

An Automated Tracking System for Locating Impact Points on a Table Tennis Surface Using Ping Pong Balls

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Abstract

This project presents a novel system for real-time table tennis ball tracking and hitting point prediction, developed using OpenCV-Python. The system is designed to contribute to strategic analysis in the sport by accurately identifying the ball's trajectory and anticipating its landing point. The proposed system is comprised of four key modules: ball detection, ball tracking, hitting point prediction, and data visualization. Computer vision techniques are employed to effectively detect and monitor the ball's movement. Kalman filtering is utilized to refine the prediction of the ball's landing point. The generated data is then presented visually to facilitate analysis and comprehension of game dynamics.

Keywords: Real-time detection and tracking, Hitting point prediction, Kalman Filter

1. Introduction

Table tennis, commonly referred to as ping pong or whiff-whaff, is a sport derived from tennis, albeit adapted for play on a smaller, stationary table surface demarcated by nets rather than a traditional tennis court. Players in both sports engage in a similar style of play, aiming to return the ball over the net and into the opponent's half of the playing area using rackets. Failure to do so results in a point being rewarded to the opposing player. The game can be played either individually or in teams of two and is versatile in that it can be enjoyed both indoors and outdoors, thereby appealing to a wide range of casual participants. The compact play area and the rapid trajectory of the ball in table tennis contribute to its reputation as a fast-paced sport in comparison to other ball games. Players of table tennis are required to exhibit rapid and continuous reactions during gameplay, responding to the ball's unpredictable trajectory. This demand arises from the nature of table tennis rackets, typically constructed with rubber materials that facilitate

enhanced ball spin and acceleration. The global appeal of table tennis transcends age and skill levels, with enthusiasts engaging in the sport recreationally and competitively across various settings. The sport of table tennis revolves around essential equipment, notably the table tennis ball, the table, and the racket. International regulations dictate the use of a spherical object weighing 2.7 grams (0.095 ounces) with a diameter of 40 millimeters (1.57 inches). Since 2015, these balls have transitioned from celluloid to polymer materials, offering white or orange options with a matte finish. The selection of ball color is often influenced by the playing surface and its surroundings; for instance, a white ball contrasts more effectively on green or blue tables than on grey surfaces. The table dimensions measure 2.74 meters (9.0 feet) in length, 1.525 meters (5.0 feet) in width, and stand at a height of 76 centimeters (2.5 feet). The playing surface is uniformly dark blue and matte, divided into two halves by a net positioned 15.25 centimeters (6.0 inches) high. The International Table Tennis Federation (ITTF) strictly sanctions tables crafted from wood or its derivatives. In public outdoor spaces like parks, concrete

tables with steel nets or solid concrete partitions may occasionally be encountered. Modern table tennis rackets, also known as paddles or bats, play a pivotal role in shaping a player's performance. A superior-quality racket enhances ball speed and trajectory, optimizing players' techniques and strategies. Key components of a racket encompass the blade, handle, and rubber. The blade serves as the racket's primary structure, crafted from wood. The handle, the gripping section, is tailored primarily to fit the player's hand size and grip style—Penhold or Shakehand—emphasizing comfort and control. The rubber sheets, colored red and black, affixed to both sides of the blade directly interact with the ball, requiring careful selection to align with the player's playing style. In recent years, table tennis has evolved into a fiercely competitive and increasingly popular sport. Technological advancements have revolutionized the game, particularly concerning equipment. Innovations in materials and manufacturing techniques have ushered in lighter, faster, and more spin-friendly gear. Carbon fibers, advanced rubbers, and blade technologies have empowered players to unleash greater power and spin in their shots. Furthermore, components such as balls and tables have undergone rigorous standardization by the ITTF to uphold the integrity and quality of the sport [1].

