Embedded Table Tennis Ball Launcher with a Trajectory Path Analyser for Junior Players

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Abstract

Table Tennis as one of the most popular sports in Asia that its training requires a close supervision of a coach to analyse the strength and the weakness of the player. In this project, a pitcher machine as a personal Table Tennis trainer has been designed and the trajectory path analysis of the practical performance of player is analysed accordingly. In the proposed system, a camera is presented to track the table tennis ball. The obtained images from the camera are processed by OpenCV software and the flying trajectory is predicted based on the X and Y coordinates of a ball position to analyse the performance of player in each direction. The pitcher machine is then set via smart phone to the direction with weak performance to shoot more balls in that direction. However, the spinning serve is yet to be added in the proposed system, this project offers an acceptable platform for the early stage of the table tennis training. Experimental results show the acceptable performance analysis in complex mess environment and background.

Keywords: Table tennis launcher, performance analysis, trajectory path, ball recognition.

1. Introduction

Table Tennis is one of the most popular physical activities that involves two or four players who hit a ball in sequence. Like any other sport, in table tennis also coaching has an important role in the performance of the player before and during the competition. In this regard, several research works have been done on the performance improvement of the ping pong players. The integration of sensors and devices provided more efficient analysis of the athlete performance in different aspects such as fitness, mental health, gender, and blood lactate level [1]-[6]. Moreover, with the rapid rate of change in integrated technology and development of robotics, the table tennis robots have been designed and fabricated and the trajectory generation of the ball have been developed and optimised by time [2, 7-9]. The aggressive trajectory generator was introduced in Ref. 10 to control the robot in which the sensors have vital role. The trajectory prediction of the ball spinning is evaluated in Ref. 11 to derive the physical behaviour of the spinning ball. Other trajectory prediction and generation methods were discussed and proposed [12-14]. In this paper however, the table tennis launcher and performance analyser are proposed, designed and fabricated. The motivation of this work is to improve the solo ping pong trainers by analysing the trajectory path analysis and shoot more balls in the weak performed direction.

2. Hardware Architecture and Experimental Setup

The design of the proposed embedded Table Tennis ball launcher with trajectory path analyser 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 the path analysis. The entire launching system is placed on a wooden frame stand. Hence this part is a backbone of the system and need a proper stable design. The actuator mechanism is based on the accurate shoot of only one ball at each time and the shooting trigger. To meet these requirements, a modified plastic basket is used as a ball container. The basket with half-circle shaped ball holders' disc is then mounted on a motor. The combination of motor and the disc allows the full 360-degree rotation of the launcher. A hole has been made at the bottom of the wall-side of the basket to attach the long handlebar to. the second shorter handlebar with a degree of freedom is attached to the longer handlebar to provide ease of attainability and manoeuvrability. As motor rotates, the propeller shaped disk that holds the balls will rotate and places the balls to the track of shooting. The speed of shooting can be controlled by varying the motor speed. The ping pong balls travel from the hopper propeller shaped disc into the first horizontal track. The second track is attached with 30 degrees of freedom to the first track to provide different shooting direction. The side, front, and top views of the prototype are shown in Fig. 1.

Due to the cost restrictions, and getting align with the Sustainable Development Goals (SDG), all recycled materials have been used in the proposed prototype.

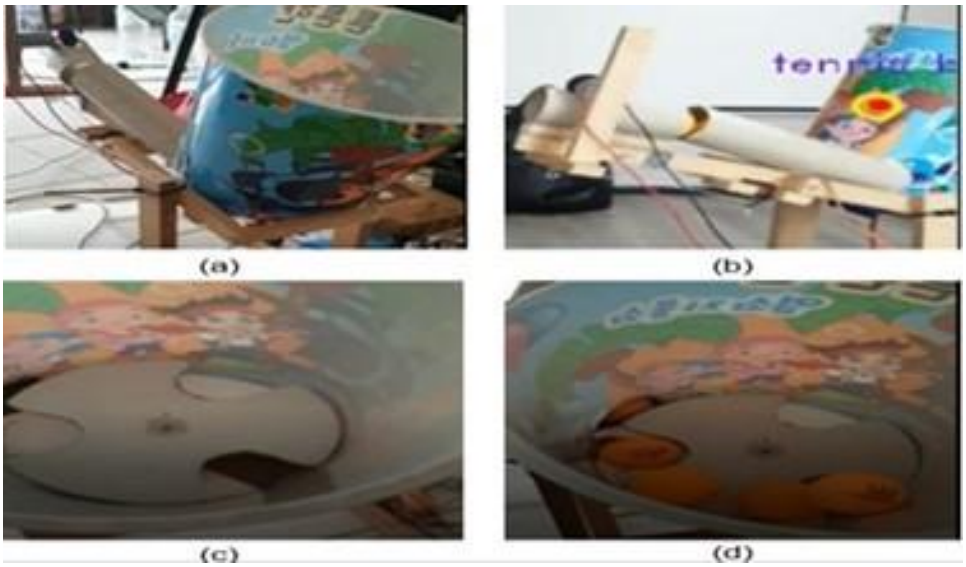

Fig. 1. The (a) Side view, (b) Front view, (c) Top view of the ball (d) Top view with the balls preparing to shoot

