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T2Snaker: a Robotic Coach for Table Tennis

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ABSTRACT

The restrictions imposed by the Covid-19 pandemic has significantly affected all aspects of daily life, especially human contact. Accordingly, an essential aspect of human contact is for training and skill acquisition, which is difficult to conduct under such restrictions. Therefore, we developed T2Snaker, a table tennis training system that comprises a robotic appendage to guide user's hand movements within a VR environment. T2Snaker's novelty lies in its flexibility to guide users movements, yet as it is not directly attached to the user's limbs, it does not impose restrictions on their movements like traditional exoskeleton systems. We explain the implementation specifics of T2Snaker and discuss its preliminary evaluation that focused on table-tennis skill acquisition. The results show that T2Snaker has high potential in skill acquisition, and users praised is ability to guide their movements and proposed various potential application domains. We discuss some design insights based on our work and present future research directions.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**.

KEYWORDS

Robotic; Appendages; Augmentation; VR; Table Tennis; Education; Serpentine; Snake;

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1 INTRODUCTION

With the spread of the new coronavirus, contact with people has become limited. Such restrictions imposed difficulties for tasks that required human-to-human contact, such as skill acquisition or training for physical activities. Previous research has shown it is possible to transfer skills learned in virtual environments to real world tasks [8, 9]. However, we believe robotic systems, such as exoskeletons or wearable robot arms [1, 10], can be more effective as they provide physical guidance of the user's limb movements and orientation, thereby potentially resulting in higher skill transfer for physical activities.

Accordingly, we developed T2Snaker, a robotic system that allows remote table tennis training without the need of physical interaction. Our system comprised of a VR environment and a robotic appendage equipped with a table tennis racket, which all run within a synchronized environment (Figure 1). We explain the specifications of T2Snaker, and evaluate its effectiveness in table tennis training when compared to a VR environment. The results show that users had relatively high success rate after practicing table tennis with T2Snaker, and participants provided various insights to improve T2Snaker for future applications. Lastly, we provide our conclusion and future work direction.

2 RELATED WORK

Various researchers investigated various systems for learning and practicing table tennis in virtual and augmented reality environments[6, 7]. For example, Michalski et al. found that a commercial VR table tennis game improved players' table tennis skills [6]. Various VR systems focused on different aspects of table tennis training [3, 5, 11], and some solely focused on the element of rotation [13].

T2Snaker also extends various works within wearable robotic appendages for interactive applications. HapticSnakes [2] explored the use of snake-like robotic appendages to provide multiple types of haptic feedback within VR. Similarly, Fusion [10] demonstrated a two wearable robot arms that are strapped to the users hands, which were used for teaching users to play music instruments or to guide them during different physical tasks. Similarly, Encountered Limbs [4] used two wearable robot arms to convey encountered objects within VR.

T2Snaker builds upon the previous works by extending robotic appendages and provided high flexibility to match user's movements in various postures. As T2Snaker is not strapped to the user's wrist or worn, it does not restrict users' hand movements like exoskeletons, as users can let go of the racket. Moreover, the flexibility of its design enable attaching various other end-effectors to match other domains, such as for calligraphy or maintenance

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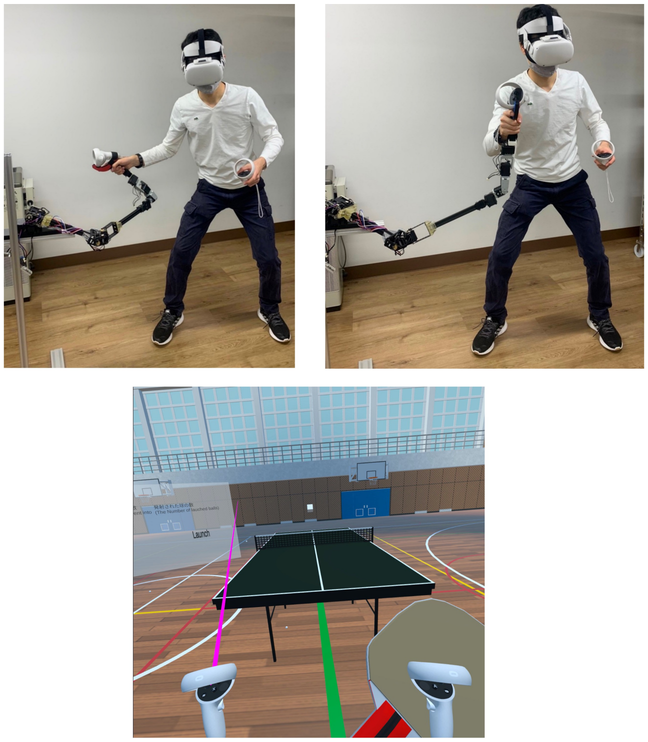

