

Towards Human-Like Table Tennis Serving: Preliminary Exploration with Simplified Serving Motion Using an Industrial Robotic Manipulator in NVIDIA Isaac Sim

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Abstract— In this report, we present our latest work-in-progress result of table tennis serving simulation. The ultimate goal for our research is realization of human-like table tennis serving with a 6-joint robotic arm. The preliminary evaluation indicates the potential of multi-joint bionic serve motion planning with extended topics and future directions discussed.

I. INTRODUCTION

Among the many techniques in competitive table tennis, the serve is the most fundamental and crucial. In table tennis matches, scoring is often related to the serve, making the return of service extremely important. In service return of competitive ball games, observing the opponent's serving is a mandatory skill [1]. Using industrial robotic arms to plan and mimic human serving motions instead of a modern commercial serving machines has become the ultimate goal of this research [2], [3].

Currently, much research is focused on developing robotic systems capable of accurately returning an incoming ball. In contrast, research on table tennis serving robots is very limited. One of such examples is the research presented by Professor Yamakawa's team at IEEE ICRA 2025 [4]. They used a sample-efficient adjustment-learning (SEAL) method to progressively adjust the robot's serving motion to target locations. The practical evaluation was conducted using an industrial robot (UR5e, Universal Robots, Denmark). However, in the team's demonstration video, the robotic arm's serving motion differs significantly from that of a human arm. Furthermore, most research on returning the incoming ball focuses solely on achieving a successful return. Therefore, we believe that biomimetic motion planning remains a significant challenge in table tennis robot research.

Recent research on table tennis robots focused less on simulation while considering physical and mechanical parameters. Meanwhile, NVIDIA Omniverse platform has been extensively used in front-end robotics research. Considering our ultimate goal is hard to achieve without importing physical and mechanical parameters, we also use Isaac Sim for digital twin and simulation construction [5].

In this work-in-progress research, we present a preliminary exploration of table tennis service simulation. Planning of a human-like serving motion is expected challenging due to complex multi-joint coordination for a smooth kinetic chain. The service motion planned in this research involves simplified joint configurations of single-joint, two-joint, and three-joint forward kinematics planning. Analysis of the joint

and end-effector kinematics results follows according to the simulation environment and robot configuration setup. The results of the simulation in the constructed digital twin will serve as a baseline for future data with human-like serving motion planning. Furthermore, the analysis of these preliminary results will be used to discuss extended academic research and development topics, as well as future work.

II. METHODS

A. Simulation Environment Setup

The simulation environment was based on the NVIDIA Omniverse Platform. A screenshot of the Isaac Sim interface at the current stage is shown in Fig. 1. The virtual environment was developed using OpenUSD. In addition, the NVIDIA Isaac Sim 5.x simulator, with the PhysX 5 physics engine, supports GPU-accelerated rigid bodies. The simulator was constructed and run on a consumer-grade computer with an individual graphics card, an RTX 5080.

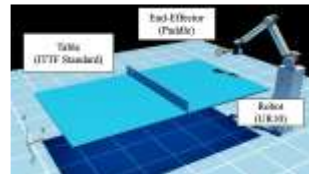


Figure 1. Robotic table tennis system in Isaac simulation

TABLE I. KEY OBJECT SETTINGS IN THE VIRTUAL ENVIRONMENT

Object	Parameter	Value	Unit
Table ^a	Length	2.74	m
	Width	1.53	m
	Surface height	0.76	m
Ball ^a	Diameter	0.04	m
	Restitution	1.00	-
Paddle	Face radius	0.08	m
	Restitution	1.00	-
	Friction	0.35	-
Base	Base Hight	1.01	m
	Arm back offset	0.40	m
	Lateral offset	-0.76	m

a. Setup according to the ITTF Standard

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Table 1 shows the settings of the objects in the virtual environment, including a table tennis table, a ball, an elevated base for the robot, a 6-joint industrial robot imported through URDF file (UR10, Universal Robots, Denmark), and a paddle fixed at the robot’s end effector. The environment origin was set at the center of the table tennis table surface, with the X axis pointing along the length, the Y axis pointing along the width, and the Z axis pointing upward. For simplicity, the ball was held still in mid-air above the table surface for 0.25 m before the racket struck it.

