Recent Patents on Computer Science **2017, *10*, 000-000** **1**

RESEARCH ARTICLE

Interactive Smart Tennis Ball Collecting Vehicle

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Abstract: ***Background:*** As one of the most popular racket sports in the world, tennis usually takes a considerable amount of repetitive training that uses a great number of tennis balls. After the training, collecting the tennis balls is an annoying, time consuming, and labor taking task. To cope with such problem, a great number of tennis ball collectors such as the stroller-based, basket-based, and wheeler-based collectors were proposed. However, existing tennis ball collectors mostly require manual operation. To eliminate human intervention, a recent trend is to automate the process by electronic devices.

Methods: Our new collector combines a wheeler-based collector with a smart vehicle providing both automatic programmed route and interactive remote-controlled collection. To accommodate tennis balls of various sizes, the basic collector comprises two discs of resilient material attached with four springs. By cascading a number of basic ball collectors side-by-side with an axle through their center, we may extend the basic tennis ball collector from single channel to multiple channels.

Results: In order to simulate the distribution of tennis balls after a practice session, 30 tennis balls are randomly distributed over a half court at the start of each test. In interactive navigation tests, the user is requested to collect the 30 tennis balls as soon as possible by controlling the vehicle through a smartphone. The test results showed that the amount of time taken to complete the interactive collection fall into the range of 4 to 15 minutes; on the other hand, the time taken to complete automatic preprogramed route collection is around 14 to 15 minutes.

Conclusion: In comparison with traditional labor work that usually takes more than 15 minutes, our novel design greatly reduces the collection time and improves the user experience by changing the tennis ball collection from a dull and painful task to an interesting one.

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INTRODUCTION

Tennis is perhaps one of the most popular racket sports nowadays. To learn the basic or advanced strokes, the player usually has to do repetitive training. After the training procedure, it is not uncommon to see a large number of tennis balls spreading over the entire court. Collecting these widely scattered tennis balls usually takes a large amount of time and is an extremely heavy burden for both the trainer and the trainees. To cope with such problem, a large number of tennis ball collectors were invented.

Traditional tennis ball collectors such as the stroller and basket based [1-6], wheeler style [7-15], or a combination of both [16] are mostly manual devices designed to facilitate the collection of tennis balls. For example, a typical frame-based collector usually is consisted of a handle and a framed basket or a rolling frame [1-6]; in which, the frame spacing is specifically made so that the tennis balls whose diameter is slightly larger than the spacing can be squeezed and kept in the frame. However, owing to the large variation in the size of the tennis balls, varying from 2.57 to 2.70 inches, it is hard to find a proper spacing for all sorts of tennis balls. Furthermore, such type of devices still requires a considerable amount of human labour.

Inspired by the wheeler-based golf ball collectors [17, 18], a large number of wheeler-based [7-15] or a combination of trolley and the wheeler style collectors [16] were proposed to improve the collecting efficiency. However, they still require human intervention.

To minimize human intervention, a recent trend is to incorporate the tennis collector with electronic circuitry. Examples such as the vacuum-based collector [19] and the vehicle/robot based collectors [20-24] were reported lately.

To improve the collecting efficiency, the vacuum-based collector [19] automates the tennis ball retrieval process by applying a vacuum suction device. However, the collector movements still require human labour. Moreover, the variation in the sizes of tennis balls may cause the collection unsuccessful.

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A more recent design automated the movement of the collector by using the smart or autonomous vehicle. Approaches of this type are called the vehicle or robot based collectors [20-24]. With such type of collectors, human intervention in tennis ball collecting process is greatly reduced. However, the collecting efficiency may vary greatly according to the design of the collector and the navigation speed.

For example, the Bear Claw Collector by M. Farrell *et al.* at Berkeley University uses a color camera to locate a tennis ball and grab it with a pair of mechanical claws. Although the design is highly automated, it is far from efficient by tracking and collecting the tennis balls one-by-one.

In summary, we have found at least two major problems in most concurrent designs: firstly, low collecting efficiency resulting from the inappropriate design of the tennis ball collector; secondly, high latency and prolonged navigation time resulted from inefficient tracking and navigation control.