Recent research has focused on developing automated systems for tracking table tennis balls and their impact points. Authors in [2] proposed a low-cost acoustic system using sensors placed under the table, achieving positioning accuracies above 94%. Study in [3] explored ball impact localization on rackets using piezo-electric sensors, with a linear regression method yielding RMSEs of 22.1mm and 19.8mm in transversal and longitudinal directions, respectively. Authors in [4] reported on a student-built system that tracks ball location and keeps score in real-time using video analysis. Prototype [5] developed a machine vision-based algorithm for tracking ball rotation and trajectory, incorporating deep neural networks, Fourier transform-based speed measurement, and CNN-based rotation direction detection. These advancements in automated tracking systems demonstrate potential applications in training, match analysis, and even robotic assistance in table tennis. The real-time automated tracking ball is a novel approach that leverages advanced imaging techniques and machine learning algorithms to enhance the precision of gameplay analysis. This system not only identifies the exact locations where the balls make contact with the surface but also analyzes the speed and angle of each shot, providing players with valuable insights to improve their performance. By integrating real-time data visualization, coaches and players can make informed decisions during training sessions, ultimately leading to a more strategic approach to the game. Furthermore, the system can be adapted for various training scenarios, allowing for customized drills that target specific skills such as spin control, shot placement, and reaction time. This adaptability ensures that players at all levels can benefit from tailored feedback, fostering a deeper understanding

of their strengths and areas for improvement. In addition, the technology can track progress over time, enabling athletes to set measurable goals and monitor their development, which enhances motivation and accountability in their training regimen. This continuous feedback loop not only helps in refining techniques but also builds confidence as players see tangible results from their efforts [6]. Furthermore, the integration of video analysis allows players to visually assess their performance, making it easier to identify patterns and make necessary adjustments in real-time. This holistic approach to training empowers athletes to take ownership of their development, encouraging a proactive mindset that translates into improved performance on the field [7, 8, 9].

The sport is undoubtedly growing in the right direction, having said that, some challenges might hinder table tennis development. Many players do not understand the significance of strategic analysis in the context of table tennis gameplay, especially in light of evolving game strategies and tactics influenced by modern playing styles and equipment innovations. The problem could also be caused by individual casual players who cannot afford to invest in those expensive professional training systems or are just unfamiliar with the concept of strategic analysis in table tennis [10].

Incorporating advanced technologies like computer vision into training and match analysis tools remains a challenge due to the complexity of real-time data processing and accuracy requirements. With faster-paced rallies and heightened player athleticism, there is a growing need for tools that can analyze and adapt to these dynamic gameplay scenarios. Effective coaching and player development relies on accurate performance analysis tools that can provide actionable insights into both strategic decision-making and technical execution.

When considering the design and implementation of a computer vision system for table tennis tracking and prediction utilizing OpenCV, the primary challenge is consistently presented by the rapid movements and spins of the table tennis ball in comparison to other ball sports, thus potentially affecting the accuracy of trajectory estimation. The prediction of ball trajectory may be influenced by the diverse hitting patterns of players' rackets and their individual playing styles [11].

Implementing algorithms for real-time detection and localization of the hitting points where the ping pong ball lands on the table involve utilizing image processing techniques to identify the exact location where the ball makes contact with the table surface. Problems will likely occur during the process of providing real-time feedback on the landing position to players and coaches for performance analysis and training purposes. Not to mention that vary minor aspects including lighting

conditions, player movements, and ball speed variations could possibly decrease real-time processing accuracy.

In this paper a real-time table tennis ball tracking and hitting point prediction system was designed and developed based on OpenCV-Python platform. The result of the system includes the ball trajectory and hitting point prediction was performed through a graph using Matplotlib.

2. Methodology

The system is a real-time table tennis ball tracking and hitting point prediction system. The system can be divided into four sections: ball detection, ball tracking, hitting point prediction, result visualization, and plotting. The system should be able to detect table tennis balls and track the ball's movement. Based on the ball's movement, a trajectory of the ball should be drawn. After that, the system should predict the hitting point of the ball by implementing ball trajectory data and the Kalman filter. Finally, after getting the prediction result, the system should plot out the ball trajectory and hitting point prediction in graph form. Major hardware components that are used in this project include a table tennis ball, a table tennis table, a camera, and a processing platform which is a laptop.

Fig. 1 illustrates a ping pong ball tracking and hitting point prediction system. It involves detecting the ball's location, tracking its movement, predicting where it will hit the table, and visualizing the results. OpenCV is used in this project, it is an open-source software library that developed for Artificial Intelligent, Computer Vision, object detection and Deep Learning purpose. The OpenCV library includes various functions such as image loading and resizing, real-time video processing, colour converting and detection, making this library fits perfectly to this project. There two programming languages can be used to operate the OpenCV library: C++ and Python language. Python language was chosen in this project due to its ease of use and rich yet complete libraries available.



