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A BADMINTON ROBOT - SERVING OPERATION DESIGN

Kim Seng Chia, Xien Yin Yap and Ee Soong Low
Faculty of Electrical and Electronic Engineering Universiti Tun Hussein Onn Malaysia Parit Raja, Batu Pahat, Malaysia
E-Mail: kschia@uthm.edu.my

ABSTRACT

Building a sport robot that can defeat human players in sport activities is the aim of many researchers and engineers in robotic related fields. This paper presents a design of a mobile badminton robot that can serve a shuttlecock as a human player in a standard badminton court. A transporting shuttlecock system was designed to preload six shuttlecocks. A serving mechanism was designed to swing a standard badminton racquet to hit a dropping shuttlecock timely. The challenges and the proposed solutions that involved during the development of the shuttlecock serving system and serving mechanism are discussed. Findings indicate that the proposed design is able to preload and serve six shuttlecocks continuously with a success serving rate of 89% in a standard badminton court when the time between swinging the racquet and dropping a shuttlecock was optimized.

Keywords: badminton, mobile robot, serving operation.

INTRODUCTION

Building a sport robot that can defeat human players in sport activities is the aim of many researchers and engineers in robotic related fields. Competitions e.g. RoboCup has been organized to not only motivate researchers and engineers to develop higher performance robots, but also acknowledge their efforts and contributions in this field. Besides, throughout the development of sport robots, many theories, algorithms and practical inventions have been discovered in various topics (Arenas, Ruiz-del-Solar, Norambuena, and Cubillos, 2009; Xiaopeng, Ye, Qiang, Weimin, and Zhangguo, 2010; Yang, 2013; Zitzewitz, Rauter, Steiner, Brunschweiler, and Riener, 2009). In addition, sport robots can be designed for teaching and learning purposes in specific courses e.g. control system and programming (Zhang, 2014), and entertainment purpose e.g. playing an interactive sport activity with human (Laue, Birbach, Hammer, and Frese, 2014).

Badminton is one of most popular sports in Malaysia. In June 2015, three of Malaysian players were ranked as three of the top 46 men's singles in the world by Badminton World Federation (BWF). This achievement could be one of the reasons that makes badminton popular in Malaysia.

Badminton is considered as a very dynamic game because the speed of a smash can up to 332 kph according to the recorded in the 2005 Sudirman Cup. In order to counter back such high speed shuttlecock, a player needs to react quickly and accurately. A mobile robot must have the capability to estimate the shuttle trajectory and react with the estimation accurately and timely in such ways the robot that can achieve the performance as a human player does.

To develop this kind of high precision robot, an integration of mechanical design, sensor technology, estimation algorithm, and motion control is vital (Stoev, Bartic, Gillijns, and Symens, 2010). This challenge provides lots of opportunities for researchers carry out different experiments that may enhance our understanding of the state of the art. For example, a classical model-based technique should be used instead of model-free approach if a reliable model is available. This because the latter requires a longer time for exploring and learning (Liu, Depraetere, Pinte, Grondman, and Babuska, 2013).

This paper presents a design of a serve system in a mobile badminton robot that includes a transporting shuttlecock system (also known as a feeder) and a serving mechanism.

METHODOLOGY

Transporting shuttlecock system

Figure-1 illustrates the transporting shuttlecock system (also known as feeder) that is one of the important parts of a mobile badminton robot. This system should be able to preload several shuttlecocks, and then to drop a shuttlecock timely so that a moving racquet can hit the shuttlecock in order to complete a serving. The present designed feeder is capable of preloading six shuttlecocks, and then serving these shuttlecocks continually. Since the function of the feeder is to drop a shuttlecock at the correct time so that the racquet to hit the shuttlecock, the feeder is located at the top front of the robot.

The main parts of the feeder are the G15 cube servo, the feeder's body (i.e. rotor) and the base (i.e. stator). Both the rotor and stator are made of perspex acrylic sheets which are joined by using hot glue. The shape of the rotor is heptagon. The rotor consists of seven equivalent spaces. Six of the spaces are used to preload six shuttlecocks. The last space cannot hold a shuttlecock because there is a hole under it and it is desired as a dropping location. The dropping area in the stator was designed with the same size as the space of the heptagon to prevent obstruction during dropping.