THE INTERACTIVE SMART TENNIS BALL COLLECTING VEHICLE

To cope with the aforementioned two problems, we proposed a novel smart tennis ball collecting vehicle. The new collector combines an extensible multichannel tennis ball collector with a smart vehicle. To allow high efficient tennis ball collecting, a set of extensible wheeler-based collectors adaptive to tennis balls of various sizes is proposed. On the other hand, an Arduino-based smart vehicle providing automatic preprogrammed route and interactive remote-controlled navigations through smartphone touch-based interface is deployed to reduce the navigation time.

As shown in Fig. (**1**), the multichannel tennis ball collectors are served as the front wheels of the smart vehicle.

On the top of each collector channel, an elastic curved plate called the ejection arm is used to eject the clamped balls. Rolling upward with the collecting wheels, the clamped balls were ejected by the ejection arms to the container. Counting is triggered as a ball touched the microswitch attached to the end of the ejection arm. To show how it works, a series of snapshots is given in Fig. (**2**).

We begin the discussion of our patent with the highly efficient extensible multichannel tennis ball collector followed by the smart vehicle.

The Tennis Ball Collector

According to the discussions given in Section 1, a good tennis ball collector should have at least two essential properties.

- Firstly, it has to adaptable to tennis balls of various sizes: typically, the diameter ranging from 2.57 to 2.70 inches.
- Secondly, the collecting efficiency must be high enough to minimize the collection time.

To satisfy both requirements, we developed an extensible multichannel wheeler-based tennis ball collector. We begin our discussion of such collector with the design of the basic collector followed by a multichannel extension of such collector.

The Basic Tennis Collector

Our basic tennis ball collector, as shown in Fig. (**3**), comprises a pair of parallel discs. To accommodate tennis balls of various sizes, the two discs are made of resilient material and four springs are attached near the center. As the discs rolling through a tennis ball, the ball is then clamped by the two discs.

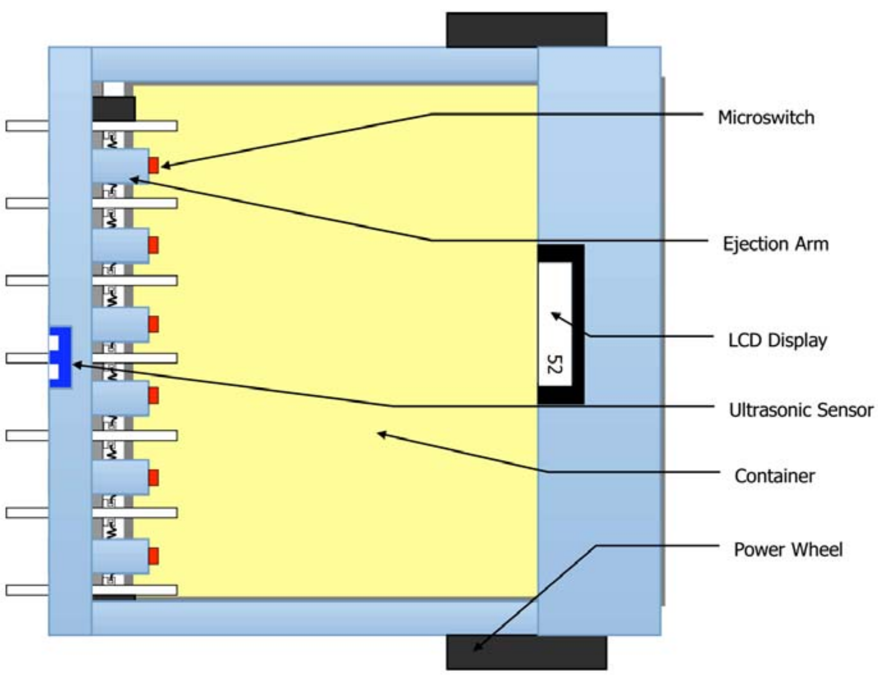
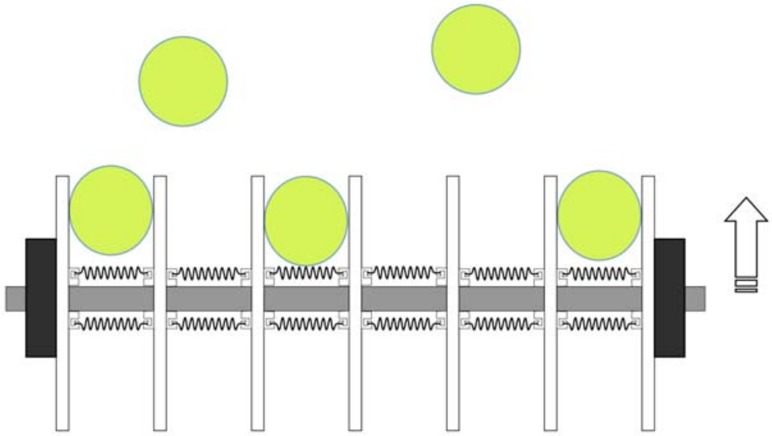
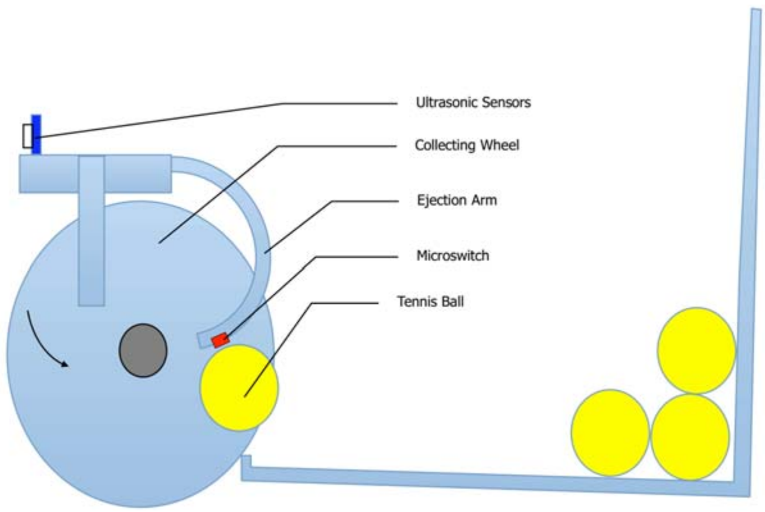


