Efficient Ball Position Estimation for Tennis Court Robot Assistants using Dual-Camera System

Abdullah Alraee
Department of Human Intelligence Systems, Kyushu Institute of Technology,
2-4 Hibikino, Wakamatsu, Kitakyushu, Fukuoka, 808-0196 Japan.
E-mail: alraee.abdullah-abdul648@mail.kyutech.jp

Hussam Alraie
Department of Electrical and Electronic Engineering, Middle East Technical University,
Guzelyurt, Turkish Republic of Northern Cyprus.
E-mail: hussam@metu.edu.tr

Mohammad Albaroudi
Department of Human Intelligence Systems, Kyushu Institute of Technology,
2-4 Hibikino, Wakamatsu, Kitakyushu, Fukuoka, 808-0196 Japan.
E-mail: albaroudi.mohammad344@mail.kyutech.jp

Raji Alahmad
Department of Human Intelligence Systems, Kyushu Institute of Technology,
2-4 Hibikino, Wakamatsu, Kitakyushu, Fukuoka, 808-0196 Japan.
E-mail: raji@brain.kyutech.ac.jp

Kazuo Ishii
Department of Human Intelligence Systems, Kyushu Institute of Technology,
2-4 Hibikino, Wakamatsu, Kitakyushu, Fukuoka, 808-0196 Japan.
E-mail: ishii@brain.kyutech.ac.jp,

Abstract

During tennis training, professional players use many balls that will be distributed randomly around the tennis court. Collecting the ball can be done manually, However, the effort and the time make it inefficient. The mobile robot for ball collection has been introduced as a solution to save power and training session time. The robot tasks involve several steps: ball detection, estimating their positions, and finding the best path for efficient collection. In our previous work, we addressed the ball detection issue utilizing a neural network algorithm using YOLOv8. This study focuses on the next step, ball position estimation, using two cameras to cover the entire court. The results demonstrate successful ball position estimation along the x-axis and y-axis, achieving an accuracy of 97.76 %.

Keywords: AI, Position, detection, robot, Dual-Camera

1. Introduction

One key requirement Human-robot interaction (HRI) in sports has been the subject of extensive research recently, and robots are being developed to replace humans as a form of sports training and practice that was previously confined to human life. Usually, Robots connect to the camera and the video frames or images can be analyzed using several methods [1]. The tennis court, especially the open grass court, is one of the spaces where a lot of physical activity takes place. It is also the place where tennis matches are held, and the audience can enjoy them live. Therefore, the development of robots that support various tennis matches and enhance the enjoyment of these matches is a meaningful research direction from both scientific and engineering standpoints. However, the development of tennis court robots for assistance in various tennis games or research is still very rare. For tennis court robots to support various tennis games or sports research they can visually detect the tennis ball and predict its position [2], [4]. There may be other requirements, but a few key points are of immediate importance. For example, priority is given to visual processing time rather than the position estimate error in real-time tennis ball tracking for operating the on-court robot. Existing literature on robots for sports training can be divided into two classes: the robots that tend to be trainers and the robots that tend to be trainees [3], [5]. On the one hand, some studies have been conducted on the development of robot trainers for tennis. The robot can swing the golf club precisely and measure the hit ball direction using optical sensors. Another tennis assistant club uses servomotors to control the swing of the stick, and a belt embedded with metal tracks to assist the player in controlling the stick in real-time. On the other hand, an indoor tennis robot can also be found in some studies [6]. This robot was designed for professional players to improve their game. It consists of a mobile shooting platform, a feeder arm with adjustable shot capability, and advanced software to control speed, direction, and spin, along with helpful features such as target point pre-selection. However, the design of this

Robots are complex and expensive to produce. With this understanding, this paper presents a novel visual system that uses two cameras to efficiently estimate the current ball position on the tennis court. The challenge of the tennis ball mobile robot application is to calculate the distance from the camera. Knowing the distance of the ball from the camera helps the robot go directly to the ball, unlike scanning the entire tennis court, which contributes to increasing the efficiency of the detection system and saving training session time.

2. Methodology

The distance had been calculated using one camera based on the relationship between the angle in the image, and the angle in the real world as shown in Fig.1. The accuracy was 71%.