The first and the most important step in this project is to detect and track the ball. This process requires some additional steps to boost up the accuracy of the detection technique. For this purpose, the RGB color has been converted to HSV to describe the colors similar to those human eyes can detect. For this purpose, the manual tracking or Detection-free trackers has been used in OpenCV. This has been decided to prevent pre-training of the object detection. To filter the required results, the trackbarPos code is used. This helps to generate the track bar and adjust the required HSV levels. The result of track bar code on changing the image threshold in runtime is illustrated in Fig. 2.

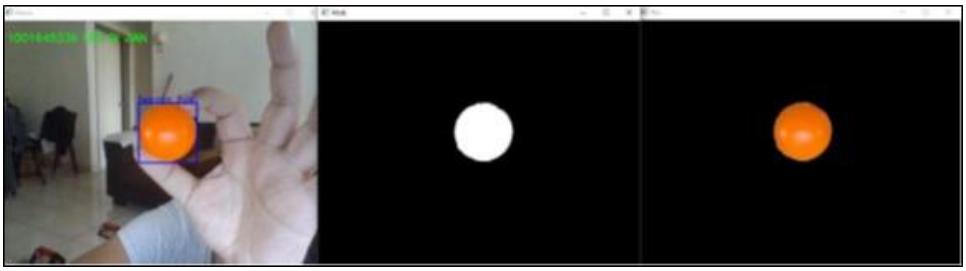

Fig. 2. The HSV level adjustment based on the TrackbarPos

The location estimation of the ball requires a technique to measure the relationship between the physical dimensions of the ball and the practical area of counter, and the pixels that the ball appears in. For this, the contour area measurements have been setup as shown in Fig. 3.

Fig. 3. The contour area measurements

In practice, there are several ways to estimate the location of ping pong ball. In this project, we have derived an equation to measure and detect the position of the ball based on the counter area. This equation is described as per Eq. (1):

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

To achieve that, the camera is placed at a fixed position and the separation distance between the area of the contour and the camera is plotted in excel. With the help of excel function and the Python code, equation (1) is generated to estimate the separation distance. The Trendline between area and distance of contour is plotted in Fig. 4.

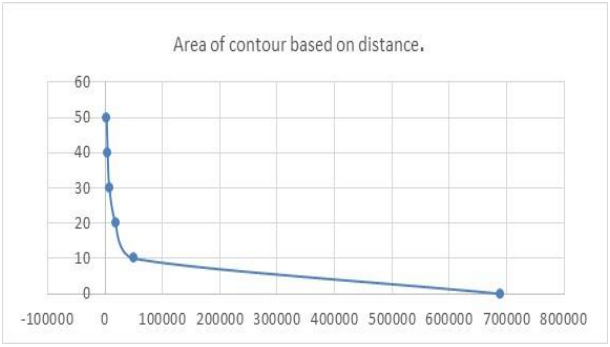

Fig. 4. The Trendline between area and distance of contour

To test the accuracy of the measurement and the contour measurement function using OpenCv, a physical measurement has been conducted as shown in Fig. 5. The comparison illustrates the acceptable accuracy.

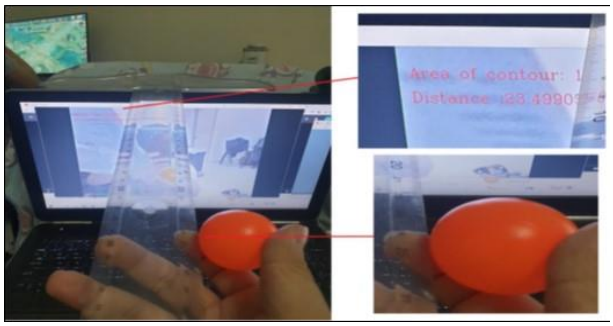

Fig. 5. Distance measurement accuracy check

The accurate result has been proved by comparison between physical and virtual measurement done by ruler and OpenCV measurement. To efficiently store and trace the movement of the ball in different points, the ball has been first detected and each tracked point is saved by the deque datatype in Python is used. Hence the history points of, f(x,y) has been recorded and saved and longer trajectory paths has been created considering more ball points with processing and resizing the frames to achieve the most suitable width and height of the moving ball that

is later used for the simulation analysis. In the next step, the image blurring or image smoothing has been implemented in which, the Gaussian blur filter has been applied to the detected ball image. In this stage, the image is convolved with Low Pass Filter (LPF) Gaussian kernel, that resulted to the noise reduction of the image. With the help of Gaussian blur, the Laplacian of the source image is calculated by calculating the gradient of image intensity at each pixel within the image utilizing soble operator; hence, the computed response is stored in the destination image at the same location (x,y) and is calculated as:

$$dest = \frac{\partial^2 src}{\partial x^2} + \frac{\partial^2 src}{\partial y^2} \quad (2)$$

where src is a source image and dest is the destination image.