Fig. (1). An illustration of our invention.



(a)



(b)

Fig. (2). An illustration of the mechanism of tennis ball pick-up: (**a**) the collectors rolled over the balls and picked them up; (**b**) the clamped ball were ejected by the ejection arm and triggered the microswitch as the collecting wheels rolled forward.

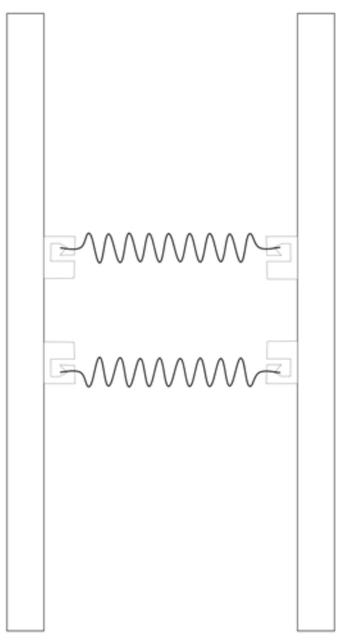


Fig. (3). A basic collector comprising a pair of parallel discs joined by four springs.

The Multiple-Channel Extension

By cascading several basic ball collectors side-by-side with an axle through their center, we may extend the basic tennis ball collector from single channel to multiple channels. To give an example, a six-channel collector with seven parallel discs and 24 springs is illustrated by Fig. (**4**).

Note that, with the six-channel collector, at most six tennis balls can be simultaneously collected. Higher collecting efficiency is achievable by cascading more basic collectors from both sides. Since each channel holds or retrieves a tennis ball at a time, counting of the tennis balls can be easily achieved via sensors located in each channel.

The Smart Vehicle

A block diagram of the smart vehicle is illustrated in Fig. (**5**).

The circuitry comprises a microprocessor control unit (MCU) and four peripheral units. The microprocessor control unit is implemented by a standard Arduino Uno powered by an ATmega328. In addition, the four peripheral units are called the motor drive unit (MDU), the sensing unit (SU), the display unit (DU), and the Communication Unit (CU), respectively.

