Body of a high-speed anthropomorphic table-tennis robot with a linkage mechanism

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1 Introduction

Robots help us understand and utilize mechanisms of human adaptive behavior. This behavior includes not only movements, such as the manipulation of objects and locomotion, but also interactions with other humans, such as in table tennis. A robot can be a valuable tool for studying high-speed human-robot interactions and human-human interactions, such as human movement/shot prediction in table tennis, which has an anthropomorphic body shape, moves fast, and hits a ball anywhere on the table-tennis court.

Many researchers have developed robots that can play table tennis [1, 2]. These robots can hit a ball anywhere on the court, but they only have an arm, making it difficult for a human to predict their future movements in the same way as in a human-human rally. Xiong *et al.* presented impedance control for a humanoid robot playing table tennis [3]. This robot had an anthropomorphic body but did not step to hit a ball, and could hit a ball only in a limited area.

For these reasons, Developing a table-tennis robot is aimed, which has an anthropomorphic body shape so that *its future movement can be predicted by a human player*, moves fast, and can hit a ball anywhere on the table-tennis court. The main contribution of this paper is to present the concept and a part of a prototype of such a robot's design.

2 Design of the table-tennis robot

Our table-tennis robot has an anthropomorphic appearance (the top right of Figure 1) so that its motion can be predicted by a human player, such as the robots in [3]. These robots had several joints and actuators to execute various striking motions and could hit a ball anywhere on the court. The robot's weight increases and its speed decreases as the number of actuators increases. Therefore, one actuator in our robot is used to drive three joints in its arm to decrease the number of actuators. Consequently, the robot can execute only two striking motions so that it moves its position along sliders as in [1] to hit a ball anywhere on the court. It was assumed to be crucial for a human player to predict the other player's motion from the motion of the arm and trunk, so that the robot has an arm and trunk. This design approach can be used for other robots, which move fast and interact with humans, and attaching a head and eyes to the robot enables the player to predict its motion using other ques.

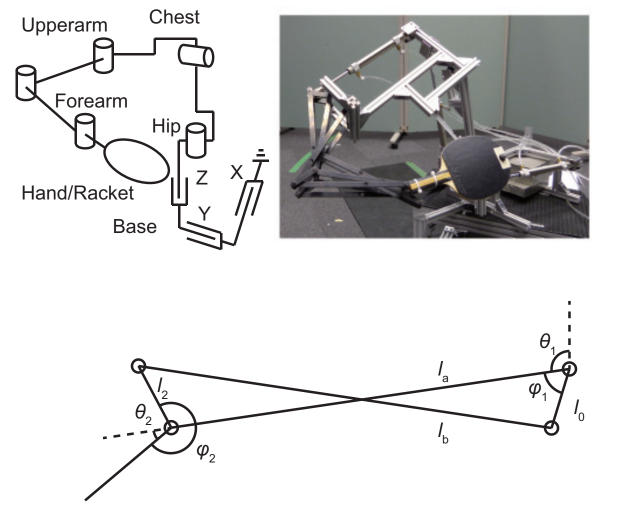

Figure 1: Joint composition of the robot (top left). Appearance of the upper body of the robot (top right). Linkage mechanism of the arm of the robot (bottom).

The robot has six links and eight joints (the top left of Figure 1). The six links are the base, hip, chest, upper arm, forearm, and hand holding a table-tennis racket. The eight joints are the X and Y joints of the sliders and Z joints of the base, hip, chest, shoulder, elbow, and wrist. The X and Y joints move the base on the sliders in front of the table to change the location of the robot. The Z joint on the base changes the height of the hip. The hip joint rotates the chest horizontally when the robot swings its arm. A linkage mechanism coordinates the shoulder, elbow, and wrist. Electric motors actuate the X and Y joints to control the position of the robot accurately, while pneumatic cylinders move the Z joint, chest, and joints in the arm for fast striking motions.

The height and weight of the body are 0.6 m and 7.7 kg, respectively. An external compressor (453×682×875 (WxDxH), 118 kg, SLP-221EBD; ANEST IWATA Corp.) sends compressed air to the robot to actuate its cylinders (CM2B20-100Z, SMC). Twelve two-port valves (EXA-C6-