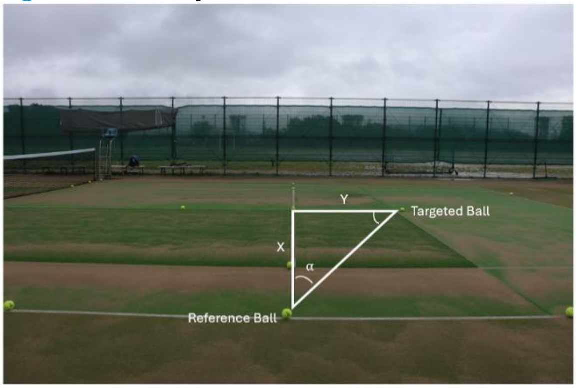

Fig.1. Position calculation using one camera

For this reason, two cameras were used to measure the distance accurately. To find the tennis ball's position, we assume that the origin is the camera for both coordinates X and Y as shown in Fig.2.

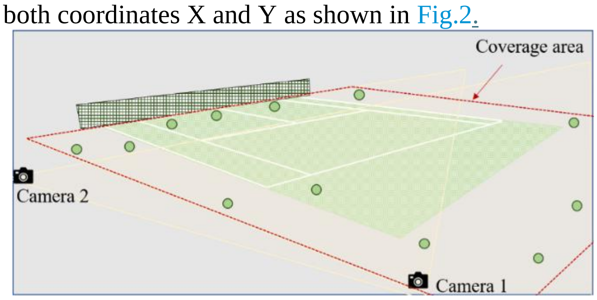

Fig.2. Dual-camera system for tennis ball detection

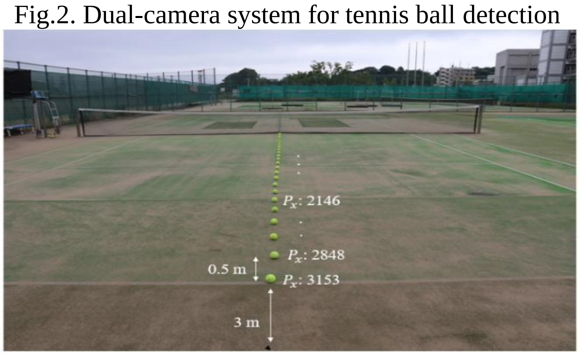

Fig.3. Experimental setup for x-ais

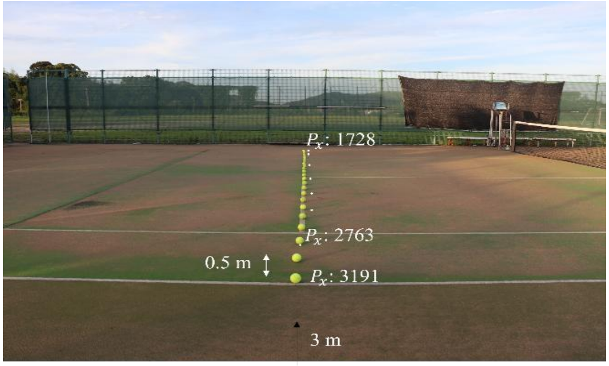

Fig.4. Experimental setup for Y-ais

Then by measuring the pixel size when we change the distance from the camera, a mathematical relationship between the distance and the pixel size is found. Images have been taken at a distance of 3 meters, which will be the offset as shown in Fig.3 and Fig.4 illustrating pixel changing when distance is changed. The tennis court is located at the Kyushu Institute of Technology Sports Center.

3. Results and Discussion

The experiment results were shown for 3- and 4-meter offsets to calculate the X- and Y-axis coordinates. The calculated coordinates were compared with the actual distances.

3.1 Estimate the position for 3M

The relationship between the distance and the pixel has been concluded as shown in Fig.5.