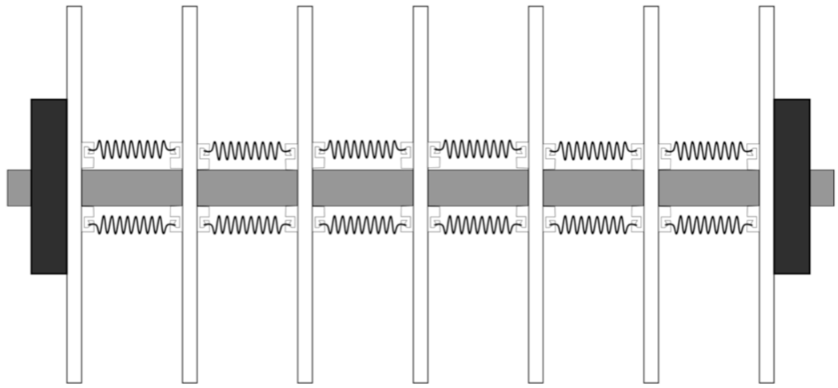


Fig. (4). A multichannel configuration of our basic tennis ball collectors.

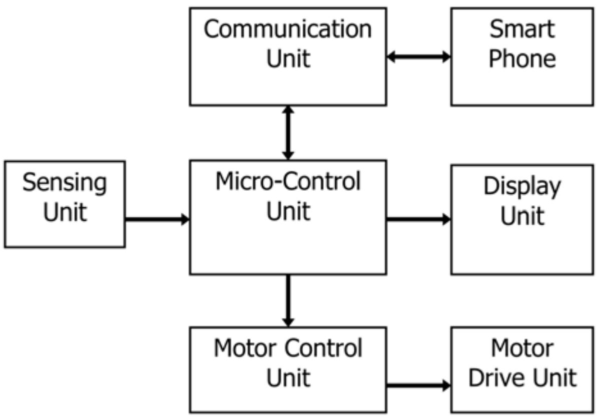


Fig. (5). A block Diagram of our autonomous vehicle system.

To provide interactive and automatic programmed navigation, an Android-based smartphone is paired with the CU through Bluetooth (BT) wireless connection.

The Micro Control Unit

The microprocessor control unit is implemented with a standard Arduino Uno powered by an ATmega328 processor. The system board has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Among the 14 digital I/O pins, six of them can be used as PWM outputs. Furthermore, it can be programmed by a computer via USB connection and powered by an AC-to-DC adapter or a battery unit [25].

The Sensing Unit

In our system, a sonic range finder and a set of microswitches are used for collision detection and ball counting respectively.

To prevent collisions, a sonic range finder, HC-SRF04, is deployed for range finding and obstacles detection. To determine the distance between our vehicle and the obstacles, we have to measure the elapsed time between the generation of an ultrasonic wave and the detection of the corresponding echo. However, a number of environmental factors such as the background noises, lights, dust, and the surface material, etc., may result in severe interferences. According to the specification of HC-SRF04, the HC-SRF04 ultrasonic sensor module is capable of measuring distances of length between 2 and 400 centimeters at a range accuracy of 3 millimeters, sensing angle no greater than 15 degrees, and effective area measuring range no less than 50 cm^2 [26].

On the other hand, the micro switches located at the top of the ejection arms are used for counting the collected tennis balls. The number of collected balls is displayed concurrently on the LCD screens of the vehicle and the smartphone.

The Communication Unit

To enable interactive remote controls, the Bluetooth wireless communication channels between the Communication Unit and user's Android-based smartphone is paired in the first place. Afterward, the user controls the smart vehicle by sending motor control signals through the Bluetooth communication.

The Motor Drive Unit

The motor drive unit, denoted as MDU, contains a dedicated motor driver (L298), a voltage regulator (78M05), and two H-bridges driving the two DC motors [27]. Master Enable is mainly used for either enabling or disabling the MDU regardless of the logic inputs, which accepted input from SU to either halt or start the movement of our vehicle. With the four logic inputs, we may control the direction of vehicle movements according to Table **1**.

The Display Unit

To allow displaying collected ball count on the vehicle, we have adopted the HD44780 from Hitachi as the display unit (DU) of our smart vehicle, which comprises an LCD controller, an LCD driver, and an LCD screen supporting screen clearing, display shifting, cursor flashing, and a set of 160 built-in 5 x 7 dot matrix fonts [28].

