Developing an intelligent assistant for table tennis umpires

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DEVELOPING AN INTELLIGENT ASSISTANT FOR TABLE TENNIS UMPIRES

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ABSTRACT

This paper outlines the idea and plan of developing an intelligent assistant for table tennis umpire in evaluating services. Table tennis is a fast sport. A service usually takes a few second to complete but there are many observations an umpire needs to take and makes a judgment before or soon after the service is complete. This is a complex task and the author believes the employment of videography, image processing and artificial intelligence (AI) technologies could help evaluating the service. The aim of this research is to develop an intelligent system which is able to track the location of the ball from live video images and evaluate the service according to the service rules. This is a pilot study and the focus is on the development of the techniques, rather than building a complete system. Various videography, image processing and artificial intelligence techniques will be experimented and evaluated. When a prototype system is built, it will be compared and tested against the judgements of a human umpire. Both the accuracy and rate of responses will be concerned. Furthermore, as well as aiding umpire, the system could also benefit players who want to have their services evaluated in real time without the need of having a human umpire present.

1. INTRODUCTION

This is a pilot study regarding the development of an intelligent system in aiding table tennis umpires to make accurate judgment about services. A table tennis service usually takes a few second to complete. However, there are over ten observations an umpire needs to take and make a judgment before or just after the service is complete. This is a very complex task and requires a lot of judgments, even for an experience umpire [1]. With the help of image processing and artificial intelligent techniques, a computer system may be able to analyze the service and make a recommendation for the umpire to consider.

There are seven rules governing the service and they are listed in the International Table Tennis (ITTF) Handbook [2]. For the benefit of those who do not familiar with table tennis rules, the seven rules regarding the service are reproduced and listed in Table 1.

Table 1. Table Tennis rules regarding the service

Index	Description
2.06.01	Service shall start with the ball resting freely on the open palm of the server's stationary free hand.
2.06.02	The server shall then project the ball near vertically upwards, without imparting spin, so that it rises at least 16cm after leaving the palm of the free hand and then falls without touching anything before being struck.
2.06.03	As the ball is falling the server shall strike it so that it touches first his court and then, after passing over or around the net assembly, touches directly the receiver's court; in doubles, the ball shall touch successively the right half court of server and receiver.
2.06.04	From the start of service until it is struck, the ball shall be above the level of the playing surface and behind the server's end line, and it shall not be hidden from the receiver by the server or his doubles partner or by anything they wear or carry.
2.06.05	As soon as the ball has been projected, the server's free arm shall be removed from the space between the ball and the net. Note: The space between the ball and the net is defined by the ball, the net and its indefinite upward extension.
2.06.06	It is the responsibility of the player to serve so that the umpire or the assistant umpire can see that he complies with the requirements for a good service.
2.06.06.01	If the umpire is doubtful of the legality of a service he may, on the first occasion in a match, declare a let and warn the server.
2.06.06.02	Any subsequent service of doubtful legality of that player or his doubles partner will result in a point to the receiver.
2.06.06.03	Whenever there is a clear failure to comply with the requirements for a good service, no warning shall be given and the receiver shall score a point.
2.06.07	Exceptionally, the umpire may relax the requirements for a good service where he is satisfied that compliance is prevented by physical disability.

This paper focuses on two rules, 2.06.02 and 2.06.04. Rule 2.06.02 is notoriously difficult for umpires to judge. This could lead to inconsistent judgments between umpires.

In rule 2.06.02, two points are particularly difficult for a human being to judge. Firstly, it is hard to determine whether the ball is projected near vertically upward. Furthermore, the wording of "near vertically upward" is quite ambiguous. It does not state what degree of deviations is acceptable. The second difficult point of this rule is that it is sometimes quite hard for a human being to determine whether the ball rises 16cm after leaving the palm. Moreover, a service usually takes a few seconds to complete. Within these few seconds, the umpire has to make over ten observations and judge whether all the actions comply with the rules. This is not an easy task and the author believes the intelligent system could help umpire to make a better judgment.
The aim of this research is to develop an intelligent system which is able to track the location of the ball from a live-fed video link, measure how many degrees the ball deviates from a vertical line and measure how high the ball rises after leaving the palm. The system should also be able to check whether the ball goes under the playing surface or is hidden from the receiver. This is a pilot study. The focus is concentrated on the development of the techniques, rather than building a complete system. Therefore some of the details of a table tennis service will not be considered.

