Net touching detection by sensing displacement

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Abstract: there is a need for a device to detect net touching in table tennis. However, there are a number of challenges in the design of such a device. In a detailed investigation of the net touching process, it is found that the device should target small displacement of the net when the ball is moving in a horizontal direction over the net. In an experiment using a specially designed instrument, it is found that most players will be able to notice a net displacement of 0.4mm or more. Hence a net displacement sensor should be able to achieve a sensitivity of 0.4mm. Amongst the various transducers commercially available in the market, none can readily satisfy all the design requirements. The transducer technology developed in K-Square Design is to optically sense the displacement of a small film with sub-millimetre chequered pattern printed and with connection to the net. Merits of this design include digital displacement sensing, reliable sensitivity, no need for calibration and small size. This design is implemented using a subminiature transmissive IR optical sensor and digital integrated circuits. An ultra bright LED is used to signal net touching. The sensitivity achieved for the hand made prototype is better than 0.4mm with much room for improvement. With a promising technology in place, it is proposed that consideration be given to objectively define the meaning of net touching.

Keyword: net touching detector, optical displacement sensor.

1. INTRODUCTION

The rule of table tennis requires that whenever a served ball touches the net, it has to be served again [1]. However, there is no objective definition of net touching. This is usually left to the judgement of the umpire, if there is one. Inevitably, this often causes disagreement among players and the umpire.

Compared with other ball sports, the table tennis ball is probably the smallest and lightest. The following factors have made the design of a practicable net touching detection device for table tennis particularly challenging:

(a) The ball is moving at a very high speed.
(b) Unless the overlap of the ball and the net is substantial, the effect of net touching on the ball and the net is very hard to notice.
(c) The device should be able to give real time response to net touching so that the progress of the game is not affected and it should be easy to use.
(d) The components of such a device should not interfere with the game, players and umpire. Hence, they should not be big or heavy enough to affect the ball and net
(e) The technology should be safe to everyone including spectators. Hence laser technology is not preferred.
(f) The device should be sensitive enough to detect hard to notice net touching, precise enough to give consistent and credible detection result, and yet careful adjustment or calibration should not be required before using.
(g) The power consumption of the device should be very low so that it can work on battery for extended period of time.
(h) The technology used should enable low cost mass production of the device.

2. ANALYSIS OF NET TOUCHING

2.1 Displacement of net

It is essential to investigate carefully the net touching mechanism before embarking on the design of a net touching detection device. Theoretically, when the ball touches the net, there is a collision between the ball and the net. The basic laws of physics dictate that there will be changes to the velocities of the ball and the net which is initially stationary. When the overlap between the ball and the net is significant, the ball will be seen to be deflected and the net displaced noticeably. However, when the ball is fast and the overlap is small, the deflection of the ball and the displacement of the net will be very small. As it is much more difficult to detect the small deflection of a fast moving ball, it makes sense for a net touching detection device to aim at the detection of the displacement of the net.

2.2 Direction of ball

In table tennis, the need to detect net touching is when serving. In most cases, the ball is served as low as possible to make it hard to be attacked by the opponent. This means that the highest point of the trajectory of the ball is usually at a position just over the net. As shown in Fig. 1, the direction of the ball changes from upwards to downwards at its highest point and is therefore very close to horizontal when it is at a point vertically above the net.

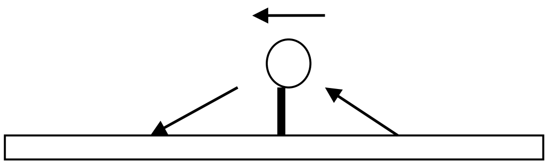

Fig. 1 Direction of ball when over the net

2.3 Magnitude of net displacement

In order to analyse the displacement of the net, there is a need to find out the magnitude and direction of the displacement of the net. An experiment was designed to find out the minimum magnitude of net displacement observable by an average table tennis player. Fig. 2 is a picture of an instrument specially designed for this purpose.