In this project, the HSV value of the source image has been extracted from OpenCV trackbar and then filtered out. Moreover, a mask has been constructed for the ball color detection. In this project, an orange ball mask has been implemented. The biggest contour of the mask determines the ping pong ball.

To determine that if the ball is hit or not, the value of the y-coordinate is considered. If the value of y-coordinate is negative, it shows that the ball has been shoot towards the player, and if the y-coordinate gets positive, this means that the player has hit back the ball and consequently, the trajectory path is turned back. The result of the y-coordinate value has been tested and shown in Fig. 6. Based on the result of the Y-coordinate value, the performance of the player can be determined. To have a reasonable performance measurement, a simple analysis on the X and Y coordinates of the ball tracking has been implemented. In this case, the Y-coordinate 150 values have been considered, if the overall value is negative, this means that the player did not counterplay the ball and hence the performance will be marked as weak. Once the weak performance is detected, the trainer will be set to shoot the ball to the poor performed direction. This is done by using the pitcher machine for launch the ping pong ball and shoot on the direction that is controlled by trainer, the coach, or even the player. Moreover, the IR remote control for controlling the pitcher machine and next is draw the trajectory of ping pong ball has been implemented to monitor the player's playing style.

Fig. 6. Trajectory path calculation based on Y-coordinate values

3. Results and Discussion

As a pre-processing step towards the result analysis, the image thresholding is utilized in this paper. This technique is used to remove the un-necessary parts of image and consequently, produces a more accurate image of a ping pong ball. The image thresholding is known as the simplest image segmentation technique in which, the image is divided into two groups of black and white to categorize the background and foreground respectively. For this step to be done, the regions with saturation of greater than threshold level is translated to white region and the rest remain as black. The threshold selection is done manually in this project. The result of threshold selection for both background/foregrounds, and the threshold value are illustrated in Fig. 7.

Fig. 7. Threshold value selection for (a) background/foreground, (b) level adjustment from 0 to 255

The object overlapping scenario is also considered as a false condition in this project. In case of any overlapping of ping pong balls, at the current stage of our work, the ball detection is failed, and the result is not counted in the analysis. Consequently, there will be an issue of ball tracking that will be tackled in our future work.

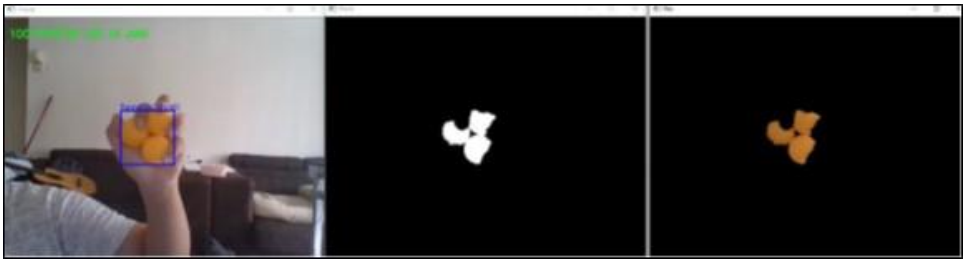

Fig. 8. Tracking failure due to the objects overlap

The third Python file has been created to draw the trajectory and provide the movement. To increase the accuracy of the ball detection, the counter number is limited to one counter at each time. For instant, if two ping pong balls are detected in the screen, the one with the larger radius would be detected as the main ball. The tracking failure due to the objects overlap has been implemented and illustrated in Fig. 8. This auto ball selection and the tracking of only one object at the time has been illustrated in Fig. 9. Plenty of stuffs has been added to the screen to ensure the accuracy of the ball detection in a crowded environment.