Figure 1: Upper: T2Snaker can be used for table tennis practice. Lower: VR Table Tennis environment.

tasks. Lastly, T2Snaker paves the way to explore various forms of mutual actuation, which can include initiating, guiding or augmenting the user's movements at different phases of the training or tasks [7, 13].

3 SYSTEM DESIGN AND IMPLEMENTATION

T2Snaker comprises a table tennis system that runs on a VR headset (Oculus Quest2[1]) which is connected and synchronized to a robotic appendage. For ease of use, we fixed T2Snaker to an aluminum base, however, it can also be worn like previous systems [4, 10]. We explain the components of our system below.

VR Environment and robot Control: The VR table tennis software is created with Unity3D game engine[2] and includes a VR table tennis, scoreboard, and an instruction video as well as cheerleaders to motivate users during play. The VR environment is connected to the inverse kinematics system (Figure 2) to controls and synchronizes the racket's movements with the robot movements using WebSockets[3]. The IK system calculates the correct robot posture in order to conduct a correct swing based on the VR environment (Figure 2). Lastly, the calculated robot angles are sent from the IK system to the robot control system, where they are sent directly to the robot.

Robot Design: We were inspired by previous works [1], which showed the versatility of snake-like robotic appendages for various

[1]https://www.oculus.com/quest-2/
[2]https://unity.com/
[3]https://datatracker.ietf.org/doc/html/rfc6455

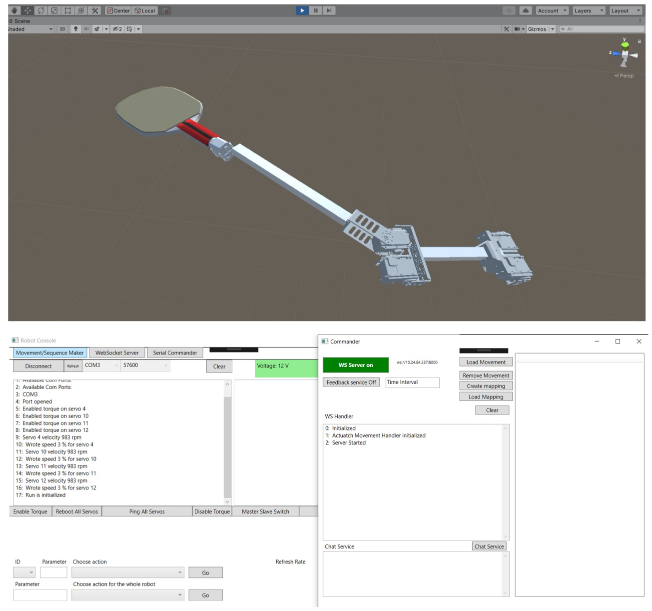

Figure 2: Our Unity3D environment(Upper) included an IK solver and a 3D model of our robot to generate robot movements, which are then sent through WebSockets to the robot control software shown on the lower.

applications. Therefore, our robotic appendage consists of 9 serially connected servomotors (9 degrees of freedom) (Figure 3). We used three MX106T motors, two MX64AT, and four AX12[4]. The motors are connected using both aluminum frames and PLA frames. The end-effector is table tennis racket shaped commonly used in VR games, and it has a mount for the oculus-quest controller that enables tracking its location in VR.