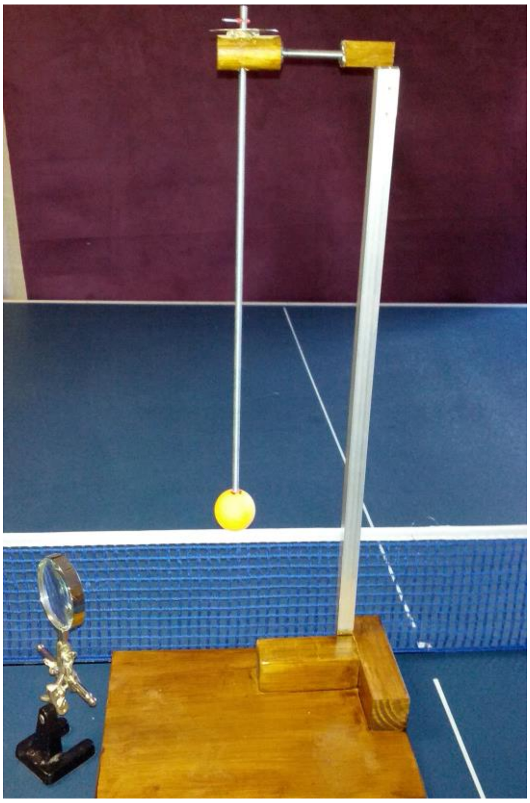

Fig. 2 Instrument designed to cause net displacement

It is basically a pendulum with a yellow standard 40 mm ball fixed to the end of a threaded rod. The pitch of the thread is 1.2 mm per turn. Hence, a 30 deg rotation of the rod will change the length of the pendulum arm by 0.1 mm, that is, shift the position of the ball 0.1 mm longitudinally. With the help of a magnifying glass, the length of the pendulum arm was carefully adjusted so that the ball was on the verge of touching the net. Hence, turning the threaded rod by a further 30 deg will result in a 0.1 mm overlap of the ball and the net. Obviously, the overlap is also the magnitude of displacement of the net.

The experiment was conducted in a club environment with normal playing lighting. A total of 10 players were invited to observe the swinging of the ball with various overlap of the ball and the net. They were experienced amateur players and regular participants of club level events. Each time, one to two players stood at one end of the table trying to observe any displacement of the net from the angle of the player. For each value of overlap, the ball was swung 10 times, 5 towards the observer and 5 away from the observer. The observers were not told if there would be any net touching but were requested to note the number of times they could see it happen. Fig. 3 shows the percentages of net touching claimed to be observed by the participants for various amounts of overlap of the ball and the net, that is, the magnitude of net displacement.

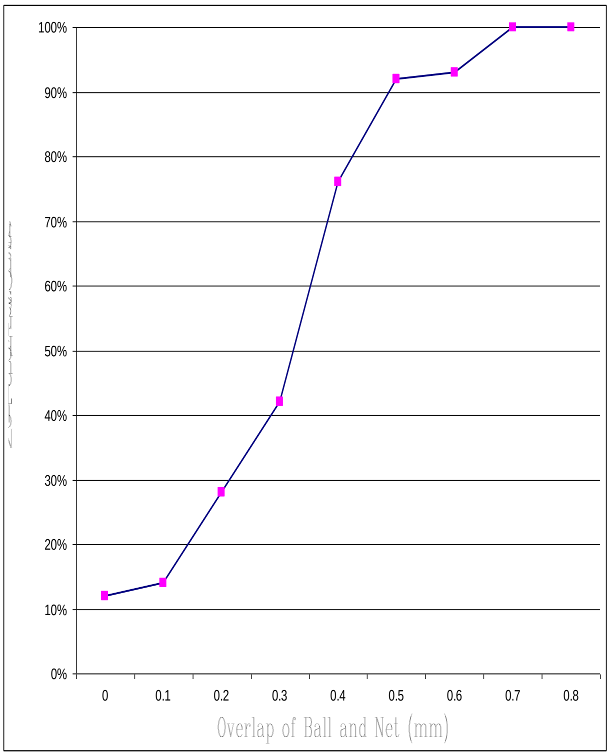

Fig. 3 Percentages of net touching observed

Each dot in Fig. 3 represents the percentage of observed net touching for a total of 100 swings (10 swings per observer times 10 observers) of the ball. The following observations can be drawn from the graph:

(a) Even when there was in fact no net touching, a few observers still claimed that net touching was observed. This resulted in the 12 % positive observation when there was in fact no overlap.

This may be due to the observer's expectation that there would be net touching.

(b) When the overlap was equal to or smaller than 0.2 mm, most observers could not see the minute displacement of the net.

(c) There was a big jump in observed net touching when the overlap was increased from 0.3 mm to 0.4 mm.

(d) When the overlap was equal to or more than 0.4 mm, most observers could see the net displacement.

(e) When the overlap was more than 0.6 mm, all observers could see the net displacement.

