

Development of service sensor tools on table tennis net

KAMAL FIRDAUS¹, DEBY TRI MARIO²

^{1,2}Department of Sport Education, Faculty of Sport Science, Universitas Negeri Padang, INDONESIA

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Abstract

Service in table tennis is one of the important indicators to rely on for winning the competition. However, nowadays coaches or referees do not have an accurate instrument to assess the service in table tennis due to the limitation of supporting tools like sensor technology. This research is the research and development and intends to develop a service sensor tool on a table tennis net that can be used for learning or during table tennis matches. Also, it aims to produce a product and test its effectiveness. Four stages guide such process, that is tool design, circuit making, program development, and tool testing. We used the adapter 220 v (12 Vdc) 2A, Arduino Uno, SW 420 vibration sensor, step down DC-DC voltage drop, and 1 ch relay driver as the material. These aforementioned components were designed, assembled, and both programmatically and physically installed on the table tennis net. After going through all steps, the new tool was validated by different experts, mainly electrical engineering experts, table tennis experts, and table tennis referees in the wake of determining its weaknesses and usefulness. Then, it underwent field trials on table tennis athletes who competed at the regional level for sports week events in West Sumatra, Indonesia. Results of the expert validity test obtained 89.81 or very good category. Besides, the results of field trials show that the service sensor detects all service balls especially when they touch the net. Based on the data harvested, the results of the tool's reliability test were very high. That said, the tool can accurately, objectively, easily, and practically assess and also be used in learning or during table tennis matches to make it easier for assessing performance and services.

Keywords: table tennis, sensor technology, service, net

Introduction

Table tennis is one of the mandatory lessons integrated into the physical education programs in higher education for sports students. It is classified as an anaerobic-aerobic sport. Anaerobic is related both to the structure of the game and the tempo of the game. While aerobics one generally related to the duration of the game or competition (Loh & Krasilshchikov, 2015). The game is score dependent, which includes multiple rallies with multiple strokes (average of 4.0 strokes per rally) (Belli et al., 2019). The athlete's ability to properly hit the ball is the key indicator that predicts the winning match (Iino & Kojima, 2016). These efforts include leg movements with short accelerations and decelerations, and arms to make strong punches (Padulo et al., 2016a, 2016b). Yet, ball speed and hitting accuracy in table tennis are the two main and dominant factors that determine or predict the outcome of the match (Girard & Millet, 2009; Rota et al., 2014). Players with high technical ability will have good movement coordination, and control the power of the stroke, control the speed of the ball, as well as the speed of rotation of the ball (Bańkosz & Winiarski, 2018).

Apart from that, service stroke is believed to be one of the important indicators that players need to have in table tennis (Fuchs et al., 2018; Malagoli Lanzoni et al., 2014; Tamaki et al., 2017; Zhang et al., 2013, 2018). It is a form of acquisition of knowledge that needs to be trained and taught through various appropriate training programs. Then, a well-designed learning program (training) will get maximum results or better achievement (Firdaus, 2015a, 2015b, 2016; Mario, 2017). It is worth mentioning also that an effective application of service and the return of serve by the opponent are key success factors in the game of table tennis at the elite level (Munivvra et al., 2015). The many variations of service players have, make it difficult for opponents to anticipate the arrival of the ball. In other words, the ball returns by the adversary become easier to turn off (Ibrahim et al., 2020; Li & Yang, 2020). This effective serve and return are controlled by the spin, speed, and direction of the ball (Katsikadelis et al., 2013). Therefore, the service techniques are needed to be taught by the teacher (coach), since it has been proven as an outstanding indicator to win table tennis matches (Katsikadelis et al., 2013).