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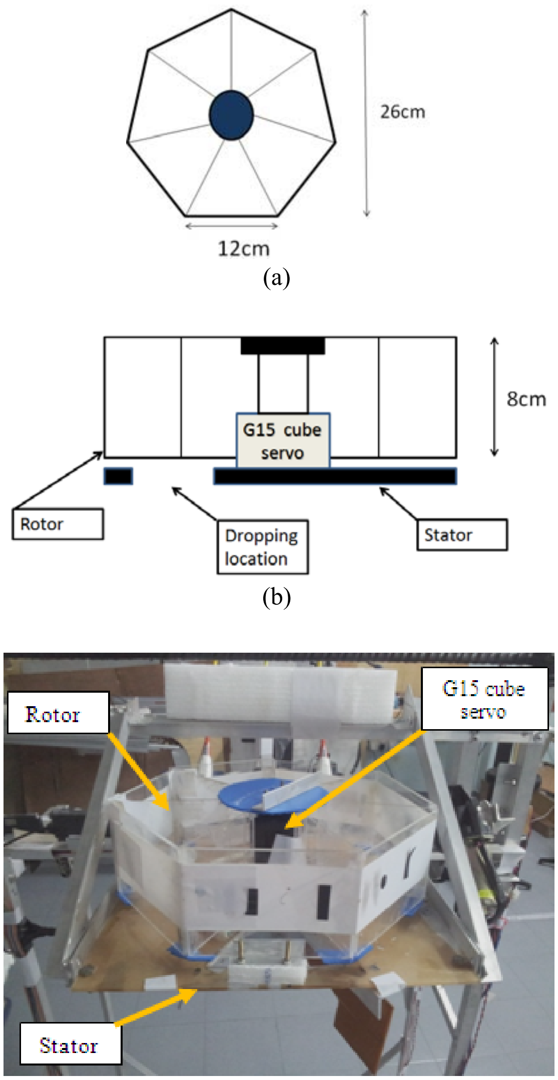

(c)

Figure-1. The transporting shuttlecock system: (a) the top view, (b) the side view, and (c) the prototype.

G15 cube servo is used because it is able to perform 360 degree rotation movement with a controllable rotational velocity. Moreover, it rotates accurately and it has a stable structure at the bottom of the motor. A G15 cube servo is attached on stator and is used to rotate the rotor.

In addition, polystyrenes are put between the rotor and the stator so that the rotor can be rotated smoothly. The polystyrene is used instead of mini wheels to support the rotor because a small amount of friction is needed so that the rotor can be stopped instantly without overshoot problems once the G15 cube servo is stopped.

Positions of shuttlecocks

The initial location of each shuttlecock is different in the rotor. Each of them will be transported to the dropping location of the system to complete serving action. Since the accumulated frictions are different for each shuttlecock during its transporting movement, the position of each shuttlecock might be varied when it has reached the dropping location. To avoid this uncertainty, a track that made of wires was installed to ensure that the position of shuttlecocks can be maintained while they have been transported from their initial location to the dropping location.

Figure-2 illustrates the top view of the designed transporting shuttlecock system. This shuttlecock system is capable of preloading six shuttlecocks. The distance between the dropping location and the shaft of the racquet is around 33.5 cm. The servo motor was used to turn the rotor in anticlockwise from the top view. During the pre-loading stage, each of six shuttlecocks was positioned vertically in the six locations of the rotor.

Serving mechanism - initialization

A Vexta DC motor with an operating voltage of 24V, 30watt, 250 rotations per minute (r.p.m.) was used to move the racquet. The racquet was attached to a shaft that attached to the DC motor directly. Initially, the racquet of the robot is automatically moved to its initial position. The initial position is approximately 100 degrees from the horizontal right axis. The dimension of the badminton robot is stated as that illustrated in Figure-3. A variable resistor is used to determine the position of the racquet.