2. VIDEO IMAGES

As the system is primarily designed to aid umpires, the video should be taken at a position and an angle similar to the umpire's perspective. Figure 1 shows an example of the captured image, which was taken from the position of the umpire.

Figure 1. Umpire's view – A service is about to start. [Source: This image is extracted from one of the demonstration video files in the web site of the Umpires & Referees Committee of the ITTF]

The video should be filmed at a frame rate that is high enough to capture all the important movements of the ball but low enough to reduce processing time. A typical service takes two to three seconds to complete. The speed of the ball can go up to several meters per second during service. To determine the most suitable frame rate, several different frame rates will be experimented in this study.
The resolution of the image is another important factor that needs to be optimized. Again, too high the resolution will waste a lot of processing time, but too low the resolution will not show the details of balls and other objects.
During the development phase, we only consider services from one end (umpire's left hand side) of the table although services can come from both ends of the table. Instead of using live-fed video images, recorded video clips are initially used to develop the system. The principle of analyzing images from a live video input is the same as that from a recorded video clips. When the system is developed, live video will be used to test the system.

3. IMAGE PROCESSING

The video taken will be analysed by the system. The main task is to locate and track the ball from the images.
In a table tennis match, before the service starts, the server is required to place the ball on the open palm of his/her stationary free hand (the hand that is not holding the racket). The ball usually stays on the open palm for one to a few seconds before the service starts. This short pause of stationary can be used to identify the start of the service. The ball should subsequently be tracked until it is struck.
Locating the ball from the image could be achieved by searching through the image pixel by pixel until a pixel with a colour similar the ball is found. Then the surrounding pixels should be checked and see if they are also similar to the colour of the ball. If these pixels together form a circular shape object and has the size of the ball, we could assume this is the ball. However, if an object with similar colour and shape of the ball presents in the scene, it may confuse the system. Luckily, in a match environment, such object is not allowed to present as it may confuse the players as well. Furthermore, during a service the real ball should be in motion whereas other objects with similar colour are likely to be stationary.
Another problem with this technique is that when the ball is moving fast, it may appear to be oval rather circular. One way to combat this is to increase the frame rate so that moving objects will appear to be stationary in the image.
To determine whether the collection of pixels which match the target colour range is indeed the ball, a neural network is suggested to be employed. The network will be trained with various different balls and ball shape objects captured by the video images. More descriptions of neural networks will be shown in next section.
Once the location of the ball is established from the first frame, the ball needs to be tracked from sequential frames. Similar technique can be used to locate the ball but the area of the frame needed to be searched can be much smaller as the location of ball from the previous frame is known and

the ball is expected to be in the neighbourhood. Apart from the ball, the palm of the free hand may need to be identified as well so that the moment the ball leaves the palm can be marked. The tracking should be continued until the ball is struck.

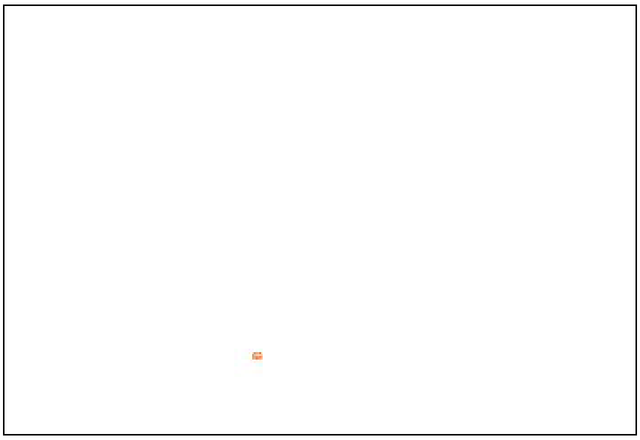

Figure 2a. The ball is extracted from Figure 1.