Nowadays, many teachers (coaches), and referees do not have accurate data to make policies or make decisions about service scoring in table tennis. One of the reasons is the limitation of technology-based supporting tools (Ihsan et al., 2020, 2021; Komaini et al., 2021, 2022; Rifki et al., 2022). Without technology, it is somehow impossible for athletes to achieve optimal performance. Moreover, the use of technology in terms of measurement is highly recommended to reduce errors in data collection. As such far, cutting-edge technology

Figure 1 depicts the components needed during the development of a service sensor tool on a table tennis net. All of these components are well assembled and fixed one another so that they can accurately detect service faults and mitigate undesired mistakes in table tennis.

Participant

This research involves three experts who are competent in their fields, namely an electrical engineer, a table tennis expert, and a table tennis referee. Their main role is to validate the so-called instrument through testing stages so that its weaknesses and strengths/advantages of the designed product are known. Then, two table tennis athletes from Gunung Pengilun were used as the initial trial data. While athletes competing in regional sports week events throughout West Sumatra as the final trial data, which was 8 matches in aggregation. The criteria for participants are aged between 14-17 years and have participated in several table tennis competitions (at least in regional student sports week).

Procedure

The procedure in this study consisted of four main stages.

- Stage 1: tool design. In this process, device design, electrical circuit design, and the coding stage for the microcontroller are carried out. The design of the tool uses a vibration sensor, which functions as a detector when the net rubs against the ball. Three vibration sensors are installed on the net. The sensor used is a type of SW420 vibration sensor with digital data.
- Stage 2: network creation. Implement a series of block designs that have been designed in the previous stage, it is then implemented on a circuit board. The design of the tool is made simple, easier to use, and placed on a table tennis system that does not yet use a net detector. We create circuit designs and PCB layouts using the EAGLE autodeck application.
- Stage 3: programming. Coding is a sequential and repeated command line that is continuously carried out by the microcontroller. We use an Arduino microcontroller as the main controller, which functions as a vibration sensor data reader and processes the data based on the number of vibration intervals. Then, the vibration interval data is converted into the form of output (digital reading).
- Stage 4: tool testing. The test was carried out with several experiments involving instrumentation experts to find out the weaknesses and advantages of the designed tool. After that, the resulting tool was tested for use in the field. The trial process consists of two stages, namely the initial stage and the final stage. In the initial stage, it is carried out for two consecutive days, where the athlete serves, and the number of times the sensor detects when the ball hits the net is counted. Furthermore, the final stage was tested in regional student sports week matches with the same scoring system.

Statistical analysis

Validity analysis of the new product was based on descriptive statistics, namely calculating the percentage level of the feasibility of the tool. Then, the reliability test is based on calculations from several trials (early stage and final stage), with the criteria of the service sensor being able to detect when the service ball hits the net.

Result

Tool Validity

Validity measurement is operationally defining the concept that is measured up to the creation of a service sensor device on a table tennis net.

Table 1. Expert validation

Indicators	Electrical engineer		Table tennis expert		Table tennis referee		Average indicator
	Score	%	Score	%	Score	%	
Arduino uno runs smoothly, receives, and displays vibration results from the ball	4	11.11	4	11.11	4	11.11	11.11
The vibration sensor can receive the results of the touch of the table tennis ball smoothly, and send the results to the arduino uno	4	11.11	4	11.11	4	11.11	11.11
Service sensor size on table tennis net	3	8.33	3	8.33	3	8.33	8.33
Rubric tool design setup	3	8.33	4	11.11	4	11.11	10,19
Sensor layout to detect service ball	4	11.11	3	8.33	3	8.33	9.26
Instrument led size	3	8.33	3	8.33	4	11.11	9.26
Sensor circuit schematic	3	8.33	4	11.11	4	11.11	10,19
User effectiveness	4	11.11	4	11.11	3	8.33	10,19
Valid accuracy test results	4	11.11	3	8.33	4	11.11	10,19
Score	32	88.89	32	88.89	33	91.67	89.81
Maximum score	36	100.00	36	100.00	36	100.00	100.00

Table 1 shows that the overall average percentage of expert validation is equal to 89.81% which is presented in the following histogram below:

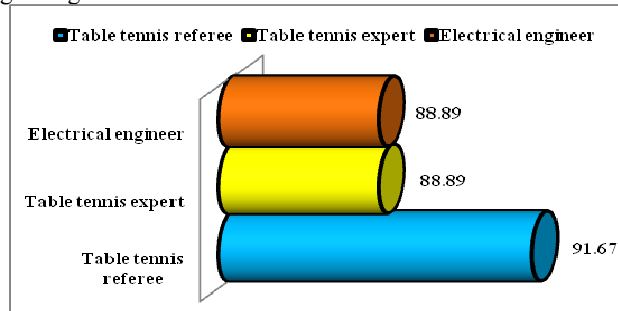


Figure 2. Percentage of expert validation assessment

Figure 2 showcases the percentage of assessments from electrical engineering experts and table tennis experts which stands at 88.89%, whereas the percentage of table tennis referees felt at 91.67%. In other words, based on these highlighted results above, the service sensor tool on the table tennis net is feasible and fulfillsthe requirement in order to proceed to the next step as the implementation for field trials.

Tool Reliability

After the feasibility test of the tool wasverified and fulfilled, the designed tool was tested in the field. This stage was divided into two main stages; that is the initial and the final stage of the trials.

Table 2. Results of the initial trial

Initial trial	Subject	Rep.	Test	Try the ball that hits the net	Response light on	Lights off
	Table tennis athlete Gunung Pengilun, Padang, West Sumatra, Indonesia	1	First day	50 times	50 times	0
		2		50 times	50 times	0
		1	The second day	50 times	50 times	0
		2		50 times	50 times	0
Total				200 times	200 times	0

As described in Table 2, the results of the initial trials (first and second day) with 50 trials each, the service sensor device on the table tennis net detects when the service ball hits the net. This is indicated by the lights on, and no lights going out when the service ball hits the net. Furthermore, the results of the final stage of the trial showed the same results during the table tennis match of the regional student sports week, West Sumatra, Indonesia (Table 3).

Table 3. The results of the final test of the tool

Final stage trial	Subject	Competition	The ball hits the net during the game	Response light on	Lights off	Match duration
	Table tennis regional student sports week competition, West Sumatra, Indonesia	1	6 times	6 times	0	5 sets
		2	5 times	5 times	0	5 sets
		3	4 times	4 times	0	3 sets
		4	3 times	3 times	0	3 sets
		5	7 times	7 times	0	4 sets
		6	6 times	6 times	0	3 sets
		7	5 times	5 times	0	3 sets
		8	5 times	5 times	0	5 sets
Total		41 times	41 times	0	31 sets	

Based on data in Tables 2 and 3, it can be said that the level of tool reliability is 1.00 (very high/strong). In other words, the service sensor tool on the table tennis net is reliable and consistent with data collection.

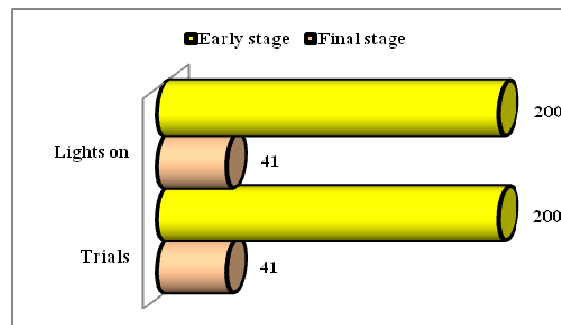


Figure 3. Histogram of test results for the initial and final stages

Figure 3 explains the comparison of the overall results between the initial and final stages of the trials. In the initial stage, the total is 200 trials. While in the final stage the total number of balls touching the net during the match amounted to 41 times.