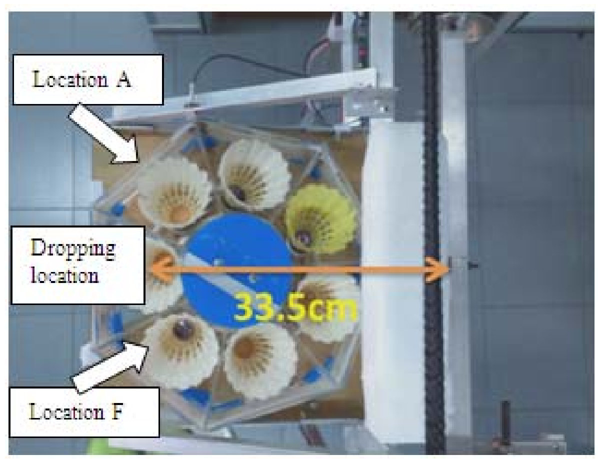

Figure-2. The top view of the shuttlecock system.

Since the linear distance from dropping location to the location where the racquet can hit a shuttlecock is around 0.54 m, the time taken from a shuttlecock reach the location where the racquet can hit a shuttlecock is around 0.33 seconds, with an assumption that the acceleration of the freefall shuttlecock is 9.8 ms^{-2}. Next, the angle between the initial position of the racquet and the position that it can hit a dropping shuttlecock is around 232 degrees or 4.049 rad. Thus, the racquet must be swing by a motor that can complete a rotation within 0.512 seconds or an

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average speed of 119 r.p.m. In order to swing the racquet from its static state to hit a dropping shuttlecock within 0.33 seconds, the Vexta DC motor was operated at full speed so that sufficient energy can be provided to move the racquet from its initial static state and to overcome existing friction.

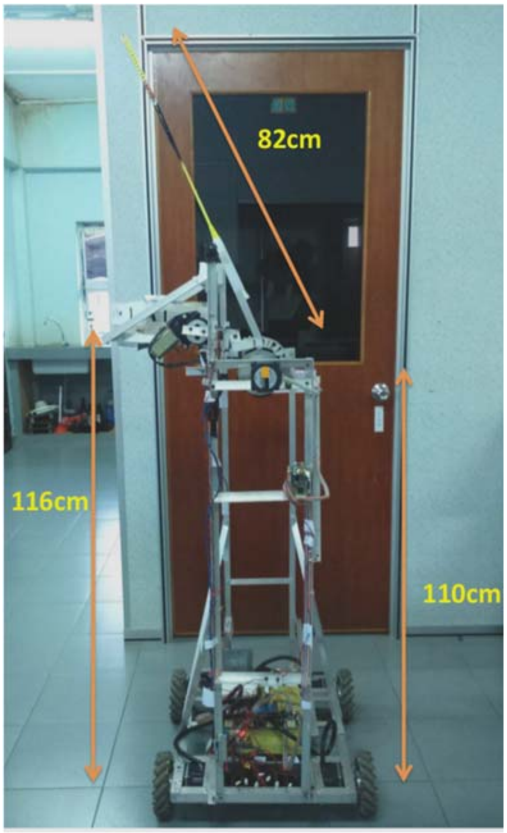

Figure-3. The side view of the badminton robot.

Serving Mechanism – Serving operation

When a serve operation is activated by a user, there are three steps to complete the serving. First, the feeder will transport a shuttlecock to the standby position. The standby position is the position of a shuttlecock in the transporting shuttlecock system before the shuttlecock drops. In this position, the shuttlecock will be dropped once the shuttlecock system is rotated further slightly.

Second, the Vexta DC motor will be activated with full power to swing the racquet with the maximum speed. Third, after a specific time, Ts the feeder will be rotated further and a shuttlecock will drop out from the dropping location immediately. The specific time, Ts is a tuneable parameter that determines when the rotor should be turned after the racquet has been swung. The relationship between the different specific time and the serving performance of the badminton robot were examined in a standard badminton court in Universiti Tun Hussein Onn Malaysia, Parit Raja, Malaysia. This serving operation is summarized in Figure-4.