THE SOFTWARE SYSTEM

Our system is implemented on two platforms, i.e., the Arduino and Android. The navigation control and collision avoidance routines are implemented with Arduino IDE running on the MCU as the server process. On the other hand, a set of client apps running on an Android-based smartphone

Table 1. Motor rotation status table.

Motor	Rot. Mode		Control	Port		Speed	Regulation
		IN1	IN2	IN3	IN4	ENA	ENB
	Forward	H	L	-	-	H	-
M1	Reverse	L	H	-	-	H	-
	Stop	L	L	-	-	H	-
	Forward	-	-	H	L	-	H
M2	Reverse	-	-	L	H	-	H
	Stop	L	L	-	-	-	H

STEP 1 STEP 2 STEP 3

Amarino Plugin Bundle Amarino 2 I-CatchBot

Fig. (6). The three steps to install associated Android Apps and their corresponding QR codes.

or pad issued user's commands according to the clicks on corresponding command buttons of the apps on the touch screen. Automatic or interactive navigation commands and Bluetooth connection establishment are issued by the client application I-CatchBot. To bridge the platforms between Android and Arduino, apps including the Amarino Plugin Bundle and Amarino 2 are used to establish the Bluetooth communication between the Android-based smart-phone and the communication unit of autonomous vehicle [25].

We begin our discussion with the client apps running on the Android-based smartphone followed by the server process running on the Arduino platform.

The Client-Side Application on Android Platform

To assist the installation of the client, the associate QR-Code of the driver and the client applications are presented in Fig. (**6**).

The user may use the QR code scanner app running on their smartphone to assist the installation of the client apps, i.e., the Amarino Plugin Bundle, Amarino 2, and the I-CatchBot, using Step 1, 2, and 3 QR codes, respectively.

To establish Bluetooth wireless connection with the server and to offer interactive navigation controls over the smart vehicle, the app I-CatchBot is deployed. A snapshot of the client app, the I-CatchBot, is shown in Fig. (**7**).

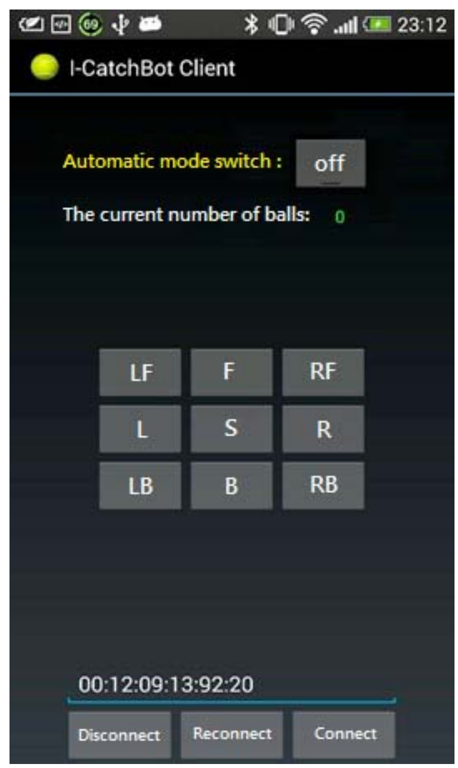


Fig. (7). A snapshot of the client-side application, the I-CatchBot, running on the Android smartphone.

Before the start of the client, the server must be online and the smartphone's Bluetooth connection must be switched on. If the connection has been established, the user may click on the connection buttons listed on the bottom of the screen to either connect or disconnect the client from the server.

Once the connection is established, the user may start either automatic or interactive navigation by pressing on the on/off button on the top of the screen. If automatic mode has been switched on, the smart tennis ball collecting vehicle will carry out the collecting process along a preprogrammed route automatically without user's interference; otherwise, the vehicle moves according to the user's navigation commands triggered by pressing corresponding buttons displayed on the center of the screen, i.e., LF for turn left and forward, F for forward, RF for turn right and forward, etc.

The Server-Side Application on Arduino Platform

As we have mentioned earlier, the server-side application running on Arduino platform directly controls the vehicle and accepts Bluetooth connections from Android-based smartphones. The discussions will be given in the following subsections.