Final Form of Product developed

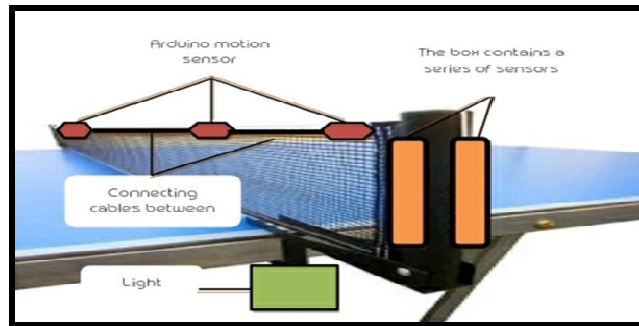


Figure 4. Final shape of the product

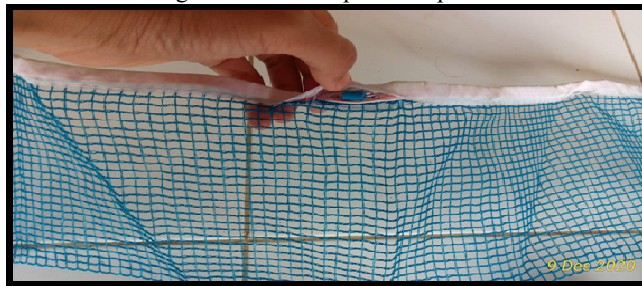


Figure 5. Sensor placed in a fold of white tape

The electronic components attached to the table tennis are well designed and fixed. The red Arduino vibration sensor is mounted in a white fold of the net (Figure 5). This is intended so as not to interfere with the course of the game/match. Then, the red lights on the side of the net pole are neatly installed to make it look attractive. The box (Figure 4) is a series of all table tennis net sensors. The box is taped under the table tennis court.

Discussion

Based on the results of the research we conducted, the results of the validity test from the experts met the requirements and were in the very good/decent category. While the results of the reliability test show that the service sensor tool on the table tennis net is reliable and consistent in data collection (all lights turn on when the service ball hits the net). This service sensor tool is a tool for teachers (coaches) and referees when leading a table tennis match. These results are consistent with previous research, which reported that sensor technology can help both the learning and the training process (Bańkosz & Winiarski, 2020). Other studies also reported that technology is widely used to improve and support training, as well as develop elite and amateur sports (Camomilla et al., 2018; Matsuoka & Latzka, 2019; Oh et al., 2019), and thereby sports coaching must be based on science and technology (Firdaus, 2011). Another study also states that the presence of technology can make learning more efficient (Hussin, 2018), and help success in teaching (Shoraevna et al., 2021).

Worthy to mention also that, sensor-based technology has the characteristics of portability, low cost, and ease of use (Sha et al., 2021). In accordance with the results of previous studies, sensor-based technology enables to detection of table tennis strokes in time-series data, and the classification of each stroke into the correct type of stroke category (Blank et al., 2015). Sensor technology can also measure the speed and spin of the ball in table tennis (Blank et al., 2017). Another study also reports that the use of sensors allows for better and sharper data quality (Izzo et al., 2022; Nogueira et al., 2020). Nevertheless, the measuring instrument that we developed is inseparable from its shortcomings. In addition, our research did not reach the stage of mass production, because it requires a company as a business partner, and requires a fairly large cost. Another drawback is that there is no comparative instrument so far. To our knowledge, this is the first study to use a service sensor device on a table tennis net. Therefore, we emphasize that this tool only detects service errors when the ball hits the net, not detects service skills/movements.

Conclusions

The conclusion from the results of this present study is the design and the development of a service sensor tool on a table tennis net. This service sensor is used to detect service errors especially when the ball hits the net. Before getting used, this tool has been validated by experts who are competent in their fields, with a

cumulative validity score of 89.81, or fits in the very good category. This was evidenced by its implementation in the field. That means, the newly invented tool detects all service balls when they touch the tennis net and is immediately responded to a lit lamp. The initial test showed that as many as 200 trials of the service ball that touched the net were immediately responded to by a lit lamp. Furthermore, the final test showed 41 times the service ball that touched the net during a table tennis match, also responded by a light that was on. In other words, the service sensor device on the table tennis net can objectively assess, so it is expected to be useful in learning (training), as well as for table tennis referees especially when leading a match. Future research based on sensor technology is needed to assess motion errors in the implementation of table tennis services. This becomes interesting to assess overall, both from the aspect of motion, as well as service errors when the ball hits the net.

