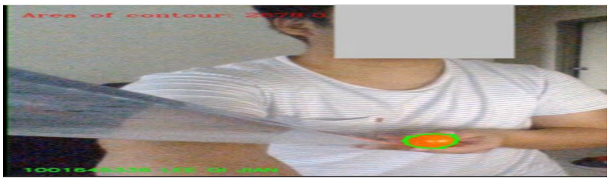

Fig. 3. Contour Area Measurements

When it comes to real world scenarios there are methods to determine the location of a ping pong ball. In our project we have devised an equation that allows us to accurately measure and identify the balls position by using the counter area as a point of reference. This equation serves as a tool in determining the balls position on the table during gameplay and it is shown in Eq. (1):

$$y = -4.963453 + \frac{5296.735 + 4.963453}{1 + \left(\frac{x}{0.09193972}\right)^{0.4415413}} . \quad (1)$$

To accomplish this, the camera is positioned in a stationary manner, and the distance between the camera and the contour area is measured and recorded in an Excel spreadsheet. Eq. (1) is derived by utilizing Excel functions and Python code to estimate the separation distance. Fig. 4 shows a plot of the trendline between the area and the distance of the contour.

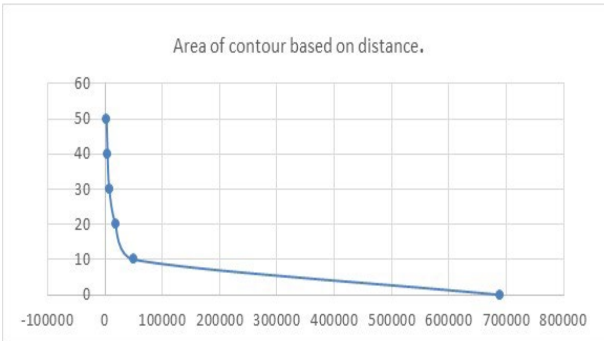

Fig. 4. The Trendline Between Area and Distance of Contour

A physical measurement has been conducted to test the contour measurement function using OpenCv and the measurement accuracy as illustrated in Fig. 5. The comparison indicates that the achieved accuracy is acceptable and meets the desired standards.

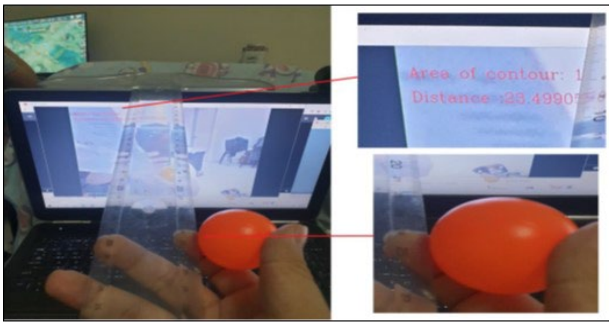

Fig. 5. Distance Measurement Accuracy Check

We have validated the accuracy of our results by comparing physical measurements taken with a ruler to virtual measurements obtained using OpenCV. To effectively store and track the ball movement at various points, we employ a deque datatype in Python, which allows us to save each tracked point. This enables us to create longer trajectory paths and maintain a history of points, represented as f(x,y). This comprehensive tracking approach ensures that we capture the complete movement of the ball. To ensure the ball is presented in the most suitable manner for analysis and simulation, the frames are processed and resized to achieve the optimal height and width. This ensures that the representation of the moving ball is suitable for further analysis and accurate simulation. Moving on, we utilize image blurring or smoothing techniques to enhance the quality of the detected ball image. Specifically, we apply a Gaussian blur filter, which involves convolving the image with a Low Pass Filter (LPF) Gaussian kernel. This process effectively reduces noise in the image, resulting in a clearer and more refined appearance of the ball. This step enhances the accuracy of our analysis and tracking procedures. To gain an understanding of the intricacies within an image we can employ the blur technique to calculate the Laplacian. This method involves examining the intensity gradient at each pixel using the Sobel operator. By applying a Gaussian blur to the image we effectively eliminate any noise or irregularities that may be present. This process of smoothing allows, for calculations of the gradient resulting in a clearer and more accurate depiction of how the images intensity changes. In terms employing Gaussian blur helps us refine image quality and extract details for further analysis. Therefore, at the same location (x,y), the computed response is stored in the destination image and is calculated by: Eq. (2)

$$dest = \frac{\partial^2 src}{dx^2} + \frac{\partial^2 src}{dy^2}. \qquad (2)$$

where dest is the destination image and src is a source image. In this project, we extract the HSV value of the source image by using the OpenCV trackbar and apply filtering techniques. We create a specialized mask that is designed to detect the color of the ball, specifically an orange ball mask in this case. By analyzing the contours within the mask, we identify the largest contour, which corresponds to the ping pong ball.
To determine whether the ball has been hit or not, we examine the y-coordinate value. If the y-coordinate is negative, it indicates that the ball has been shot towards the player. Conversely, if the y-coordinate becomes positive, it indicates that the player has successfully hit the ball back, causing the trajectory path to change direction.The y-coordinate value result is shown in Fig. 6.

