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Painless Tennis Ball Tracking System

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***Abstract*— Tennis ball machines help tennis players develop their game to perfect a particular stroke or area of performance. However, current commercial tennis ball machines do not provide an automatic feedback mechanism of tracking their performance, and so the collection of shot data captured during a training session is manually recorded onto paper or an electronic record. With improvements of video technology, such as computing power and resolution rate, the motion analysis and tracking of objects have been actively researched and partially successful in some sports, particularly in baseball and soccer. However, tracking a fast moving, small tennis ball is a challenging task. To solve this problem, Painless Tennis Ball Tracking System (PTBTS) has been developed to automate the collection of shot data during a tennis training session using computer vision techniques. A new algorithm has been developed to detect the boundary of court, the tennis ball's movement, and the bounce location of a player's shot. Hardware components were designed for real-time video capture and image processing as well as communication with hand-held devices. Experimental results show that our approach is robust and has a tracking accuracy that can be integrated with current commercial tennis ball machines, which would be installed by local companies. Details of the system and future enhancement are discussed.**

Keywords - image processing, motion analysis and object tracking, tennis ball machine

I. Introduction

Success in the game of tennis requires a player to hit consistent, well-placed shots; tennis ball machines assist players to repetitively practice a given stroke. During training sessions, a player sets a target on the opposite site of the court, and hits the function of "feeds" from the ball machine as close to the target as possible. The data of the landing location of the player's shots are collected and used to improve the player's game [1]. However, the current tennis ball machine doesn't provide an easy way to track the players' performance. It is required for a coach to watch the player's whole practice session and manually mark the landing location of each shot from the court to track their performance. This manual process is inefficient, labor-intensive, and produces inaccurate data on the quality of shots hit by a player during training. Although some commercial systems such as Hawk-Eye are available for shot tracking with multiple high-performance cameras, they are expensive and difficult to install and calibrate correctly for the average tennis player, which makes them impractical for tennis clubs to purchase for their tennis ball machines [2].

The Painless Tennis Ball Tracking System (PTBTS) provides a relatively inexpensive, portable, and easy-to-use shot-tracking system that automates the process of data collection during a training session with a tennis ball machine. The system analyzes live video in real-time, and automatically detects the tennis court; therefore, it constructs perspective mapping to interpret the on-screen location of key points of the court into real-world coordinates. It detects and records the landing position of the shots that have been struck. The system also includes a flexible mechanism that delivers the shot data to players in a tractable format.

II. Literature Survey

Some research have been conducted on computer vision techniques to solve similar challenges in tennis using a single camera feed. Yan *et. al.* created a system that is capable of analyzing off-air tennis broadcasts to the trajectories of balls, the positions of players on the court, and the locations of "key" events [3]. Ball candidates are initially detected using pixel-level temporal differencing followed by blob detection. Trajectories are then identified for each ball candidate, and key events are detected by looking for abrupt deviations from the predicted trajectory. Connaghan *et. al.* created a system that uses computer vision to automatically isolate and index key events in tennis videos, and include ball bounces and player movement [4]. The index can be queried by coaches who are interested in isolating certain patterns of play or assessing the ability of a player. Pingali *et. al.* researched ball-tracking and shot placement using a network of six cameras placed in a precise location around a tennis court or stadium, and then calibrated into four pairs [5]. A commercial version of this technology is Hawk-Eye, which is used in live tennis matches to detect with high accuracy and precision the landing positions of shots. Hawk-eye is used primarily to ensure correct line calls during professional tennis matches, but it is also capable of providing analytics on flight paths, distribution of shots, and player positioning [6]. Various line detection algorithms were also studied [7][8].

III. Methodology

The PTBTS uses a single visible-light camera which is placed behind the court to detect shots struck by a player and record their landing location. The PTBTS consists of three major components: Hardware, Image Processing, and Wireless API.