4 PRELIMINARY USER STUDY

Objective: Our initial evaluation focused on 1) investigating whether or not T2Snaker can improve table tennis skills when compared to a VR table tennis systems, and 2) to explore user impressions and opinions about using T2Snaker.

Participants: We hired 10 participants, aged between 20 to 27 years old (m=22.90, SD=1.91), who were undergraduate and graduate students, and all participants indicated they have used VR before.

Procedure: We designed our own test based on our consultation with a table tennis expert, who has 10 years experience in table-tennis, to evaluate how well users performed after using the system. The first part (Skill Test 1) of the test measures whether or not users are able to reflect the ball onto the opponent's court. The second part (Skill Test 2) is the same as the first part, yet we asked the users to hit the far left and right corners of the table upon receiving the ball. Each part of the skill test consisted of 10 trials (20 trials in total), and each user's score was calculated based on their number of successful trials. We separated the participants onto two equal groups, one conducted the experiment with T2Snaker, and one

[4]https://www.robotis.us/

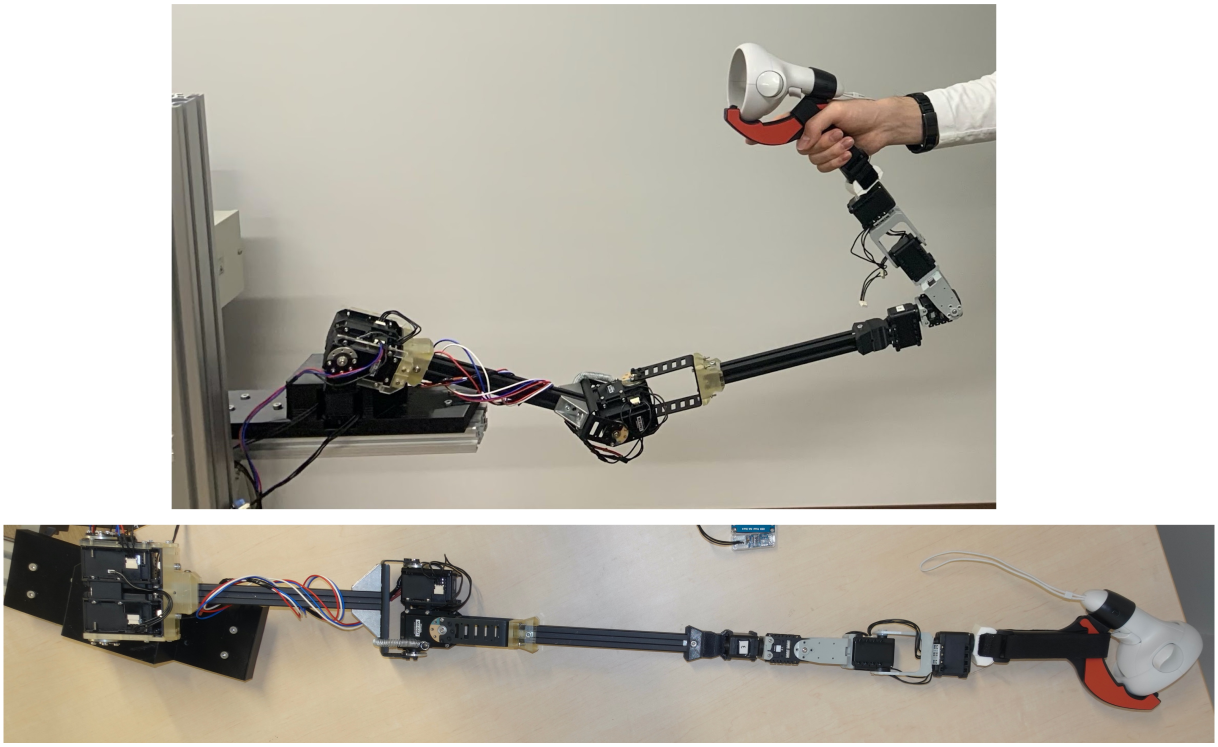

Figure 3: The robot is composed of serially linked servomotors connected through aluminum and PLA frames, with a total length of 990mm and weight of 2.25kg

using the VR environment only. First, users took a bibliographic questionnaire and were introduced to the system. Next, participants took the skill tests, after which we conducted the table-tennis training session (depending on the user's group, in T2Snaker or VR). Upon finishing the training, participants took the skill tests again. Next, participants in each group were asked to try the other groups system for 14 minutes (e.g. VR group used the T2Snaker system, and vice versa). Lastly, participants took a semi-structured interview that covered their overall impressions and opinions about using T2Snaker.