Conflict of Interest

The authors declare no potential conflicts of interest concerning the research, authorship, and publication of this article.

References

- Bańkosz, Z., & Winiarski, S. (2018). Correlations between angular velocities in selected joints and velocity of table tennis racket during topspin forehand and backhand. *Journal of Sports Science and Medicine*, 17(2), 330–338. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5950751/>
- Bańkosz, Z., & Winiarski, S. (2020). Using Wearable Inertial Sensors to Estimate Kinematic Parameters and Variability in the Table Tennis Topspin Forehand Stroke. *Applied Bionics and Biomechanics*, 2020, 1–10. <https://doi.org/10.1155/2020/8413948>
- Batool, M., Jalal, A., & Kim, K. (2019). Sensors Technologies for Human Activity Analysis Based on SVM Optimized by PSO Algorithm. *2019 International Conference on Applied and Engineering Mathematics, ICAEM 2019 - Proceedings*, 145–150. <https://doi.org/10.1109/ICAEM.2019.8853770>
- Belli, T., Misuta, M. S., de Moura, P. P. R., Tavares, T. dos S., Ribeiro, R. A., dos Santos, Y. Y. S., Sarro, K. J., & Galatti, L. R. (2019). Reproducibility and Validity of a Stroke Effectiveness Test in Table Tennis Based on the Temporal Game Structure. *Frontiers in Psychology*, 10, 1–9. <https://doi.org/10.3389/fpsyg.2019.00427>
- Blank, P., Groh, B. H., & Eskofier, B. M. (2017). Ball Speed and Spin Estimation in Table Tennis using a Racket-mounted Inertial Sensor. *Proceedings - International Symposium on Wearable Computers, ISWC, Part F1305*, 2–9. <https://doi.org/10.1145/3123021.3123040>
- Blank, P., Hoßbach, J., Schuldhaus, D., & Eskofier, B. M. (2015). Sensor-based Stroke Detection and Stroke Type Classification in Table Tennis. *ISWC 2015 - Proceedings of the 2015 ACM International Symposium on Wearable Computers*, 7(11), 93–100. <https://doi.org/10.1145/2802083.2802087>
- Blank, P., Kautz, T., & Eskofier, B. M. (2016). Ball Impact Localization on Table Tennis Rackets using Piezo-electric Sensors. *International Symposium on Wearable Computers, Digest of Papers*, 12–16, 72–79. <https://doi.org/10.1145/2971763.2971778>
- Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors (Switzerland)*, 18(3), 1–50. <https://doi.org/10.3390/s18030873>
- Firdaus, K. (2011). Evaluation of the Field Tennis Sports Development Program in the City of Padang. *Indonesian Sports Science Media*, 1(2), 127–132.
- Firdaus, K. (2015a). Perception Students Against Modification of Learning Through Small Game in Education Sport and Physical Health in Junior High School 36 Padang. *International Journal of Research in Education Methodology*, 7(3), 1219–1222. <http://repository.unp.ac.id/1692/1/PERCEPTIONSTUDENTSAGAINSTMODIFICATIONOFLEARNING.pdf>
- Firdaus, K. (2015b). The Evaluation of Physical Education to Enhance Teaching Program in Schools. *International Journal of Research in Education Methodology*, 10(February 2014), 1201–1229. <http://repository.unp.ac.id/16952/1/THEEVALUATIONOFPHYSICALEDUCATIONTOENHANCETEACHING.pdf>
- Firdaus, K. (2016). the Effect of Repetition Exercise Method and Intensive Interval Exercise Method on the Students 100 Meter Sprinting Ability At Smp N 1 Pariaman. *Journal of Social Science Research*, 10(4), 2168–2172. <https://doi.org/10.24297/jssr.v10i4.4714>
- Fuchs, M., Liu, R., Malagoli Lanzoni, I., Munivrana, G., Straub, G., Tamaki, S., Yoshida, K., Zhang, H., & Lames, M. (2018). Table tennis match analysis: a review. *Journal of Sports Sciences*, 36(23), 2653–2662. <https://doi.org/10.1080/02640414.2018.1450073>
- Girard, O., & Millet, G. P. (2009). Neuromuscular Fatigue in Racquet Sports. *Physical Medicine and Rehabilitation Clinics of North America*, 20(1), 161–173. <https://doi.org/10.1016/j.pmr.2008.10.008>
- Hegazy, H., Abdelsalam, M., Hussien, M., Elmosalamy, S., Hassan, Y. M. I., Nabil, A. M., & Atia, A. (2020). Online detection and classification of in-corrected played strokes in table tennis using IR depth camera. *Procedia Computer Science*, 170(2019), 555–562. <https://doi.org/10.1016/j.procs.2020.03.125>
- Hussin, A. A. (2018). Education 4.0 Made Simple: Ideas For Teaching. *International Journal of Education &*