Fig.1. Ping pong ball tracking and hitting point prediction system overview.

The programming code for this system was started by importing relevant Python libraries. The first library is OpenCV library, which includes the majority of functions that will be then utilized in the program such as, real-time video capturing and processing, color filtering, target object tracking etc. The second library is the NumPy library, a Python library used for working with arrays, it

includes functions for working in the domain of linear algebra, Fourier transform, and matrices. In Python, there are lists of other libraries and functions that serve the purpose of arrays, but they are slow to process. NumPy on the other hand is able to provide an array object that is up to 50x faster than traditional Python lists. The last library is the Matplotlib library, it is a low-level graph plotting library in Python that serves as a visualization utility. In this program, Matplotlib serves the purpose of plotting out the ball trajectory and hitting point prediction in easily understand graph form.

2.1. Ball detection

For object detection, a camera port is needed to capture real-time video. Python code 'Cv.VideoCapture ()' was used to define a camera port. The number in the bracket for this function determines the device selected for video capturing. For Windows System devices, '0' by default brings to the computer a prebuilt webcam, while other numbers indicate external connect camera devices based on USB ports.

There are various ways to achieve object detection in OpenCV such as by movement, by shape of the object and by colors, etc. Both shape and color detection methods were tried in this project to compare the performances, pros, and cons of each method. For the shape detection method, the color will not matter for the detection, therefore the camera output needs to be blurred and greyed. At the same time, lowering the clarity and image quality can lower the detection and calculation difficulty for later processes. Any circle-shaped object that occurs inside the camera angle will be detected and tracked. The second method of ball detection is the color detection method. The orange color object will be detected in this case. The color detection method was preferred over the other one. This is mainly because while the shape detection method is much easier to execute, it performs with lower accuracy when the detection range and distance is increased. Objects that are nearly circle could be defined as a ball that causes more than one object to be captured. The downside of the color detection method is the need for better lighting conditions in surroundings. After the system successfully detects a table tennis ball, a blue dot will be generated at the center of the ball image.

2.2. Ball tracking

The program followed by ball tracking section. In the previous part, a blue dot that represented the real-time location of the ping pong ball was generated. Based on the dots, the system was programmed to draw out a yellow line trajectory of the ball. It draws lines connecting the points in the trajectory list if drawing has started and there are at least two points. The yellow line will only start drawing once blue dots are detected.

2.3. Hitting point prediction

The third section of the system was hitting point prediction calculation. In this project, we utilized the Kalman Filter for prediction algorithms. The Kalman Filter is a powerful mathematical tool used for estimating the state of a system from noisy measurements. In trajectory prediction, it is used to estimate the future position of an object based on its current position and velocity, while accounting for noise and uncertainty in the measurements. This part of the program started by setting up all the parameters for the filter including State Transition Matrix (A) which defines how the state evolves over time, Measurement Matrix (H) which relates the observed measurements to the state, Process Noise Covariance (Q): which defines uncertainty in the process model, measurement Noise Covariance (R): which defines uncertainty in the measurement and Error Covariance Matrix (P): which represents the uncertainty in the initial state.

Fig. 2 shows the camera view window that will be generated while the system's program is running. The blue dot that is located at the center of the ball is achieved by the ball detection section programming code. A yellow line was drawn which indicated the ball movement trajectory. After this, the yellow dot signifies the anticipated point of impact of the ball, as calculated periodically using the Kalman Filter algorithm. This projection is established through a fusion of the ball's prior trajectory and velocity.

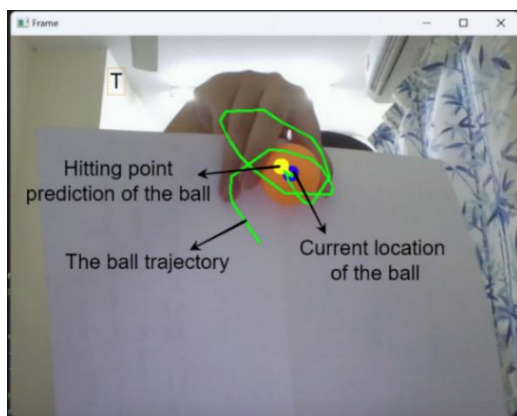


Fig. 2. Camera view while ping pong ball tracking system is running.