5 RESULTS AND ANALYSIS

As shown in Figure 4, we normalized each users' data in order to understand the effect of both systems on users performance (Normalized Data = score after training - score before training) similar to previous work [12]. The resulting normalized data show that users had an overall higher skill gain in T2Snaker for skill test 1 (T2Snaker m=0.40 ,SD=1.52, VR m=-1.20 ,SD=2.59). For skill test 2, users had slightly higher skill gain in the VR system than T2Snaker (T2Snaker m=2.00, SD=2.00, VR m=3.00,SD=1.73). Although these results partially indicate the potential of T2Snaker for training, we believe the results are inconclusive due to the small sample size, and should be extended to confirm the results.

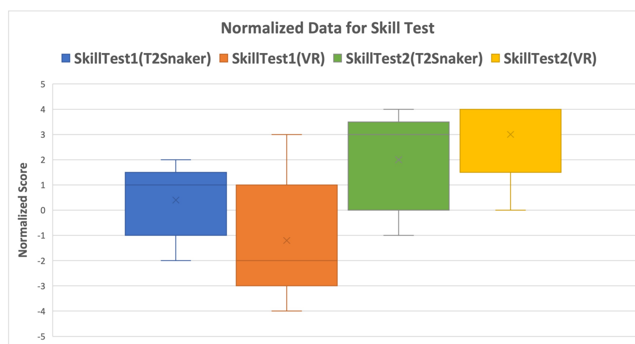

Figure 4: Normalized Data for Skill Test

Participants rated their experience about using T2Snaker (Likert scale results, 6 is best), and they also provided their general impressions and opinions. Participants praised the physical table tennis instruction, one participant said "I think it's good that the robot arm can more directly convey the feeling of swinging", and another one added "It feels like a coach is supporting me in the real world". Participants also highlighted some challenges, one participant said "I found the practice with the robotic arm tiring.", which is expected with such training. Other participants highlighted another shortcoming with the robot movement, which one participant summarizes as "I didn't know the range of motion of the robot arm, so I was worried about breaking it.". Such challenges indicate that the robot structure should perhaps be made more flexible, wearable or with a larger works-space. Also, participants proposed improvements like providing users with virtual avatars to represent and see their movements, providing a rating for their training performance, and visualizing the range of robot motion, location, and workspace in VR.

Overall, some people said that as a hobby, VR only was more fun because they could move their wrists freely, but many participants said that T2Snaker was better for the purpose of improving their table tennis skills. Overall, participants thought that T2Snaker was enjoyable (m=4.9, SD=0.57) and it motivated them to continue table tennis training (m=4.9, SD=0.57), and suggested other application domains, such as for baseball, tennis, and calligraphy, with various types of end-effectors.

6 CONCLUSION AND FUTURE WORK

In this experiment, the skill level of the group using the robotic arm improved more, but the number of subjects was small due to the new coronavirus, and the evidence was insufficient. We will correct the problems with T2Snaker that we found in the questionnaire results and aim to update it further.

In the future, we would like to implement functions for advanced table tennis players. Also, since we only implemented the forehand function this time, we will implement the backhand function. Lastly, we would like to make a robot that can be used for actual table tennis games, such as for augmenting users while playing table-tennis.

We also think that there are many improvements to be made in the control method of the robot arm. This study was based on the positional control of the robotic arm. To enhance the training effect, adapting the control strategy of assistance as needed would be beneficial. Especially, using admittance control of a end-effector part would be helpful for adjusting the interactive force for the user to provide higher level of instruction.

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