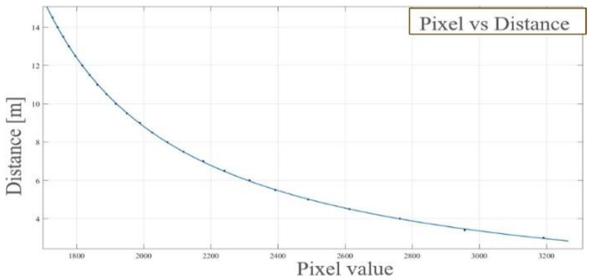

Fig.5. Pixel value vs the actual distance on the X-axis

The curve fitting of the plotted extracted in a mathematical formula is shown in the following equation:

$$D_x = \frac{\beta\,(P_x) + \mu}{(P_x + \mathcal{E})}$$

Where D_x is the calculated distance coordinate on the x-axis distance. β , μ, $\mathcal{E}$ are coefficients, and P_x is the pixel value of the x-axis. The accuracy had been calculated based on the following equation:

$$\text{Accuracy } \% = \left(\frac{1 - \text{Absolute Error}}{\text{D}}\right) \times 100$$

The absolute error is calculated as a difference between the actual distance and the calculated distance as follows:

$$\boldsymbol{Absoulute\ Error} = |\boldsymbol{Edx} - \boldsymbol{D}|$$

Where $\boldsymbol{Edx}$ is the estimated distance.

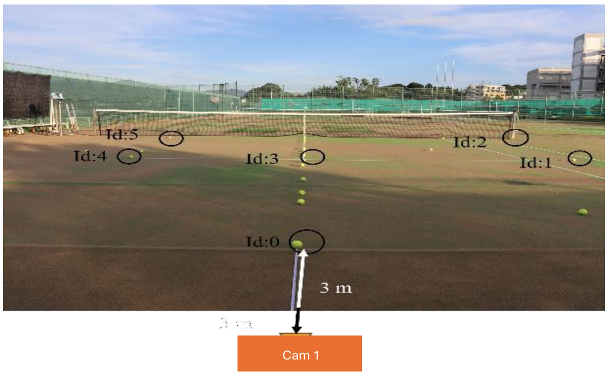

Fig.6. Position validation along X-axis

Fig.6 shows the manual identification of each tennis ball which helps us with the documentation and comparison, Table 1 shows the comparison between the actual and the calculated distance.

Table 1. Comparison between the actual and calculated distance of 3m.

ID	P_x	$D_x\ (m)$	$E_{dx}\ (m)$	Diff.	Acc. %
0	3191	3.00	2.96	0.04	98.67
1	2047	8.43	8.24	0.19	97.75
2	1756	14.75	13.60	1.15	92.20
3	2026	8.43	8..48	-0.05	99.41
4	2002	8.43	8.78	-0.35	95.85
5	1721	14.75	14.72	0.03	99.80

Were; Diff is the Difference Between $D_x\ (m)$ *and* $E_{dx}\ (m)$

Acc.: The Accuracy of estimation

The average accuracy of the calculated distance in comparison to the actual distance is 97.28% from Table1 for the X-axis coordinate. The same method had been used to calculate the Y- axis coordinate. To calculate the Y-axis, the second camera was used to snap the horizontal view of the tennis court as shown in Fig.7.

Fig.7. Position validation along Y-axis

The relationship between the distance and the pixel has been concluded as shown in Fig.8.

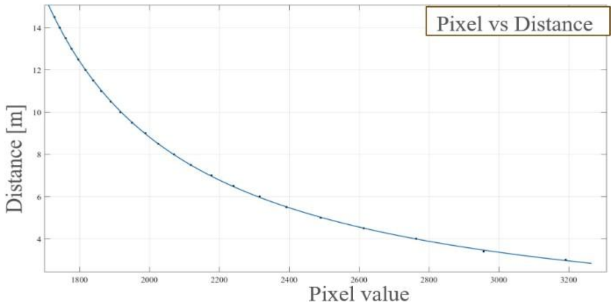

Fig.8. Pixel value vs the actual distance on the Y-axis

Table 2 shows the comparison between the actual and the calculated distance.

Table 2. Comparison between the actual and calculated distance of 3m.