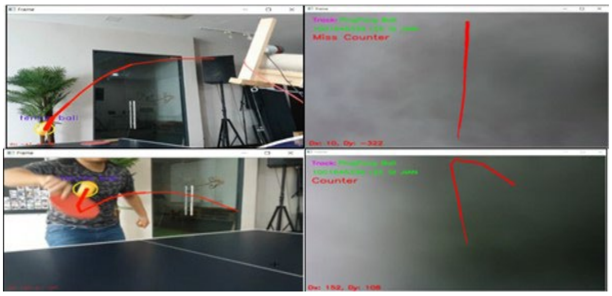

Fig. 6. Calculation of the Trajectory Path Based on Y-coordinate Values

To evaluate how well a player is doing, we can look at the Y-coordinate of the ball's movement. By examining both the coordinates of the ball's path X and Y, we can get a sense of the player's skill level. In particular, we focus on the Y-coordinate values when they reach 150. The player struggled to respond to the ball, indicating a weak performance if the overall value is negative. In these cases, the trainer steps in and uses a machine pitcher to launch the ball towards where the player had difficulties. The pitcher machine allows for controlled launches of the ping pong ball, and the direction can be adjusted by the coach, trainer, or even by the player.

To simplify things, an infrared (IR) remote control is used to operate the pitcher machine, making it easy to control and make adjustments. Additionally, the trajectory of the ball is tracked and visually displayed, providing valuable insights into the player's playing style. This tracking and visualization process allows for continuous monitoring and analysis of the player's performance, helping to identify areas for improvement and enhance overall gameplay.

3. Results and Discussion

In order to analyze the results, this paper includes a pre-processing step called image thresholding. This technique is used to remove unnecessary parts of the image, allowing the representation of the ping pong ball to be more accurate. Image thresholding is a simple method of segmenting an image by dividing it to black and white, these two groups represent the background and the foreground respectively. In this project, manual selection of the threshold is done. Any regions in the image with a saturation level above the chosen threshold are converted to white, while the remaining regions are kept as black. This helps to isolate and highlight the ping pong ball in the image for further analysis. Fig. 7 shows the threshold selection result for both background, foreground and the level adjustment.

In this project, object overlapping scenario is regarded as a false condition. The object overlapping scenario occurs when multiple objects or regions of interest in an image overlap or intersect with each other.

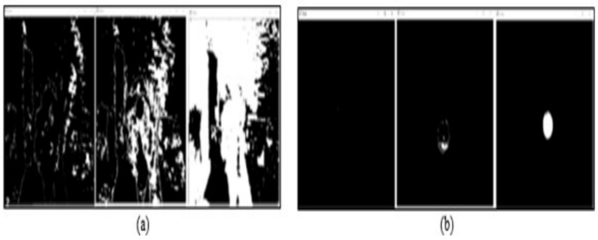

Fig. 7. Threshold Value Selection for (a) Background/Foreground, (b) Level Adjustment from 0 to 255

This situation can arise when objects are in close proximity to each other or when their boundaries overlap due to factors like complex shapes or occlusions. When objects overlap, it presents a significant challenge to track them individually over time, particularly when the objects experience occlusions or undergo significant shape changes during the tracking process. The ball detection process struggles to precisely identify and track individual balls under such circumstances. As a consequence, we exclude any instances where balls overlap from our analysis and do not incorporate them in the final results.

However, it is crucial for us to address the challenge of ball tracking in scenarios where balls overlap. We acknowledge the significance of accurately detecting and tracking multiple balls, even when they are overlapping, as this is a common occurrence in real-world situations.

In this regard, we propose the object separation segmentation technique to avoid or minimize the overlapping problem. By utilizing segmentation algorithms, we can effectively separate and segment overlapping objects based on their unique visual characteristics. These algorithms can accurately distinguish between the objects, even when they are overlapping. Additionally, if depth information is available, it can be leveraged to further enhance the accuracy of the segmentation process.

We have then created an additional Python file dedicated to drawing the trajectory and facilitating the movement of the ping-pong ball. To enhance the accuracy of ball detection, we have implemented a rule that allows only one ball to be counted at any given time. For example, if there are multiple ping pong balls detected on the screen, we consider the ball with the larger radius as the main ball. This selected ball is then chosen for further analysis and tracking. By adopting this approach, we ensure a more precise and dependable ball detection process, contributing to the overall accuracy and reliability of the system. Object overlap has been implemented and the corresponding tracking failure is shown in Fig. 8. Auto selection of the ball and tracking of a single object at a time is demonstrated in Fig. 9. In order to ensure accurate ball detection, particularly in crowded environments, several components have been integrated into the screen setup. These additional elements have been carefully implemented to enhance the system's ability to detect and track balls effectively, even in challenging scenarios with numerous objects present. By incorporating these elements, we aim to improve the accuracy and reliability of the ball detection process, ensuring optimal performance in crowded environments.