- Literacy Studies*, 6(3), 92–98.
<https://doi.org/http://www.journals.aiac.org.au/index.php/IJELS/article/viewFile/4616/3541>
- Huỳnh, T., Blanke, U., & Schiele, B. (2007). Scalable recognition of daily activities with wearable sensors. *International Symposium on Location- and Context-Awareness*, 50–67. https://doi.org/10.1007/978-3-540-75160-1_4
- Ibrahim, N., Abu Osman, N. A., Mokhtar, A. H., Arifin, N., Usman, J., & Shasmin, H. N. (2020). Contribution of the arm segment rotations towards the horizontal ball and racket head velocities during forehand long shot and drop shot services in table tennis. *Sports Biomechanics*, 1–17.
<https://doi.org/10.1080/14763141.2020.1726995>
- Ihsan, N., Amum, K. R., Rasyid, W., & Neldi, H. (2021). Development of information and technology-based learning media in athletic materials for short distance running numbers for quality junior n 2 students in Lubuk Linggau City, South Sumatra Province. *International Journal of Human Movement and Sports Sciences*, 9(1), 124–129. <https://doi.org/10.13189/saj.2021.090117>
- Ihsan, N., Bafirman, Sujana, A., & Permana, A. Y. (2020). Design of Instrument Explosive Power Leg Muscles Sensor Based. *Journal of Physics: Conference Series*, 1594, 1–5. <https://doi.org/10.1088/1742-6596/1594/1/012038>
- Iino, Y., & Kojima, T. (2016). Mechanical energy generation and transfer in the racket arm during table tennis topspin backhands. *Sports Biomechanics*, 15(2), 180–197.
<https://doi.org/10.1080/14763141.2016.1159722>
- Izzo, R., Palma, A., Cejudo, A., Cruciani, A., Giovannelli, M., & C, H. V. I. (2022). Validation of the new technology sensor fusion K-50 based on data integration detected by GPS 50 Hz and inertial sensors. *Journal of Physical Education and Sport*, 22(3), 555–561. <https://doi.org/10.7752/jpes.2022.03069>
- Javadi, M., Haleem, A., Rab, S., Pratap Singh, R., & Suman, R. (2021). Sensors for daily life: A review. *Sensors International*, 2(July), 100121. <https://doi.org/10.1016/j.sintl.2021.100121>
- Katsikadelis, M., Piliandis, T., & Mantzouranis, N. (2013). The interaction between serves and match winning in table tennis players in the London 2012 Olympic Games. *The 13th ITTF Sports Science Congress*, 11–12, 77–79.
- Komaini, A., Hermanzoni, Handayani, S. G., Rifki, M. S., Kiram, Y., & Ayubi, N. (2022). Design of Children's Motor Training Tools Using Sensor-Based Agility Components in Physical Education Learning. *International Journal of Interactive Mobile Technologies*, 16(05), 207–215.
<https://doi.org/10.3991/ijim.v16i05.29731>