Performance analysis

The performance of the badminton mobile robot was tested in the standard badminton court in Universiti Tun Hussein Onn Malaysia. The aim of the mobile robot is to perform as a human player who need to serve shuttlecocks from one of the right service area in a standard badminton court to the other right service court on the opposite site. First, the mobile robot was positioned in the right service court. Second, the performance of the mobile robot is considered successful if the shuttlecock has been hit by the racquet, then it passes a standard badminton net, and lastly it reaches the opposite right service court. The distance of each successful serve was recorded and analyzed. The experiment was repeated thrice after six pre-load shuttlecocks were served by the robot by using a different specific time. The serving distance was measured from the dropping point of the serving mechanism to the first landing location of each shuttlecock.

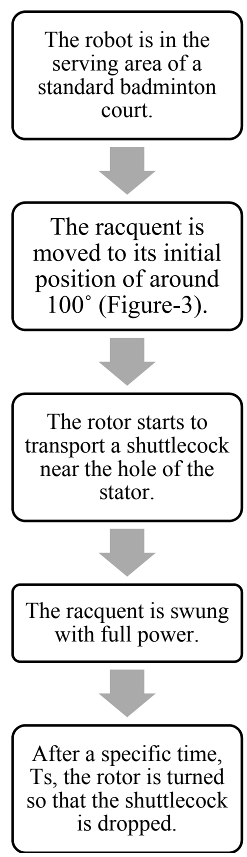

Figure-4. Serving operation.

VOL. 11, NO. 6, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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RESULTS AND DISCUSSIONS

Friction between the body and the base

Since the friction between the rotor and the stator could cause the feeder moves unstable, the timing for a shuttlecock drop was uncertain. Initially mini wheels were installed between the rotor and stator so that the rotor could rotate smoothly. However, the inertia of the rotor would cause the rotor unable to be stopped instantaneously when the G15 cube servo is stopped. Thus, polystyrenes are used to support the rotor with some friction. It is found that the small amount of friction from the polystyrene enables the body to stop instantly when the motor stopped. However, the rotational motion of the rotor was still not smooth enough. This could be due to the huge difference in friction coefficient of polystyrenes in static and dynamic states. Consequently, the designed mobile robot was only able to serve the shuttlecock with around 50% accuracy.

To overcome the challenge of transporting shuttlecock, all the shuttlecocks will be stopped in the position that just before it will drop, i.e. the standby position. In this position, the shuttlecock will drop once the G15 cube servo is activated. As a result, the effects of unstable movement of the rotor while transporting shuttlecocks can be minimized. By using the proposed strategy, the designed mobile robot is able to hit the shuttlecock with up to 89% accuracy.

Rate of successful serving

Figure-5 illustrates that the performance of the badminton robot was optimal with success rate of 89% when the specific time was 120 ms. The performance was degraded when longer specific time was used. This could be due the fact that the racquet did not manage to hit a shuttlecock when the specific time was too long. When the specific time was too short, on the other hand, the position of a dropping shuttlecock was not in the best position to be projected. Thus, it is important to determine the optimal specific time needed for the badminton robot.

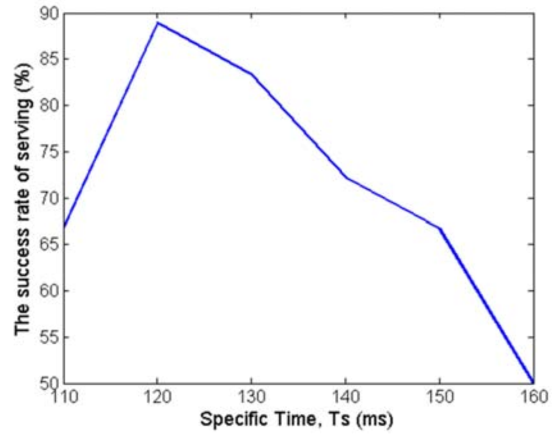

Figure-5. The success rate of serving versus different specific time.

Serving performance with different specific time

Figure-6 depicts that five of the six shuttlecocks were successfully served by the robot from one right service area to the other right service area. However, one of them did not reach the desired location. This could be due to the dropping pattern of a shuttlecock that is hardly to be consistent by using the current design. Nonetheless, the success rate might be improved if the robot was positioned closer to the center line.