The Navigation Controls

For the vehicle is driven by the two DC motors controlled by MDU, the navigation control is available by sending logic signals to corresponding control ports as described in Table **1**. To serve this purpose, we start with baud rate setting command **Serial.begin**(<*baudrate*>) to initiate the communication between the MDU and MCU. Proceed to the baud rate initialization, we use **pinMode**(<*pin*>, <*mode*>) command and **digitalWrite**(<*pin*>, <*value*>) to configure and assign logic values to MDU ports: IN1 4, respectively, according to the navigation command received from BWCU and Table **1**. For example, if 'F' button on the client's screen is pressed, the following code are executed.

```
void advance(int a)     //        forward
    {
      digitalWrite (IN1 ,HIGH);      //   motor M1
      digitalWrite (IN2 ,LOW);       //   motor M1
      digitalWrite (IN3 ,HIGH);      //   motor M2
      digitalWrite (IN4 ,LOW);       //   motor M2
      delay (a     100) ;
    }
```

Furthermore, to adjust the rotation speed of motors M_1 and M_2, one may variate the pulse width of PWM signals connected to EN1 and EN2, respectively.

Collision Detection

According to the timing of HC-SRF04 module, the collision detection of our smart vehicle can be determined as follows. Let D and T_{high} denotes the distance between our ultrasonic sensor and the nearest obstacle and the duration of high-level output from the ECHO port, respectively. We may approximate the distance D as follows:

$$D = \frac{T_{high} \times V_{sound}}{2} \tag{1}$$

where the speed of sound is denoted as V_{sound}, which is approximated by 340(m/s) in our implementation.

According to the datasheet of HC-SRF04, the minimal range of D is about 3 cm. However, this value must be calibrated according to the vehicle speed before it is put in use.

Automatic Roaming

Since the processing power offered by the MCU is not high, we choose a preprogrammed route approach to completing tennis ball collection over a half court instead of an optimal one. For example, an exhaustive search route shown in Fig. (**8**) started from the left of the court and ended by returning the vehicle to its original position after roaming the half court in a Zigzag pattern.

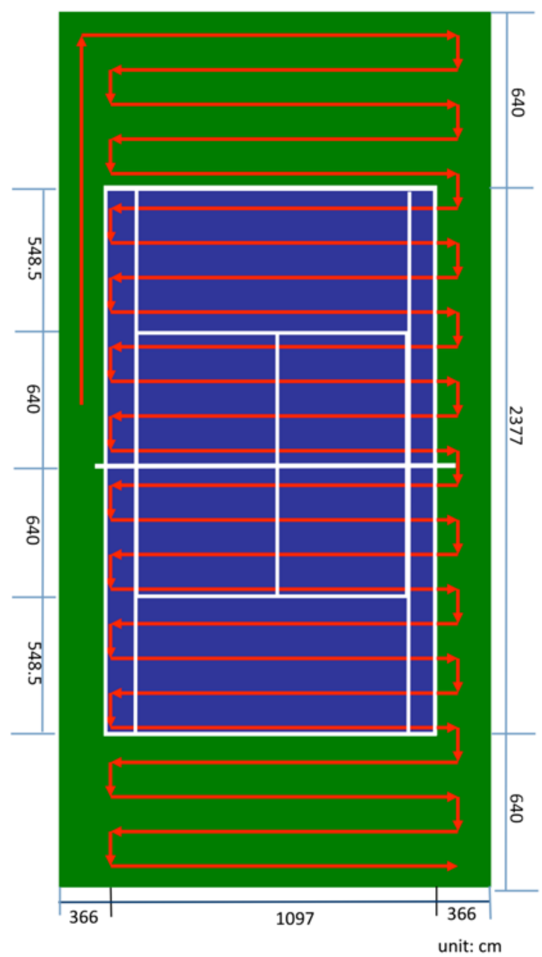


Fig. (8). An example of preprogrammed route for full-range automatic search.

To allow automatic roaming, server program must support collision detection to avoid colliding with the net, walls, or any obstacles. The amount of time taken to complete automatic roaming can be approximated by

$$T_{roaming} = \frac{L}{V_{vehicle}} + T_{turn} \times K \tag{2}$$

where $T_{roaming}$ stands for the total roaming time, L for the length of route, $V_{vehicle}$ for the speed of the vehicle, T_{turn} for the turning latency, and K for the number of turns.