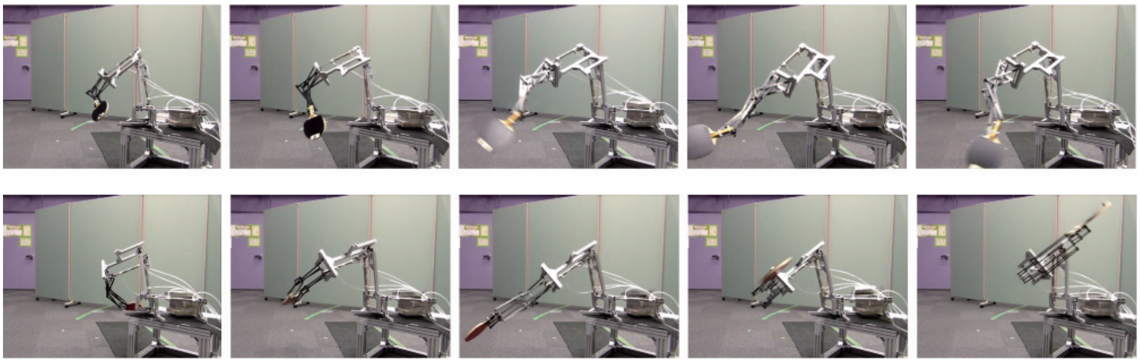

Figure 2: Snapshot of the robot swinging: driving motion (top) and pushing motion (bottom).

02CB, CKD Corporation) close and open air flow to control the air pressure in the cylinders. A computer (BeagleBone Black, Beagleboard.org) sends commands to these valves.

The robot's striking motions are pushing motion and driving motion. The robot swings its racket by extending the arm downward in the pushing motion and by bending its arm upward in the driving motion. The design parameters of the linkage mechanism (the bottom of Figure 1) was determined such that the shoulder, elbow, and wrist of the robot move from one end of their range of motion to another in these motions. The variable ϕ_2 in Figure 1 was calculated, minimizing f as

$$f = (l_b(\theta_1[0], \theta_2[0]) - l_b(\theta_1[1], \theta_2[1]))^2, \tag{1}$$

where $l_b = \sqrt{d_x^2 + d_y^2}$, $d_x = l_a \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2 + \phi_2) - l_1 \cos(\theta_1 + \phi_1)$, $d_y = l_a \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2 + \phi_2) - l_1 \sin(\theta_1 + \phi_1)$. The variable l_b was was calculated using these equations and ϕ_2. The arm was designed such that the shoulder, elbow, and wrist coordinate and moved through the ranges of $\pi/4$–$3\pi/4$ rad, 0–$\pi/2$ rad, and $-\pi/4$–$pi/4$ rad, respectively. The variables l_b and ϕ_2 were thus calculated for the upper-arm settings of $l_a = 300$[mm], $l_1 = 50$[mm], $l_2 = 50$[mm], $\phi_1[0] = \pi/4$[rad], $\theta_1[0] = \pi/4$[rad], $\theta_1[1] = 3\pi/4$[rad], $\theta_2[0] = 0$[rad], and $\theta_2[1] = \pi/2$[rad] and forearm settings of $l_a = 300$[mm], $l_2 = 50$[mm], $\theta_2[0] = -\pi/2$[rad], and $\theta_2[0] = \pi/2$[rad], respectively. The values of l_1, $\phi_1[0]$, $\theta_1[0]$, and $\theta_1[2]$ were used in the calculation of the forearm and values of l_2, ϕ_2, $\theta_2[0]$, and $\theta_2[1]$ in the calculation of the upper arm.

3 Swing experiments

The motions of the robot were measured in experiments to verify the design. The robot swung its arm in two different patterns, namely, driving and pushing patterns, in the experiments. The commands for this swinging were determined through trial and error. The pressure of supplied air was set at 0.7 MPa. The robot's motions were measured using eight motion-capture cameras (Prime13W; NaturalPoint, Inc.). A marker was attached on the racket to measure the position of the racket. The motion-capture system measured racket positions at 120 frames per second. The velocity of the racket was calculated from the measured positions.

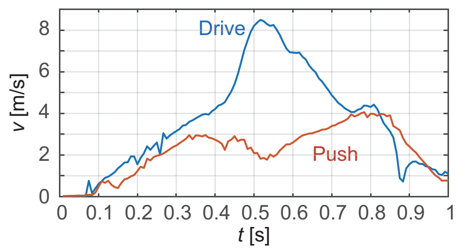

Figure 3: Speeds of swinging motions of the robot.

Snapshots of the two swinging motions executed by the robot (Figure 2) indicates that the robot could execute these different motions. Figure 3 shows the speed of the racket. The motions had a maximum racket speed of 8.5 m/s.

4 Conclusion

In this paper, the body of a high-speed anthropomorphic table-tennis robot with a linkage mechanism was presented. Experimental results indicate that the robot executed two different swings with a maximum racket velocity of 8.5 m/s. This speed was half the humans' speed of 19.4 m/s [4]. Therefore, the structural parts are going to be replaced with lighter ones to increase the speed. The whole system of the robot around the body presented here is being developed, and whether humans are able to predict the next move of the robot in table is going to be investigated.

References

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