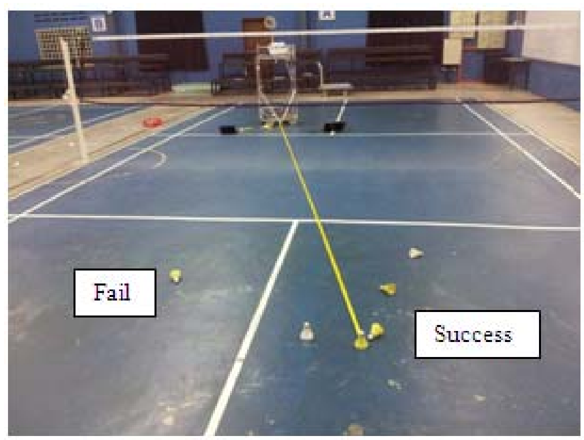

Figure-6. The performance of the badminton robot in one of experiments.

Effect of shuttlecock position in the rotor

Table-1 tabulates the recorded serving distances according to the position of a shuttlecock in the rotor with different specific time, Ts. It is worth to highlight that even though the robot was able to serve all the pre-loaded shuttlecocks across a standard badminton net when specific time was 120 ms, 130 ms, or 140 ms, some of them were unable to reach the targeted location, i.e. opponent right service area.

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Table-1. The serving distance of the badminton robot.

Shuttlecock location	Trial	Serving distance (cm) when the specific time is		
		120 ms	130 ms	140 ms
A	1	700	709	631*
	2	674	701	657*
	3	723	700	637*
B	1	696	721	687
	2	713	655	658
	3	645	692	695
C	1	750	710	675
	2	674	701	661*
	3	703	691	655*
D	1	643	648	661
	2	667	613*	642
	3	676	678	689
E	1	476*	567*	629
	2	531*	661	642
	3	622	615*	657
F	1	722	715	672
	2	662	676	696
	3	681	632	712

* denotes that the serving failed.

There are two main reasons. First, the direction of the projectile might be deviated due to the position of the dropping. Second, the optimal timing for each shuttlecock in different initial location might be different. To overcome this potential uncertainty, the use of an adaptive controller may improve the performance of the robot.

Figure-7 summarizes the serving distance of the badminton robot for shuttlecocks that were positioned in the six different positions in the rotor, from one right service area to the other right service area when the specific time was 120 ms, 130 ms, or 140 ms.

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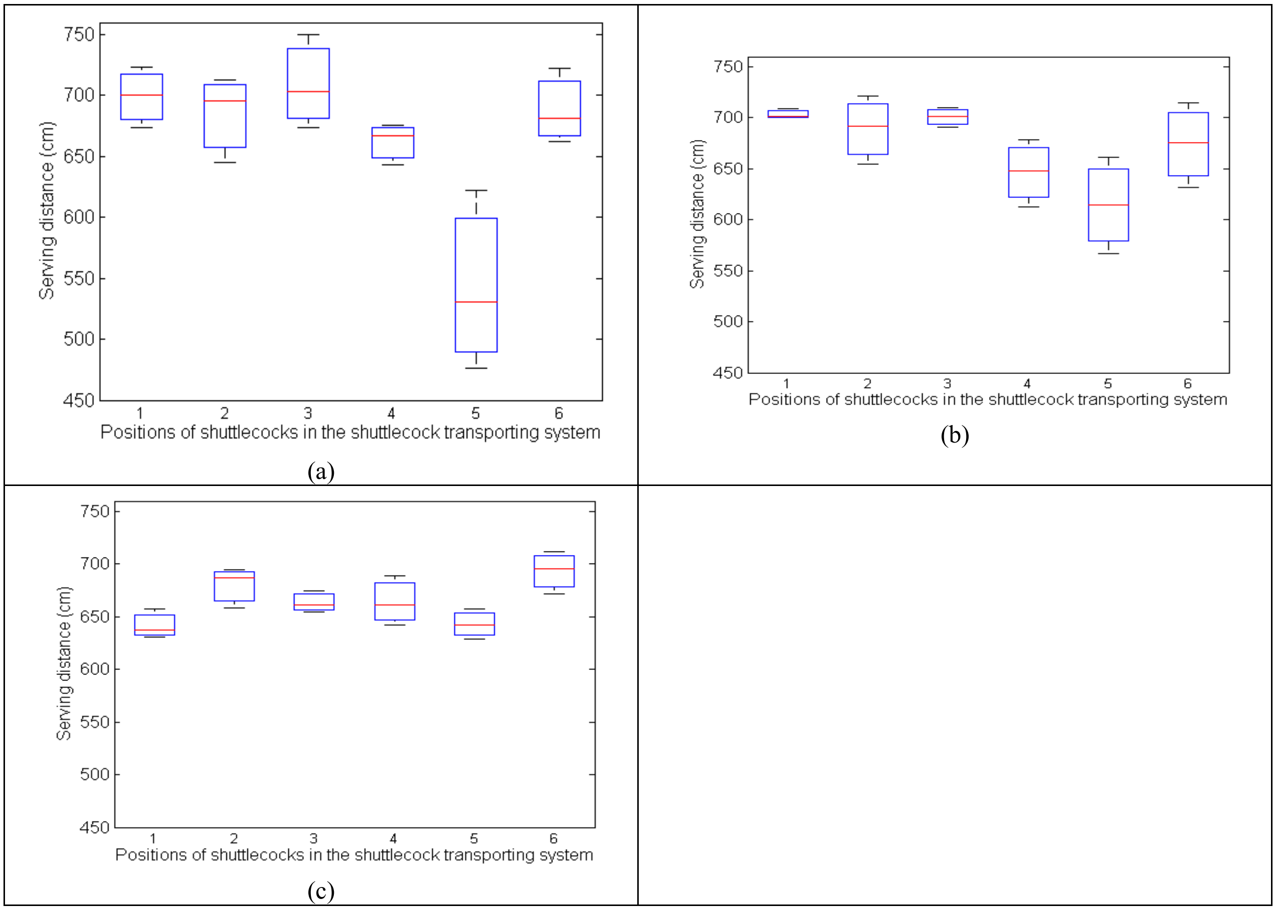