- Komaini, A., Hidayat, H., Ganefri, G., Alnedral, A., Kiram, Y., Gusril, G., & Mario, D. T. (2021). Motor Learning Measuring Tools: A Design And Implementation Using Sensor Technology For Preschool Education. *International Journal of Interactive Mobile Technologies*, 15(17), 177–191.
<https://doi.org/10.3991/ijim.v15i17.25321>
- Li, F., & Yang, X. (2020). Correction Simulation of Three Dimensional Image of Table Tennis Players Serve Position. *ACM International Conference Proceeding Series*, 16(18), 6–10.
<https://doi.org/10.1145/3419635.3419640>
- Li, R. T., Kling, S. R., Salata, M. J., Cupp, S. A., Sheehan, J., & Voos, J. E. (2015). Wearable Performance Devices in Sports Medicine. *Sports Health*, 8(1), 74–78. <https://doi.org/10.1177/1941738115616917>
- Loh, T. C., & Krasilshchikov, O. (2015). Competition performance variables differences in elite and U-21 international men singles table tennis players. *Journal of Physical Education and Sport*, 15(4), 829–833.
<https://doi.org/10.7752/jpes.2015.04127>
- Malagoli Lanzoni, I., Di Michele, R., & Merni, F. (2014). A notational analysis of shot characteristics in top-level table tennis players. *European Journal of Sport Science*, 14(4), 309–317.
<https://doi.org/10.1080/17461391.2013.819382>
- Mario, D. T. (2017). *Effects of Giving Natural Supplements in Weight Training on Increasing Muscle Mass*. Faculty of Sports Science, Padang State University.
- Matsuwaka, S. T., & Latzka, E. W. (2019). Summer Adaptive Sports Technology, Equipment, and Injuries. *Sports Medicine and Arthroscopy Review*, 27(2), 48–55. <https://doi.org/10.1097/JSA.0000000000000231>
- Munivra, G., Petrinić, L. Z., & Kondrić, M. (2015). Structural Analysis of Technical-Tactical Elements in Table Tennis and their Role in Different Playing Zones. *Journal of Human Kinetics*, 47(1), 197–214.
<https://doi.org/10.1515/hukin-2015-0076>
- Nogueira, W. J., Montebello, M. I. de L., Leme, M. L. de A., Gonelli, P. R. G., Cesar, M. de C., Viola, J. C., Bezerra, T. A. R., & Pellegrinotti, I. L. (2020). Comparison of two vertical jump evaluation tests in young athletes: vertical impulse and laser sensor instrument test. *Journal of Physical Education and Sport*, 20(1), 249–254. <https://doi.org/10.7752/jpes.2020.01033>
- Oh, H., Johnson, W., & Syrop, I. P. (2019). Winter Adaptive Sports Participation, Injuries, and Equipment. *Sports Medicine and Arthroscopy Review*, 27(2), 56–59. <https://doi.org/10.1097/JSA.0000000000000236>
- Padulo, J., Di Giminiani, R., Iacono, A. Dello, Zagatto, A. M., Migliaccio, G. M., Grgantov, Z., & Ardigo, L. P. (2016a). Lower Arm Muscle Activation during Indirect-Localized Vibration: The Influence of Skill Levels When Applying Different Acceleration Loads. *Frontiers in Physiology*, 7(242), 1–8.