Figure 2b. The ball reaches the highest point of the service.
[Source: This image is extracted from one of the demonstration video files in the web site of the Umpires & Referees Committee of the ITTF]

When the ball reaches the highest point, the angle θ and the height of the rise should be measured. During the tracking, if the ball is found to be disappeared from one or more frames, this may indicate the view of the ball is blocked and rule 2.06.04 is violated. Figure 2 illustrates the above mentioned technique graphically. Firstly, Figure 2a shows when the ball was identified and extracted out of the image from Figure 1. Figure 2b is an image showing when the ball reaches the highest point of the service. Figure 2c shows the extraction of the ball from Figure 2b along with the ball from Figure 2a. Figure 2d illustrates the evaluation of the service, i.e. measuring the angle of the ball rise and height. The challenge here is that the analysis must be conducted very quickly. Ideally, the system should be able to make a recommendation within a second after the service is complete because if it is a fault service, the umpire needs to call out as soon as it is detected.

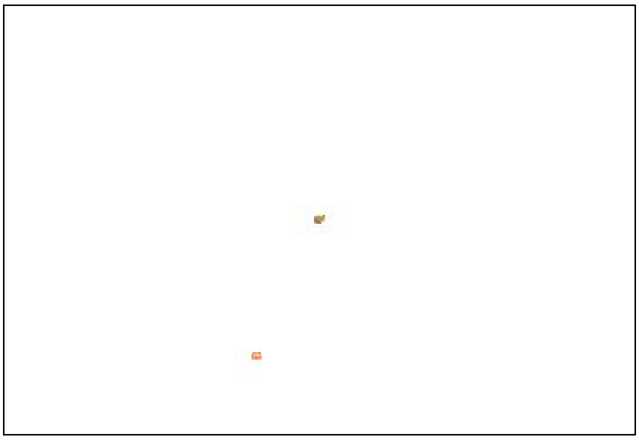

Figure 2c. The balls from Figure 2a and Figure 2b are extracted and combined in a picture.

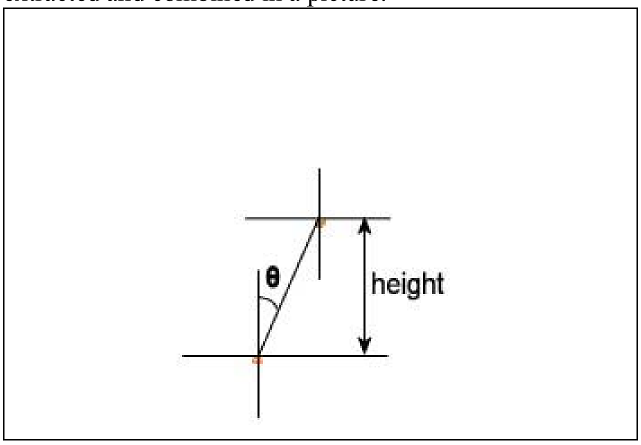

Figure 2d. Annotation are added to Figure 2c and showing how the angle and height are calculated.

4. ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANN) may be considered as a greatly simplified human brain. The network is usually implemented using electronic components or simulated in software on a computer. The massively parallel distributed structure and the ability to learn and generalise makes it possible to solve complex problems that otherwise are currently intractable. ANN is particularly good at classifying patterns. In this study, it is to be employed to determine whether a detected object is a ball and whether the ball is on the palm or in mid-air. A brief description of ANN and what and how neural networks are being employed is given below.

4.1. Neurons And Synapses

An ANN is a network of neurons connected by synapses. A neuron is an information processing unit that is fundamental to the operation of an ANN. Two basic elements can be identified from a neuron; an adder and an activation function. An adder simply sums up the input signals weighted by the respective synapses of the neuron. The activation function modulates the input signal according to a transfer function and can compress the permissible amplitude range of the output signal to some finite value. For some gradient descent learning algorithms, such as the Back-Propagation learning method (BP), the activation functions are required to be bounded and differentiable.[3] One of the most popular activation functions is the sigmoid function which bounds its output range between zero and one.