- **Hardware component** consists of a camera, an on-board processor, and power source capable of capturing the video of a practice session and processing its video stream. The Intel *ComputeStick CS125* was selected as a processor because of its processing speed, multi-threading capabilities, and small size. It also supports Bluetooth 4.1

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and Bluetooth Low Energy for wireless API. The Microsoft *Lifecam Studio* was selected because it has a 73 degree FOV and supports up to a 1080p video capture, and has a high-precision, automatic-focus glass lens.

- **Image processing component** detects the tennis court, tracking shots struck by a player, and the location of those shots on court (as shown in Fig. 1). The module was built using components from the open-source computer vision library OpenCV.

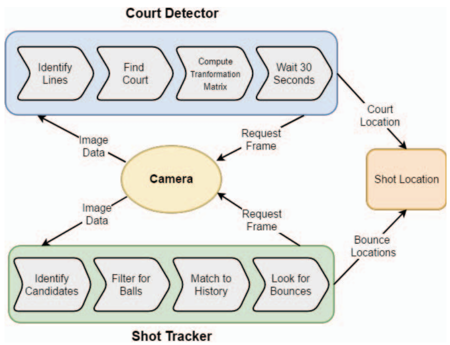

Fig. 1: Flow of image data through Image Processing Component

- **Wireless API component** allows the PTBTS communicate with other devices using the Bluetooth communication protocol. A wireless API is developed using Bluecove library (an implementation of the JSR-82 specification) for external devices to receive data through JSON-encoded plaintext.

Fig. 2 shows the interactions among three components.

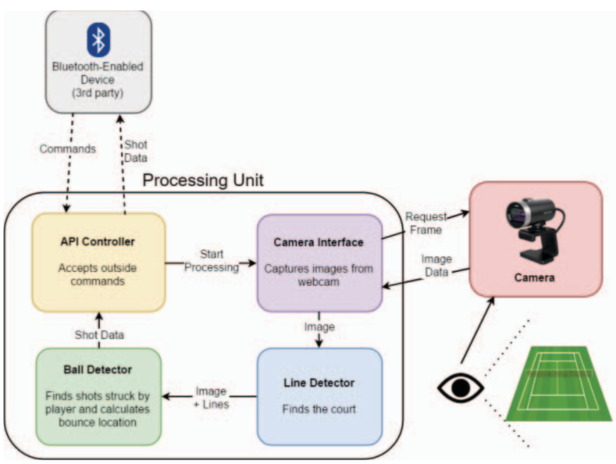

Fig. 2 System Diagram of PTBTS

IV. Experiments and Results

After the successful implementation of the PTBTS, several lab experiments were conducted that ran a series of sample videos. The PTBTS accurately located bounce locations for shots in a number of different lighting scenarios, ball speeds, and court locations. It also established a Bluetooth connection with the tracking system, sent start/end commands, and transferred the information of the shots to the user. After a total of ten 15 minute live testing sessions, the PTBTS produced a 92% accuracy rate when compared to the results (hit/miss) of judgements by a human (coach).

However, there were a few noticeable issues with court recognition. This relates to the camera having a high sensitivity to its orientation, and the reliance of a certain geometry being present in the frame, which in turn, limits the system to the detection of shots that bounce within the view of the camera on the opposite court of the hitting player. Therefore, shots that are hit into the net or out-of-frame are not detected properly by the PTBTS.

V. Conclusion

Tracking both performance and improvement is important for tennis players who are training against a ball machine. Current methods for tracking shots on a ball machine are inconvenient and time-consuming. The PTBTS that has been proposed here automates the data collection process using computer vision to detect the bounce location of shots struck by a player. The device is flexible and can be controlled from a variety of computing devices. The captured data can be used to assess the performance, ability, and improvement of players.

Future improvements to the PTBTS include the creation of a more robust handling of missed shots that account for bounce locations that are not visible, and also the improvement of camera instability. For users to take advantage of our shot-tracking system, an application should be built to integrate with our system and display the resultant data in a visually interesting and informative way.

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