2.4. Data Visualization and Plotting

The last section after the ball detection, ball tracking, and ball-hitting point prediction was data visualization and plotting. The result of the program prediction was performed by plotting it out through a graph which will automatically pop out after the user ends the program. The library that helps to achieve the plotting is Matplotlib.

Fig. 3 shows the result plotting example of the system when the program is terminated. Information that is plotted by the program includes the complete trajectory of ball movement, start and end points, and the hitting point location prediction. The plotting function is set to only start working when a trajectory is recorded, which means no graph will be displayed when no ball was detected from the beginning. When this situation happens, the program will print out the text “No trajectory points to plot” when it ends.

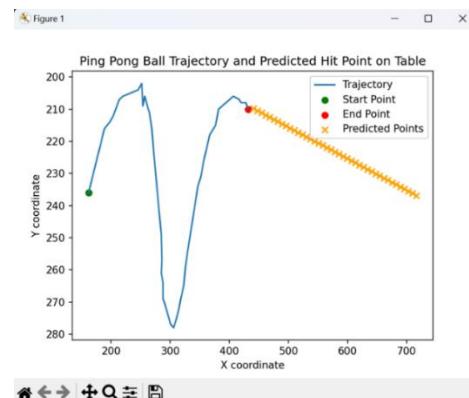


Fig. 3. The visualization of the program's outcome.

3. Results and Discussion

The project ‘Ping Pong Ball Tracking System for Identifying Hitting Points on a Table Tennis Table’ proved that the feasibility of a similar system and project in table tennis or other sports. The prototype made throughout this project achieves the basic required function according to the project objectives.

For the Ball Detection part, two common methods of object detection from OpenCV were both developed and tested to compare their performance, advantages, and disadvantages between them. In short, the shape detection method is simpler and easier to apply for only detection objects. When other functions were added to the program such as ball tracking and hitting point prediction, the detection result using shape detection is not accurate enough to support the following steps. Furthermore, the accuracy of the detection decreases when the detection distance and range is increased. Due to that reason, the color detection method was chosen to achieve better performance). However, it might struggle in cases where the ball is obscured or in environments with similar colors and when the lighting condition is poor since the lighting can affect the color depth of objects. This problem can be fixed by controlling surrounding lighting and adjusting the detection color range.

This color method is effective for objects with distinctive colors in controlled settings, aligning with the findings of [12], emphasizes the efficiency of color-based tracking techniques under stable lighting conditions. In the ball detection part of the program, the color detection

method is used to identify the ball in each video frame. It works by converting the frame to HSV color space, creating a mask for the specified color range, and finding contours. The largest contour that matches the ratio and area criteria is considered the ball. Based on the result of this project, the ball detection is well with high accuracy when all variables are under control. The elements that affect detection the most are the detection distance and ball moving speed.

The next part of the project comes to the ball-tracking part. The expected outcome of this part is to track and draw out a trajectory of the ball's movement when the ball is detected. The ball trajectory is the indispensable data that is required for later prediction calculation. Based on the data collected from ball detection part, we visualize the current location of the ball using a blue dot. Then, by recording every location of the blue dot, the program draws a yellow line connecting the points in the trajectory list if the drawing has started and there are at least two points. The yellow line will only start drawing once blue dots are detected and will stop when no blue dot is present.

During the testing and evaluation project, the trajectory visualization is clear and accurate. The annotated video frames are displayed in real-time with the ball's position, trajectory, and predicted positions. The yellow line is always drawn close to the actual trajectory, as the ball moves, its trajectory is continuously updated and drawn on the frame. Drawing the trajectory in real-time helps in understanding the ball's movement and can be useful for analyzing the ball's behavior during gameplay.

The program continues by calculating the prediction of ball hitting point from time- to time using the ball trajectory collected. In terms of hitting point prediction, several aspects have to be counted for better, including the ball movement speed, ball location, and the direction of ball movement. For that purpose, the Kalman Filter was used in this program. The Kalman filter plays a crucial role in predicting the ball's future position and refining its trajectory estimates. By combining a predictive model with measurements, the Kalman filter smooths the trajectory and handles the measurement noise. This approach is well-documented in foundational works like those of Welch and Bishop (1995), which demonstrate the filter's robustness in dynamic state estimation [6]. The filter's performance heavily depends on the proper tuning of parameters: State Transition Matrix (A) which defines how the state evolves over time, Measurement Matrix (H) which relates the observed measurements to the state, Process Noise Covariance (Q): which defines uncertainty in the process model, measurement Noise Covariance (R): which defines uncertainty in the measurement and Error Covariance Matrix (P): which represents the uncertainty in the initial state. Adjusting these parameters can improve tracking accuracy, especially in varying lighting conditions or with different ball speeds.