Figure-7. The boxplot of the serving distance for three trials when the shuttlecocks were pre-loaded in different positions with: (a) specific time of 120 ms, (b) specific time of 130 ms, and (c) specific time of 140 ms.

The best precision in terms of serving distance was achieved when a specific time of 140 ms was used for the six different positions, with a standard deviation of 24 mm. However, the success rate of serving was worse when it was compared to the robot that used specific time of 120 ms or 130 ms. The best accuracy, on the other hand, was achieved when specific time was 120 ms. Nonetheless, the robot that used specific time of 120 ms had worse precision with a deviation of 67 mm compared to that used specific time of 130 ms and 140 ms.

Overall serving distance of the robot with a different specific time was summarized in Table-1. Results suggest that a fuzzy logic controller could be used to optimize the performance of the robot via varying the specific time accordingly to suit the position of a shuttlecock in the rotor.

Table-2 tabulates the descriptive statistics of the serving distances that achieved by the mobile robot with specific times of 120ms, 130ms, and 140ms. The mean and median of the serving distances were similar even though different specific time was used. This suggests that the serving distance does not relate to the specific time.

Table-2. Descriptive statistics of the serving distance.

Specific time, Ts (ms)	Serving distance (cm)				
	Min	**Max**	**Mean**	**Median**	**SD**
120	476	750	664	675	67
130	567	721	671	684	42
140	629	712	664	659	24

SD = standard deviation

By using the optimal specific time of 120ms, the robot is able to achieve an average serving distance of 664cm with a deviation of 67cm. A relatively high deviation value was mainly due to the performance of the robot that was unable to serve the shuttlecocks that allocated in the location E of the rotor to the desired distance.

ARPN Journal of Engineering and Applied Sciences

CONCLUSIONS

The design and serving performance of the badminton robot are analyzed and discussed in the paper. Findings indicate that the time between swinging the badminton racquet and dropping a shuttlecock, Ts is crucial to optimize the performance of the badminton robot. In the present design, the robot is able to serve six shuttlecocks continuously with an accuracy of 89%, from one right service area to the other right service area of a standard badminton court. The average and the maximum serving distance were 664cm and 750cm, respectively, when Ts of 120ms was used. Besides, findings also indicate that the time, Ts does not affect the serving distance of the robot.

In future, control system e.g. adaptive and fuzzy control systems will be investigated to optimize the performance of the badminton robot.

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