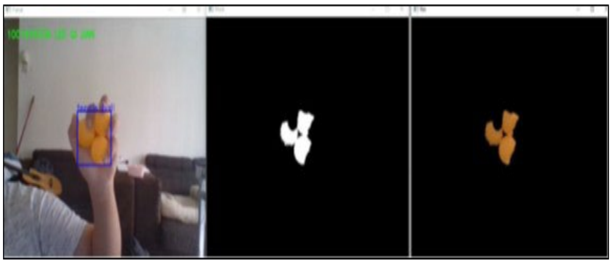

Fig. 8. Objects Overlap Causing Tracking Failure

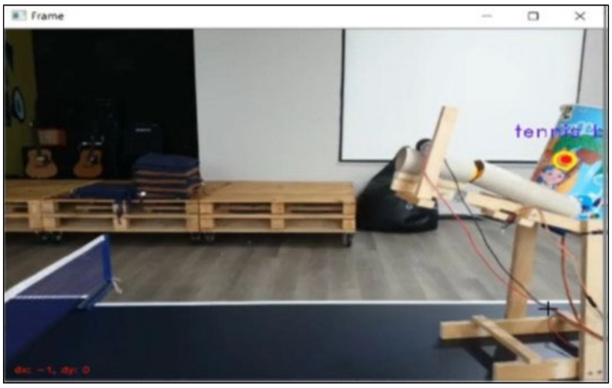

Fig. 9. Object Detection in a Crowded Area with Presence of Two Balls

Color-based object detection, despite its advantages, has certain limitations. One such limitation is the potential interruption in background tracking, whereby the similarity between the background color and the ping pong ball will cause the ping pong ball tracking to be lost. The analysis will be affected dramatically due to the reduced accuracy. Fig. 10 is proof of the tracking interruption due to the similarity of the background and the ball. As illustrated in Fig. 10, the tracking of the yellow ping pong ball is lost at the moment the passes by the container with similar background color. This issue is considered in this project and object detection enhancement will be tackled in our future work.

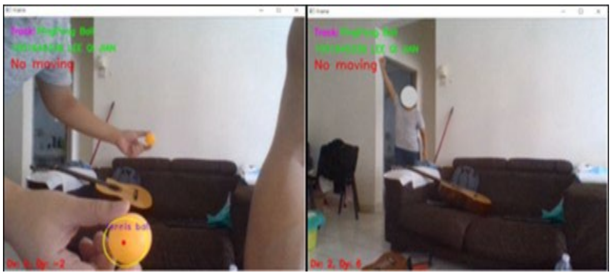

Fig. 10. Color Similarity with the Background Causing Tracking Interruption

Moreover, Due to using HSV value for tracking the ping pong ball, the balance of the light condition is important. Fig. 11 shows that the light conditions are brighter on left side. Therefore, when the ball is shooting with pitcher machine, webcam still able to detect the location of ping pong ball, but when the ping pong ball went into brighter place it will lose the target, due to the light change the colour on ping pong ball surface.

Fig. 11. Missing Ball in Bright Side

4. Conclusion

A special table tennis launcher has been created to help train players by analyzing their performance in real-time using ball tracking technology. The launcher consists of a modified basket with a servo motor underneath, which rotates to shoot the balls onto the table tennis board. Segmentation based on color is used in this system to detect the ping pong ball. Once the segmentation is complete, various factors like ball shape, location, and motion are taken into account to evaluate the player's performance.

The ping pong ball tracking is achieved using OpenCV software. The performance of the player is then assessed by calculating the trajectory path at every point depending on the distance the ball travels. This analysis allows for the identification of weaknesses in the player's performance. To address these weaknesses, a smart table tennis trainer utilizes a machine pitcher to launch ping pong balls specifically towards the areas that the player struggled in. This targeted practice helps the player improve their performance in that specific direction. Additionally, the system enables ongoing monitoring of the player's weaknesses and overall enhancement of their performance. In a nutshell, The Embedded Ball Launcher with Trajectory Path Analysis offers a wide range of advantages. It enables an objective and measurable evaluation of a player's performance, facilitating focused skill improvement and precise technique enhancement. Additionally, the system allows players to analyze and comprehend the effects of various shot parameters on ball trajectory, promoting strategic decision-making and adaptability in real-game scenarios.

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Authors Introduction

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