The study of Kalman Filter introduces two important terms and working principles of the filter: state prediction and state correction. State Prediction, the Kalman filter uses the state transition matrix to predict the next state of the ball, including position and velocity. It predicts where the ball will be in the next frame. State Correction, the filter updates its predictions using actual measurements to refine its estimates. It draws the predicted and extended predicted positions on the frame to visualize the ball's trajectory and future path. The Kalman filter assumes linear dynamics and Gaussian noise, which may not perfectly represent real-world scenarios. For more complex motion patterns, alternative filters like the Extended Kalman Filter or Particle Filter might be considered.

In the ball-hitting point prediction part, both two-dimension and three-dimension Kalman Filter parameters were setup. Even though the three-dimension involves one more z-axis of the program, the program does not seem to get much improvement in prediction performance. Having said that, the Kalman Filter still provides accurate prediction results for the program. Based on the result from testing, various factors such as ball movement speed, ball location, and the direction of ball movement were counted into the prediction too. Similar to the trajectory result, the hitting point prediction result was also visualized through annotated video frames in real time, where the hitting point is represented by a yellow dot.

Finally, after obtaining all the results and data we need for the program, a way of data-presenting method is required so that users can understand and read the result easily in a short amount of time. The library that helps to achieve the plotting is Matplotlib. The trajectory data is converted to a NumPy array and plotted using matplotlib. The Matplotlib plot shows the trajectory, start, end points, and predicted future positions of the ball. It provides a clear visualization of the ball's trajectory and predicted positions as shown in Fig. 4. Improving the graphical representation of predictions and trajectories could provide clearer insights into the ball's movement. The trajectory plot is useful for post-analysis and validation of the tracking system's performance and accuracy.

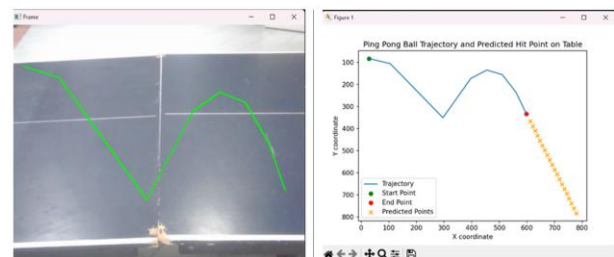


Fig. 4 Ping-pong ball's tracking and hitting point prediction.

According to the testing result conducted during this project, the ping pong ball tracking system based on the

OpenCV platform is able to perform all functionalities properly under various conditions. The system is capable of detecting a table tennis ball, drawing out the ball trajectory, and calculating the prediction of the hitting point based on it. It ends by performing program results through an easy-to-understand graph. The system effectively utilizes the Kalman filter for trajectory prediction, offering real-time tracking and visualization. However, its performance can be influenced by various factors, and further enhancements could improve robustness and accuracy.

4. Conclusion

The project concluded the process of development and design of a real-time ping pong ball tracking and hitting point system based on the OpenCV-Python platform. The system designed in this project achieved the expected outcome which is able to perform the basic functionalities of a table tennis tracking and prediction system and perform it through graph. However, the system's performance and accuracy are yet to be improved, especially in uncontrolled condition surroundings. Future development and improvement of this project could be in the direction of improving the system's performance in various surroundings such as poor lighting conditions. The accuracy of the system for detecting and capturing fast-movement balls can be improved. Another improvement that could be made in the future is to increase the data collection function so that multiple sets of data can be collected at the same time for comparison. Last but not least, a machine learning function could be added to the system so that the system can enhance its performance from time to time by studying the former data and results.

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Authors Introduction

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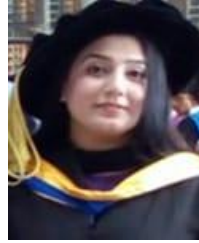
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