It should be noted that during the experiment, the observers only focused on the single point that the ball was about to touch the net. Hence it is likely that they could notice net touching better than in the situation of a competition in which they have to time share their focus on the opponent and their own strokes.

As most players will be able to notice a net displacement of 0.4 mm and more, it is considered necessary for the detector to be able to signal a net touching for all net displacements of 0.4 mm and more. In technical terms, this means that the sensitivity of the detector should be 0.4 mm. However, it should be noted that such a detector may still be able to detect a smaller displacement although it is not guaranteed.

2.4 Direction of net displacement

Obviously, the direction of displacement of the net caused by net touching cannot be along its length. It can only be horizontally forward and/or vertically downwards. As established in subsection 2.2 above, the direction of the ball when over the net is very close to horizontal. For a small overlap, say, 0.4 mm, and when the ball continues its horizontal motion without bouncing off noticeably, the displacement of the net should therefore be mainly vertically downwards so as to give way to the horizontal forward motion of the ball.

3. DISPLACEMENT SENSING TECHNOLOGIES

3.1 Available technologies

There are a number of technologies capable of sensing small displacements. For example, high speed video camera can be used to monitor the movement of the net. However, it is very difficult to give real time response as the system usually requires some manual operation especially when monitoring any sub-millimetre displacements. Any delay in judging net touching will affect the progress of the game. Furthermore, this option is too expensive to be used in weekly club events. Other technologies making use of commercially available transducers are usually based on continuous change of physical characteristics such as capacitance, inductance, resistance, frequency, voltage, or the time for a wave signal to be bounced back which are all analogue by their nature. As a result, these transducers are susceptible to interference. Furthermore, when the required sensitivity is down to sub-millimetre level, complicated electronics is usually needed and this will increase the cost of the detection device substantially.

Another widely available type of motion transducer is MEMS (Micro Electro-Mechanical System) which is mainly used in smart phones as motion sensor. It is small, accurate, cheap and easily available. However, the major drawback is that it is in fact accelerometer that senses analogue acceleration. Assuming the acceleration of the net is constant during the net contact, Eq. (1) relates acceleration to displacement:

$$s = 0.5\, a\, t^2 , \qquad (1)$$

where s is displacement, a is acceleration, and t is duration of contact.

As s depends on both a and t, the use of accelerometer requires the knowledge of t as well. Besides being very small, t is very difficult to be measured accurately in the case of table tennis. Even when it is measured, its error of measurement has a greater effect on the value of s than a as shown in Eq. (2).

$$\text{\% error in } s = (\text{\% error in } a) + 2\,(\text{\% error in } t) \qquad (2)$$

3.2 Principle of operation of the optical displacement transducer

An optical displacement transducer particularly suited to net touching detection in table tennis has been developed by K-Square Design. A small piece of negative film is optically printed with chequered pattern of 0.4 x 0.4 mm squares. It is connected to the top edge of the net by a very fine nylon string so that it is suspended between an Infra-Red Light Emitting Diode (IR LED) and a photo-transistor. The aperture of the photo-transistor is only 0.3 mm wide. Hence a single square (either opaque or transparent) of the chequered pattern of the film can completely cover the aperture. If the aperture is covered by an opaque square, no IR can reach the photo-transistor which will then be in the off state. If the aperture is covered by a transparent square, the IR reaching the photo-transistor will turn it on. As any displacement of the top edge of the net will cause the same displacement of the small piece of film, there will be a change in the type of square covering the aperture whenever the displacement is no less than 0.4 mm. Hence there will also be a change in the state of the photo-transistor. If the displacement is smaller than 0.4 mm, the change in intensity of IR reaching the photo-transistor may not be sufficient to cause it to change its state. The design is illustrated in Fig. 4.

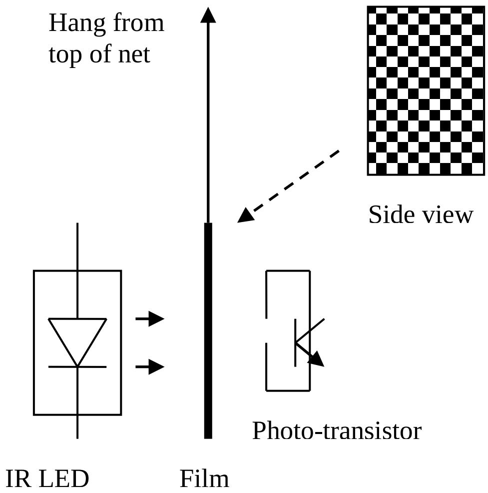

Fig. 4 Design of the optical displacement transducer

3.3 Features of the optical displacement transducer

There are significant advantages in the design of the optical displacement transducer described in subsection 3.2:

(a) The sensitivity of displacement is determined by the size of the small squares of the chequered pattern. As the pattern is optically printed on the very high resolution negative film, the sensitivity is very consistent even in mass production and no calibration is needed. In fact, the required sensitivity is designed into the pattern which is generated by computer and can be changed easily.
(b) The displacement is digitised at the very source and the digital output is highly immune to electromagnetic interference (EMI).
(c) By counting the number of transitions in the state of the photo-transistor, the amount of displacement can be quantified. This digital quantity may be needed to implement a future net touching rule.
(d) This transducer is equally capable in detecting displacements in the vertical and horizontal directions.
(e) There is no need to make adjustments to the transducer before using. The exact initial position of the film relative to the photo-transistor is unimportant.
(f) The associated electronics is relatively simple and inexpensive.

4. THE PROTOTYPE DEVELOPED

4.1 System overview of net touching detector

The detector is designed to be small, simple and easy to use. Fig. 5 shows the major building blocks of the entire detector. In the prototype developed, up to two sensor inputs can be connected. They are mounted under the table at the foot of the net so that they are unlikely to interfere with the net and ball. Their footprint on the surface of the table is small and not eye-catching. They are appropriately spaced along the length of the net so that net touching at different points of the net can be detected. The sensor units are connected by under-the-table cables to the main unit which houses the electronics. Pressing a power-on button once will turn on the detector for about one hour. This auto-power off feature will avoid accidental draining of the battery. Any detected net touching is signalled by an ultra bright LED which will glow for a short while.

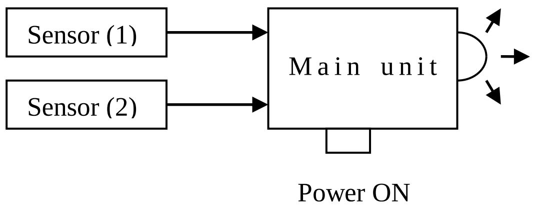

Fig. 5 Building blocks of net touching detector

4.2 Design of the electronics of the detector

Digital electronic integrated circuits have been used to implement the design. For the critical sensor unit, a subminiature transmissive IR optical sensor component (Fig. 6) has been chosen [2]. This sensor component includes the IR LED and photo-transistor, and the whole component measures only 5.5 x 4 x 4 mm and therefore enables a small sensor unit to be built.

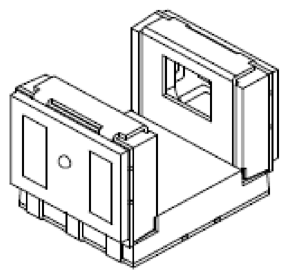

Fig. 6 TCPT1300X01 by Vishay Semiconductor

With reference to the block diagram of the electronic circuit in Fig. 7, the signals from the two sensors are first buffered by Schmitt triggers which hysteresis characteristic will eliminate oscillation when the input is around the threshold level. Each of the on-off and off-on transitions of the Schmitt triggers is converted into a negative going pulse with fixed pulse width by the edge detector and pulse generator. This pulse is used to trigger a timing control circuit which will turn on an ultra-bright LED for a short while to signal net touching. A separate power-on push button will turn on the power supply to the IR LED of the transducer which is responsible for the majority of the power consumption supplied by a pack of four AAA alkaline batteries. Hence, it is designed to be turned off automatically after an adjustable time delay. As the other parts of the circuit are built with very low power CMOS integrated circuits, there is no need to turn them off.

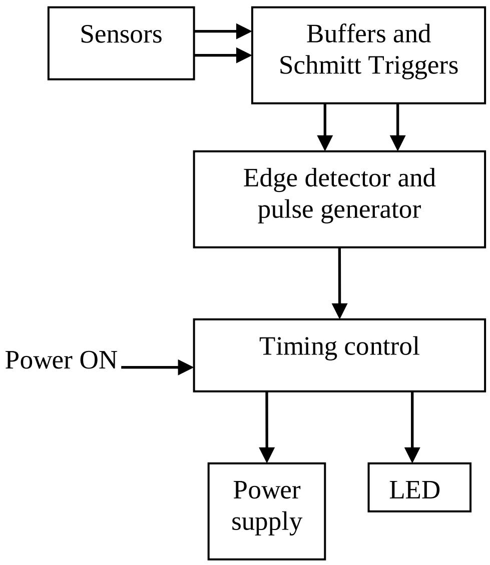

Fig.7 Block diagram of electronics

4.3 Features of the prototype

For the hand-made prototype as shown in Figs. 8 and 9, the followings are the main features:

(a) sensitivity of 0.4 mm for displacement both vertically and horizontally,
(b) sensor units mounted under the table at the foot of the net will not affect the ball and net,
(c) hardly visible linkage between sensor and top of the net by very fine nylon thread,
(d) support of multiple sensors installed at multiple positions along the net,
(e) no need to adjust before use once installed properly,
(f) auto-power off after 1 hour (adjustable),
(g) ultra-bright LED indicator for net touching,
(h) four AAA alkaline batteries provide up to 400 hours of operation (depending on number of sensors connected), and
(i) small dimensions for main unit (90 x 53 x 30 mm) and sensor unit (20 x 12 x 105 mm).

In the testing of the prototype, it was able to detect all net displacements of 0.4 mm and more. Even when the displacement was down to 0.3 mm, it was still able to detect in about half of the time. This is due to the fact that the aperture of the photo-transistor is only 0.3 mm. When the chequered film is just at the right position, a further 0.3 mm displacement is sufficient to switch the state of the photo-transistor.

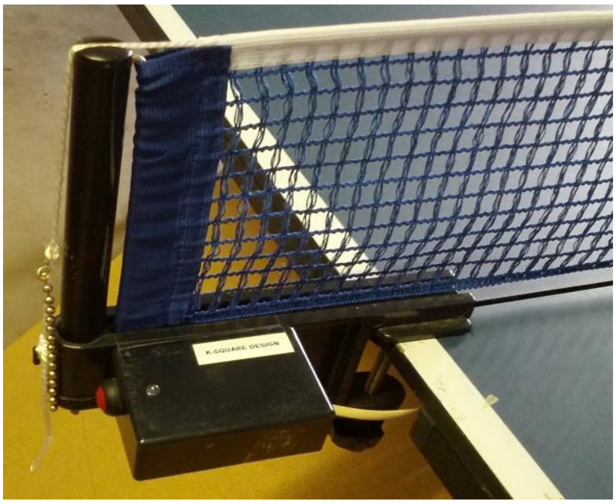

Fig. 8 Main unit

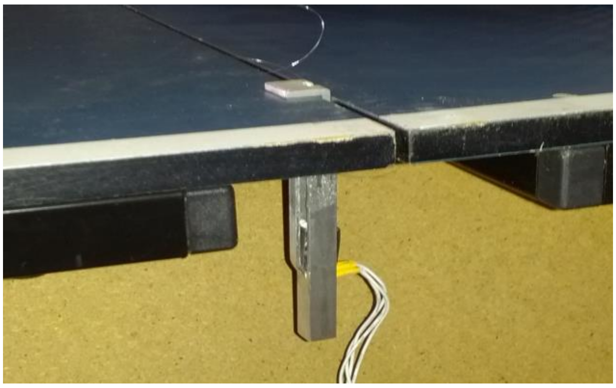

Fig. 9 Mounting of the under-the-table sensor unit

4.4 Further improvements

The following improvements to the current design have been planned:

(a) replacing the discrete electronics by a low power microcontroller to increase the flexibility in features and functionality, and
(b) modifying the design of the sensor unit to further improve the achieved sensitivity.

5. CONCLUSION AND RECOMMENDATION

The use of a small piece of negative film with sub-millimetre chequered pattern on it has enabled the design of a reliable optical displacement transducer with very high sensitivity. As demonstrated by the prototype, this design can make possible the production of a practical net touching detector. The wide spread use of such a precision instrument in the humble sport of table tennis will significantly enhance the image of the sport. Not only will it make the game fairer, but also seen to be fairer. However, the key to turn all these into reality is held by the world governing body of the sport. The formulation of an objective definition of net touching based on quantified displacement of the net, or the specification of the technical requirements for the approval of a net touching detector is instrumental in the development of such a device and its popular use.

6. ACKNOWLEDGEMENT

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REFERENCES

[1] The Laws of Table Tennis, ITTF Handbook 2012/2013

[2] Product description of TCPT1300X01 by Vishay Semiconductors (Rev. 1.9, 04 Oct 2011)