Synapses are simple connections that can either impose excitation or inhibition on the receptive neuron. Knowledge is acquired by the network through a learning process. The synaptic weights are used to store the knowledge. Through the learning process, the synaptic weights of the network are modified in such a way to map the input patterns to the output patterns.

4.2. Structure of Artificial Neural Networks

There are many possible network architectures available which govern how the neurons are organised and connected. However, one of the most popular network architectures is the feedforward networks, which is the network type this study intends to employ. The feedforward network is a network of neurons and synapses organised in the form of layers; usually consists of an input layer, one or more hidden layer(s) and an output layer.

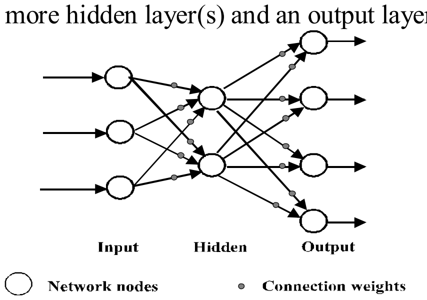

Figure 3. A 3-2-4 multi-layer feedforward network

The function of the input layer is simply to buffer the external inputs to the network. It supplies respective elements of the activation pattern, which constitute the input signals applied to the neurons in the hidden layer. The neurons in hidden and output layers however have processing abilities. The hidden neurons have no direct connections to the outside world. However, their roles are to preprocess the input signals and feed the processed signals to the next layers of neurons. These extra processing allows the ANN to be able to detect smaller features from the input signals. The output neurons combine these signals from the hidden neurons and further process them. Figure 3 shows the structure of an example multi-layer feedforward network.

4.3. Training and testing

A newly built ANN contains no useful knowledge. Before it can be used, it has to be “trained”. The training process is to modify the synaptic weights in such a way that the output signals become or close to the desired response. The training process is iterative and the weights are changed gradually in each cycle. During training, a special designed set of patterns (training patterns) which contains samples of different pattern types are inputted to the network. A pattern contains a number of input parameters and is sometimes called an input vector to the network. For feedforward networks, supervised training rules are usually employed. For supervised trainings, a set of desired output responses is associated with the training patterns. During this type of training, the actual output responses of the ANN are compared with the desired output responses. An error term is usually employed to describe the differences between the two responses. Supervised training rules use this error term to determine the direction and the magnitude of weight changes.

4.4. Application of ANN in detecting balls

In this study, the feasibility of employing ANNs to detect table tennis balls will be investigated. Two particular types of detections are crucially important to the success of this study. The first type of detection is to determine whether a detected object from a frame of the video is a ball. The second type of detection is to check whether the ball is on the palm of a player or in mid-air.

For the first type of detection, an ANN has to be trained to distinguish balls from other objects which have similar colour, shape and size of a ball. The sources of this type objects could be from the background of the match venue, spectators’ clothes and advertising materials. The trained ANN should also be able to positively identify a ball which has slightly different colour, shape and size from a prefect ball. To achieve this, the ANN must be trained by a training set which contains a large number of patterns which are derived from example images of the balls that are in slightly different colour, shape and size along with images of objects that could be misinterpreted as balls. Figure 4 shows example images of balls and ball-like objects that may be captured by the system. As can be seen from the figure, not all the real balls are in the same size because the distance the camera and the servers varied. The ball-like objects are mainly from logos and texts in the background of the images.

Real ball					
Ball-like objects	 logo	 text	 text	 logo	 logo

Figure 4 Example images of balls and ball-like objects that may be captured by the system.

For the second type of detection, a training set containing large number of patterns derived from various example images of balls which are rest on the palm and in the mid-air are required to be produced. When a ball is rest on a palm, the bottom part of the ball will be slightly hidden by the palm. This will make the image of the ball captured by the system appeared to have a missing base. Whilst the ball is in mid-air, the image of the ball should be round and circular. An ANN will be trained to detect these differences. The trained ANN should be able to indicate whether a given ball image is captured from when the ball is rest on a palm or in mid-air. Figure 5 shows example images of balls which are rest of a palm and in mid-air. Balls that are rest on the palm are partly blocked by the palm and as a result the bottom half of the balls are missing or appeared to be flatter.