- <https://doi.org/10.3389/fphys.2016.00242>
- Padulo, J., Pizzolato, F., Tosi Rodrigues, S., Migliaccio, G. M., Attene, G., Curcio, R., & Zagatto, A. M. (2016b). Task complexity reveals expertise of table tennis players. *Journal of Sports Medicine and Physical Fitness*, 56, 149–156. <https://www.minervamedica.it>
- Rifki, M. S., Farma, F., Komaini, A., Sepdanius, E., Alimuddin, & Ayubi, N. (2022). Development of Sit Up Measuring Tools Based on Arduino and Ultrasonic Sensors With Android Applications. *International Journal of Interactive Mobile Technologies*, 16(08), 182–189. <https://doi.org/10.3991/ijim.v16i08.30673>
- Rota, S., Morel, B., Saboul, D., Rogowski, I., & Hautier, C. (2014). Influence of fatigue on upper limb muscle activity and performance in tennis. *Journal of Electromyography and Kinesiology*, 24(1), 90–97. <https://doi.org/10.1016/j.jelekin.2013.10.007>
- Sha, X., Wei, G., Zhang, X., Ren, X., Wang, S., He, Z., & Zhao, Y. (2021). Accurate Recognition of Player Identity and Stroke Performance in Table Tennis Using a Smart Wristband. *IEEE Sensors Journal*, 21(9), 10923–10932. <https://doi.org/10.1109/JSEN.2021.3060914>
- Shoraevna, Z. Z., Eleupanovna, Z. A., Tashkenbaevna, S. N., Zulkarnayeva, Z., Anatolevna, L. L., & Nurlanbekovna, U. A. (2021). Teachers' Views on the Use of Information and Communication Technologies (ICT) in Education Environments. *International Journal of Emerging Technologies in Learning*, 16(3), 261–273. <https://doi.org/10.3991/ijet.v16i03.18801>
- Tamaki, S., Yoshida, K., & Yamada, K. (2017). A Shot Number Based Approach to Performance Analysis in Table Tennis. *Journal of Human Kinetics*, 55, 7–18. <https://doi.org/10.1515/hukin-2017-0002>
- Tian, G., Deng, W., Gao, Y., Xiong, D., Yan, C., He, X., Yang, T., & Jin, L. (2019). Rich lamellar crystal baklava-structured PZT/PVDF piezoelectric sensor toward individual table tennis training. *Nano Energy*, 59(March), 574–581. <https://doi.org/10.1016/j.nanoen.2019.03.013>
- Viyanon, W., Kosasaeng, V., Chatchawal, S., & Komonpetch, A. (2016). *SwingPong : Analysis and Suggestion based on Motion Data from Mobile Sensors for Table Tennis Strokes using Decision Tree*. 23–25. <http://dx.doi.org/10.1145/3028842.3028860>
- Wang, Z. L., Chen, J., & Lin, L. (2015). Progress in triboelectric nanogenerators as a new energy technology and self-powered sensors. *Energy and Environmental Science*, 8(8), 2250–2282. <https://doi.org/10.1039/c5ee01532d>
- Wu, H., Dyson, M., & Nazarpour, K. (2021). Arduino-based myoelectric control: Towards longitudinal study of prosthesis use. *Sensors (Switzerland)*, 21(3), 1–13. <https://doi.org/10.3390/s21030763>
- Xu, Y., Wu, X., Guo, X., Kong, B., Zhang, M., Qian, X., Mi, S., & Sun, W. (2017). The Boom in 3D-Printed Sensor Technology. In *Sensors* (Vol. 17, Issue 5). <https://doi.org/10.3390/s17051166>
- Zhang, H., Liu, W., Hu, J., & Liu, R. (2013). Evaluation of elite table tennis players' technique effectiveness. *Journal of Sports Sciences*, 31(14), 1526–1534. <https://doi.org/10.1080/02640414.2013.792948>
- Zhang, H., Zhou, Z., & Yang, Q. (2018). Match analyses of table tennis in China: a systematic review. *Journal of Sports Sciences*, 36(23), 2663–2674. <https://doi.org/10.1080/02640414.2018.1460050>
- Zhang, S., Ang, M. H., Xiao, W., & Tham, C. K. (2009). Detection of activities by wireless sensors for daily life surveillance: Eating and drinking. *Sensors*, 9(3), 1499–1517. <https://doi.org/10.3390/s90301499>