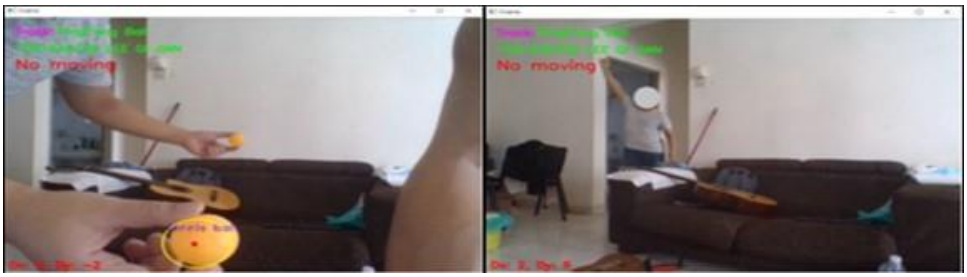

Fig. 9. Object detection in presence of two balls in a crowded area

The color-based object detection has some disadvantages such as the background tracking interruption in which, the ping pong ball tracking will be lost due to the similarity of the background color with the ping pong ball. This will reduce the accuracy and therefor, affect the analysis dramatically. Fig. 10 is a proof of the tracking interruption due to the similarity of the background and the ball. As per depicted in Fig. 10, the yellow ping pong ball tracking is lost at the moment the ball is passing by the container with similar color background. This issue is considered in this project and the project enhancement in the object detection will be tackled in our future work.

Fig. 10. Tracking interruption due to the color similarity with the background

4. Conclusion

The table tennis launcher with a real time ping pong ball tracking to train the player based on their performance analysis, has been designed and fabricated. This project is based on the operation of a servo motor that is located under the modified basket and shoots the balls on the table tennis board upon its rotation. The color-based segmentation has been used to detect the ball. After the segmentation is done, the shape, location and the motion of the ball are the factors considered to identify the performance of the player. The OpenCV software is used for the ping pong ball tracking. The player performance is then analysed based on the players trajectory path calculation in each point based on the ball traveling distance. Accordingly, the weakness of the player can be found, and the smart table tennis trainer uses a pitcher machine to launch the ping pong ball set to the direction in which the player performed weak and shoots more balls in that specified direction. This in other hand will help the player to enhance his performance in the specific direction and monitor the weakness of the player and help the improvement in his performance.

References

1. Arnold Baca (2006) Innovative diagnostic methods in elite sport., International Journal of Performance Analysis in Sport, 6:2, 148-156, DOI: 10.1080/24748668.2006.11868380
2. Z. Zhang, D. Xu and M. Tan, "Visual Measurement and Prediction of Ball Trajectory for Table Tennis Robot," in *IEEE Transactions on Instrumentation and Measurement*, vol. 59, no. 12, pp. 3195-3205, Dec. 2010, doi: 10.1109/TIM.2010.2047128.
3. Pradas, Francisco, et al. "Analysis of Specific Physical Fitness in High-Level Table Tennis Players—Sex Differences." International Journal of Environmental Research and Public Health 19.9 (2022): 5119.
4. Picabea, Jon Mikel, Jesús Cámara, and Javier Yanci. "Physical fitness profiling of national category table tennis players: Implication for health and performance." International Journal of Environmental Research and Public Health 18.17 (2021): 9362.
5. Mokayef, Miad, Mehrzad Moghadasi, and Reza Nuri. "Effect of cold water immersion on blood lactate levels of table tennis players." Int. J. Curr. Res. Aca. Rev 2.9 (2014): 115-123.
6. L. Acosta, J. J. Rodrigo, J. A. Mendez, G. N. Marichal, and M. Sigut, "Ping-pong player prototype," IEEE Robot. Autom. Mag., vol. 10, no. 4, pp. 44–52, Dec. 2003.
7. Yang, Luo, et al. "Ball motion control in the table tennis robot system using time-series deep reinforcement learning." IEEE Access 9 (2021): 99816-99827.
8. Zhao, Hongtu, and Fu Hao. "Target tracking algorithm for table tennis using machine vision." Journal of Healthcare Engineering 2021 (2021).
9. Zhang, Bo, Bingqiang Chen, and Yansong Deng. "Robot arm trajectory planning study for a table tennis robot." E3S Web of Conferences. Vol. 260. EDP Sciences, 2021.

10. Cong, Vo Duy. "Real-time measurement and prediction of ball trajectory for ping-pong robot." 2020 5th International Conference on Green Technology and Sustainable Development (GTSD). IEEE, 2020.
11. Wang, Yilei, and Ling Wang. "Machine Vision-Based Ping Pong Ball Rotation Trajectory Tracking Algorithm." Computational Intelligence and Neuroscience 2022 (2022).
12. Wang, Y. "Path trajectory prediction of rapidly rotated ping pong ball after hitting." The International Journal of Multiphysics 13.4 (2019): 351-360.
13. Andersson, Russell L. "Aggressive trajectory generator for a robot ping-pong player." IEEE Control Systems Magazine 9.2 (1989): 15-21.
14. Huang, Yanlong, et al. "Trajectory prediction of spinning ball for ping-pong player robot." 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, 2011.

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