Balls rest on palm				
Balls in mid-air				

Figure 5 Example images of balls which are rest of a palm and in mid-air.
[Source: Images of the balls are extracted from the photo gallery of the ITTF web site]

The image of the balls captured by the system can be in different sizes if the distance between the video camera and the server varies. The server is in fact allowed to start the service at different places. If the size of the image of the ball varies, it is difficult for an ANN to process as the number of input neurons of an ANN is usually constant. Hence, a preprocessing algorithm is required to convert an image of a ball into a training pattern which has fixed number of inputs. One way to achieve this may be to resize the image of the ball captured by the system into a fixed size image, e.g. 20x20 pixels. The training patterns can then be derived from the fixed image. For example, a training pattern can be constructed of a series of 400 numbers which corresponds to each individual pixel of the fixed image. Figure 6 illustrates how a training pattern is derived from an image of a ball.

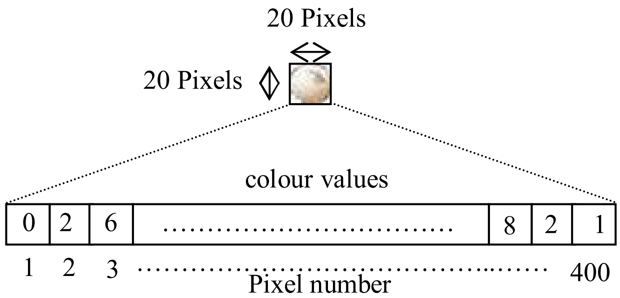

Figure 6 A training pattern derived from an image of a ball.

5. DISCUSSION

Technologies have been applied in many sport events for decades. However, almost none has been applied in table tennis umpiring. On the other hand, computational technologies and image processing have been advanced so quickly and so much in the last two decades. The cost of the related equipments has become much more affordable. Given table tennis umpiring is becoming more difficult (because of the new service rules), the author feels that computational technologies may be applied to aid umpires making more accurate decision on services.

However, table tennis is a fast sport. A service can be completed within a few seconds and umpires required to make a decision about the service soon after the service. If the system is to be of any use, it has to be able to evaluate a service through live video images in real time and produce an indication before the service is completed. This is a challenging task. The system has to be able to identify and track the ball, calculate the height of the ball rise and the angle and produce an indication within a second or so. Particularly, the image processing tasks as described in Section 3 have to be achieved very efficiently. Filtering and enhancement techniques could help identifying the ball but they will increase the processing time. Likewise, the frame rate and resolution of the capturing video have an impact on the quality of the video and the processing time. These factors will be experimented and identifying the balance points of these factors will be attempted. AI techniques will be employed in this project. ANN will be used to confirm whether a ball shape object captured is indeed a ball and confirm whether the ball has left the palm. As table tennis rules are revised from time to time, they may be changed in the future. It is therefore desirable to implement the system as a rule based system. As the rule base and the control module are separated into two units, it allows the system developer to update rules more efficiently.

When a prototype system is built, it will be evaluated and tested against the judgements of a human umpire. Both the accuracy and response rate will be concerned.

This pilot study mainly investigates the feasibility of the technologies employed. If this proves to be promising, further development of the system will be attempted so that it could evaluate the whole service. The most challenging part will be to check if the service complies with Rule 2.06.05, which involves identifying the server's free arm and tracking its movement. Detecting whether the palm of the server is fully open and the ball is resting stationary in the middle of the palm rather than on the fingers (Rule 2.06.05) is also a very challenging task.

Ultimately, the author wishes to be able to produce a system which could umpire or aid umpiring a table tennis match. It is not intended to replace a human umpire with a computer system but to help making the umpiring more robust. Furthermore, as well as aiding umpire, the system could also benefit players who want to have their services evaluated in real time without the need of having a human umpire present.

The same techniques may also be adapted and applied to other sport, especially racket sports such as tennis and badminton.

6. ACKNOWLEDGEMENT

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