If the vehicle speed is 0.5 m/sec and the vehicle turn latency is 1.5 seconds. For example, in a standard court, a preprogrammed route as the one shown in Fig 8 takes about

$$\frac{23.77 + 6.40 \times 2 + 10.97 \times 25}{0.5} + 24 \times 1.5 = 11 \text{ minutes.}$$

THE IMPLEMENTATION RESULTS

We have made a crude implementation of our idea using acrylic, angle steel, and the circuitry we have proposed earlier in this paper. A photograph of such implementation is presented in Fig. (**9**).

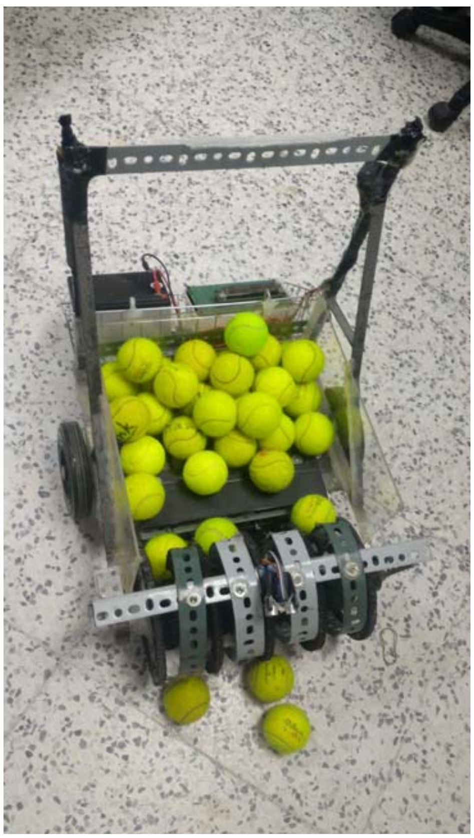


Fig. (9). A crude implementation of our invention.

To simulate the distribution of the tennis balls after a common stroke or serve practice, 30 tennis balls are randomly placed over a half court prior to the start of each test. In each test, the user has to guide the vehicle, using their smartphone, to collect the 30 tennis balls as soon as possible. According to the tests we have conducted, the amount of time is in the range of 4 to 15 minutes depending on the navigation control skill of the user, the number of obstacles, and the covering range of distribution.

In the automatic mode, our test results show that the amount of time taken to complete the tennis ball collecting by applying an exhaustive search over the half court is about 14 to 15 minutes. If the motors of higher speed are used, the amount of time can be reduced to less than 14 minutes.

However, with respect to the rate of successful collection, the experimental results revealed that the number of balls left beside the side walls or the net in the middle of the court may adversely affect the percentage of successful collection.

CURRENT & FUTURE DEVELOPMENTS

According to the experimental results, the collecting efficiency is greatly improved in comparison with labour work that usually takes more than 15 minutes. Minimal human intervention can be achieved by starting the collecting vehicle in automatic navigation mode following a preprogrammed route. Better efficiency can be acquired by interactive remote control through the touch-based interface of an Android-based smartphone. For example, in our experiments, the minimum task completion time for interactive control only takes around four minutes, which is significantly lower than the time for the automatic navigation using exhaustive search.

In comparison with modern vacuum [19] and robot- or vehicle-based tennis ball collectors [20-24], our design outperforms the others in the following aspects.

1. Adaptability: our tennis ball collector, made from resilient material and interconnected with four springs, is able to pick up a great variety of tennis balls in varying sizes.
2. Efficiency and extensibility: by cascading the basic collectors, our tennis ball collector can be easily extended to a multi-channel collector that can pick up multiple tennis balls at once. Hence, its efficiency is far better than existing vacuum [19] and robot- or vehicle-based tennis ball collectors [20-24].

Furthermore, with the more advanced touch-based interface of common Android smartphones, the experience of tennis ball collecting turns out to be an interesting task. Both the trainer and the trainees can rest comfortably beside the court either manipulating the smart tennis ball collecting vehicle interactively or simple starting its automatic preprogrammed route navigation. Hence, we may conclude that our system is successful.

In the future, a number of issues might be of interests to the reader. Firstly, for a preprogrammed route, what pattern of route minimizes the navigation time by reducing the chance of collisions and the number of turns? Secondly, if object recognition technology is deployed, how to compute an optimal route with respect to collecting time and energy consumption?

DISCLOSURE

Part of this article has been previously published in Computer, Consumer and Control (IS3C), 2016 International Symposium [29].

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are base of this research.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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