B. Preliminary Motion Planning

For this work-in-progress report, simplified one-joint, two-joint, and three-joint configurations for serve motions were planned in the simulation. Table 2 shows the initial and strike configurations of the robots for each planned motion. For the active (moving) joints, joint-space trajectory planning was used with smoothstep interpolation. In addition, all the active joints moved at their maximum angular velocities.

TABLE II. KEY OBJECT SETTINGS IN THE VIRTUAL ENVIRONMENT

Motion Pattern	Joint Number	Initial angle (°)	Strike angle (°)
1-joint planning	Joint 1	-159	-69
	Joints 2 to 6	-56/90/-34/90/0	- ^a
2-joint planning	Joints 1 and 3	-159/90	-69/80
	Joints 2, 4 to 6	-56/-34/90/0	- ^a
3-joint planning	Joints 1, 3, 6	-159/90/0	-69/100/45
	Joints 2, 4, 5	-56/-34/90	- ^a

^a. Fixed joint(s) during serving motion

III. RESULTS AND DISCUSSION

A. Preliminary Evaluation Results

The kinematic results for the robot’s joints and end effectors, and the spatial states of the ball, are analyzed. With the settings explained in the previous section, the ball was successfully served to the other side for all motion patterns. In this short report, we focus on some of the robot’s end effector and the ball’s results.

Fig. 2 depicts the results of the ball’s spatial states and velocities of the end effector for all serving motion planning. It can be observed that the ball’s trajectories in the three motions are very similar. Although not significant, the ball velocity was higher when more active (or moving) joints were involved in the serve. Meanwhile, the end effector’s velocity for the three-joint motion was also higher (but not significant) than the other two motions.

If we compare the serving motion pattern of a robotic arm to that of a human motion, the rotation of the first joint resembles trunk rotation, the rotation of the third joint resembles arm swing, and the rotation of the sixth joint resembles wrist rotation. From the perspective of sports biomechanics, the kinetic chain from the foot, through the trunk and arm, to the wrist is essential not only for ball return but also for ball serving [6]. A significantly faster ball serve was, in fact, expected for the three-joint serving motion. The

possible reason for the failure to achieve an insignificant result may be due to inadequate consideration of configuration and bionic motion planning.

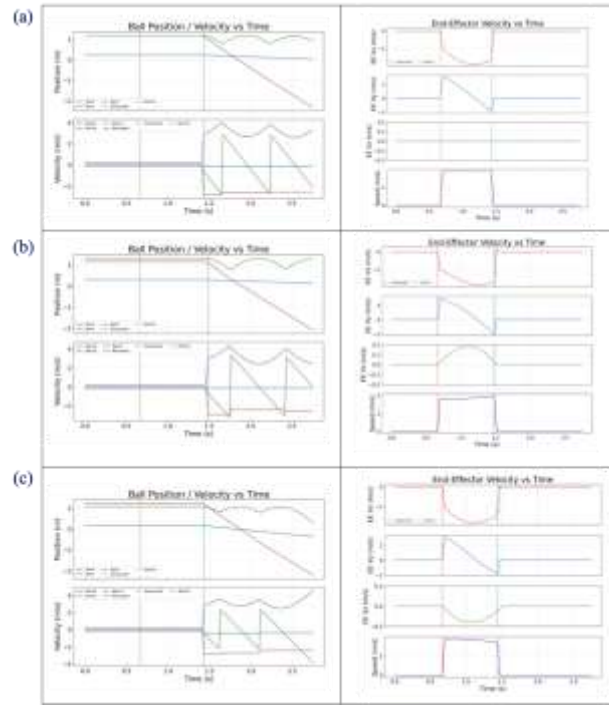


Figure 2. The ball position, velocity, and end-effector velocity to time plots for (a) one-joint serving motion; (b) two-joint serving motion; (c) three-joint serving motion. The vertical, dotted, orange line indicates the timing of the robot’s motion initiation. The vertical, dotted, light green line indicates the timing of the ball strike event

B. Extended Topics and Future Works

Despite the original motivation of serve return observation training, the preliminary evaluation results of the simulation indicate the potential and necessity of a bionic, human-like motion planning for high-quality serves. Other future works include improving the simulation environment with a more complete physics parameter setting and real-to-sim evaluation.

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