ID	P_y	$D_y\ (m)$	$E_{dy}\ (m)$	Diff.	Acc.%
0	3138	3.00	3.05	0.05	98.33
1	2577	4.37	4.40	-0.03	99.31
2	1951	8.45	8.47	-0.02	99.76
3	1706	12.48	13.10	-0.62	95.03
4	1663	15.00	14.48	0.52	96.53
5	1675	13.90	14.00	-0.01	99.28

The average accuracy of the calculated distance in comparison to the actual distance is 98.04 % from Table 2 for the Y-axis coordinate.

3.2 Estimate the position for 4M offset:

Table 3 shows the comparison between the actual and the calculated distance for the x-axis.

Table 3. Comparison between the actual and calculated distance of 4m.

ID	P_x	$D_x\ (m)$	$E_{dx}\ (m)$	Diff.	Acc. %
0	2677	4.00	3.99	0.01	99.75
1	1869	9.43	9.17	0.26	97.24
2	1615	15.75	14.50	1.25	92.06
3	1847	9.43	9.48	-0.05	99.47
4	1832	9.43	9.71	-0.28	97.03
5	1587	15.75	15.56	0.19	98.79

The average accuracy of the calculated distance in comparison to the actual distance is 97.39 % from Table 3 for the Y-axis coordinate.

Table 4 shows the comparison between the actual and the calculated distance for the Y-axis in 4m.

ID	P_y	$D_y\ (m)$	$E_{dy}\ (m)$	Diff.	Acc. %
0	2737	4.00	4.07	0.07	98.25

1	2384	5.37	5.40	-0.03	99.44
2	1917	9.45	9.46	-0.01	99.89
3	1728	13.48	13.50	-0.02	99.85
4	1676	16.00	15.39	0.61	96.19
5	1675	14.90	15.43	-0.53	96.44

The average accuracy of the calculated distance in comparison to the actual distance is 98.34 % from Table 4 for the Y-axis coordinate.

3. Conclusion

This paper provides an experimental study to estimate the tennis ball position using two cameras. Two different offsets (3, and 4 meters) were used to calculate the relationship between changing the pixel and the distance. The results show that the performance was located between 97% and 98%. The curve fitting for both X- axis and Y-axis looks similar to an exponential relationship between changing the distance and pixel value. This relationship may expand to make a general mathematical formula for any offset value in future work.

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Authors Introduction

Mr. Abdullah Alraee

He received his bachelor's degree in Communication Engineering from Al-Wataniya Private University, Syria, in 2018, and a master's degree from Kyushu Institute of Technology, Japan, in 2024, where he researched "Tennis Ball Detection and Position Estimation for Mobile Robots." He is currently pursuing a Ph.D. at Kyushu Institute of Technology, focusing on robotics, artificial intelligence, and image processing.

Dr. HUSSAM ALRAIE

He is currently a postdoctoral researcher, and lecturer at the Department of Electrical Electronic Engineering at Middle East Technical University, Northern Cyprus. Received a Ph.D. from Kyushu Institute of Technology in 2024, Japan. His research interests are Wireless Communication, Underwater Communication, Networking, image processing, Machine learning, and Artificial Intelligence (AI).

Mr. Mohammad Albaroudi

He received his M.Sc. degree in Radio and Mobile Telecommunication Systems from Higher Institute of Applied Sciences and Technology, Damascus, Syria in 2021. He is currently pursuing a Ph.D. in the Department of Life Science and System Engineering at Kyushu Institute of Technology, Fukuoka, Japan. His research interests are machine learning algorithms, image processing, and mobile telecommunication.

Dr. Raji Alhmad

He is currently a researcher at the Department of Human Intelligence Systems of Kyushu Institute of Technology, Japan. He obtained his MEng degree in 2018 and his DEng in 2021 at Kyushu Institute of Technology. His research interests are AI algorithms, Logistics, Underwater Robotics, Image processing, and Neural networks.

Prof. Kazuo Ishii

He is currently a Professor at the Department of Human Intelligence Systems of Kyushu Institute of Technology, Japan. He obtained his M. S. degree in 1993 and his D. Eng. degree in 1996 at The University of Tokyo. His research interests are in the fields of Underwater Robotics, Field Robotics, Neural Networks, and Intelligent Systems