Detection of Tennis Strokes using Wearable Sensor

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***Abstract*—Analysis has become an important part of professional sports every major professional team employs expert analysts to improve the team. With the availability of high-quality data, high processing power, and advanced algorithms have been explored. Statistical models made an evolution in sports life. Using wearable sensor to gather data with a combination of an accelerometer and gyroscope of 3 principles axes. That sensor will be worn on wrist of player. Each stroke performed would be saved with its type in the sensor hardware then sent to PC wirelessly for more plays analysis. Using machine learning technique (ANN) on data to analyze for getting detection stroke type and prediction how accurate the player would play in the further plays according to player statistics. The accuracy recorded for this project is 96 percent on classification. For upgrading the strategy-making information predisposing procedures to evaluate data quality. The assessment of the concocted strategy shows promising outcomes contrasted with a comparable technique.**

***Index Terms*—Tennis, Tennis Strokes,Accelerometer , Machine learning , Gyroscope, Sensors**

I. Introduction

The job of information in sport has filled essentially lately, being a subject of exploration in a continuous turn of events. Experts and novices search for a way of getting data about their presentation or the chance of progress. Machine Learning considers the creation of objective measures, it empowers the recognition of impossible analysis by people. These days, the improvement of new sensors of more modest size and lower utilization permit information assortment through convenient or outside sensors to be accomplished significantly more effectively, without interfering with the exercises completed. The data got by these sensors are of the incredible interest in a wide assortment of uses, for example, clinical applications for the checking of patients with illnesses that need checking, in the restoration of sicknesses or wounds by observing the advancement of the patient in the assemblage of sports measurements for the representation of the advancement made [1], or in the improvement of procedure in the exhibition of certain games [2].

In recent years, human activity recognition (HAR) has been growing through the advancement of innovative methods that permit more prominent precision in the order of exercises from sensors [2]. Data analysis has been improved over the years which increases the improvement in tennis because data are the source of improving anything, so it has been

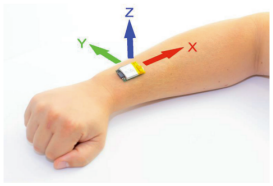

Fig. 1. Example of a sensor design.

focused on as important as teaching basics of the game and seeking the best professional career for the player [3]. A few explorers have been led in Tennis Activity Detection (TAD) utilizing a uniquely constructed wearable. They have been planned in research centers with installed ME-MS-based inertial sensors and miniature regulators. A smaller than normal wearable gadget and framework are created and intended for development and Biomet information securing and stroke identification. Previously, researchers used high costly devices for detecting the player moving for tennis stroke (moving of player hand) which focuses on in this project and different types of equipment like using a camera and wearable sensor its components cost much so cannot be affordable for everyone. Machine and deep learning methods have been used for analysis [4] and deep learning to work on data and get from its analysis. Machine learning techniques like ANN, and Random Forest as mentioned before analyzing and develop the game performance so trying as possible to make it affordable for everyone and easy to use. In tennis, analyzing has been very focusing recently as the technology getting forward to it makes it easy to use not like before it was hard. There are so many ways for analyzing or gathering the data and they differ from the purpose of analyzing in this project just using wearable sensors for the best results as it is an easy way and very effective as others as it's cost not much as others. An accelerometer sensor is an instrument that actions the speed increase of anybody or an item in its immediate rest outline. It's anything but a direction speed increase and the gyroscope adds an extra aspect to the data provided by the accelerometer by the following turn or control. So together have a gyroscope that answers rapidly, yet floats over the long haul, and an accelerometer that answers gradually yet is exact over the long

run. Then can consolidate these two sensor readings to give a speedy reaction that is likewise precise[5].

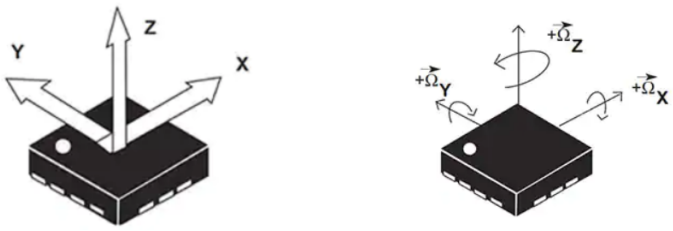

Fig. 2. Accelerometer and Gyroscope structure.

For introducing tennis there are 3 types of tennis strokes which are forehand, backhand, and serve. Every stroke has a different technique for hitting to deliver the ball in the best place on the court depending on the player. Each technique is used depending on the situation the player on and with different plays it delivers the ball to the opponent's court [6]. Here are the stroke types that look like working on as shown in figure 3.

Fig. 3. 3 Types of Tennis Strokes.

II. Related work

Generally, neural networks had contributed to improving the performance of players in the tennis field. There are previous attempts in this field for solving the analyzing tennis strokes of players, but it differs in how the data get collected and what was the technique used for getting information from the data. Firstly, some researchers working on collecting the data with high expensive tools such as high definition cameras, and sensors with many features but do not use them all so it is not preferable as it increases the cost without need, so high-resolution video camera to record the play then cut this video into frames, multiple sensors on the player (on a racket, hand, and head) and working on this data with not advanced techniques as it increasing the cost of the final product [7]. Others work on fewer cost tools but high techniques on data for analysis to get valuable information as it is more interesting for the public [8]. Secondly, some combine both as they use hard and expensive tools with advanced techniques which conclude [9] in high cost for the players use and it is preferable in the market. Some of the techniques used on data as Random Forest, ANN, LSTM, BILSTM and SVM.There are others but those were most of the used in machine learning and deep learning models on similar data. Researchers used different models depending on the objective of the work. Finally, the latest technology developed recently is to detect the shots the player takes and classify each type of shot.This technology used convolution neural network and Res-Net as the data set was generated from wristband sensor[10].

III. Data-set

Data set working on is taken from a paper called "Tennis stroke detection using inertial data of a smartwatch" [11]. This data set consists of 3 folders each folder for tennis stroke (forehand, backhand, serve). Each folder consists of 32 CSV files, the CSV file components are 6 columns (Accelerometer x, y, z axis and Gyroscope x, y, z axis) and 39 rows. The description of t h e file that each row is a sec of the movement of record by accelerometer and gyroscope reads (from the start of action till to the end of action). The sampling rate for inertial sensors accelerometer and gyroscope is set to 50Hz. Each CSV file is one action performed. So have 32 tries for forehand, backhand and serve.

	A	B	C	D	E	F
1	ax	ay	az	gx	gy	gz
2	-4.02717	-7.64971	3.250227	1.587292	-0.13742	-0.70736
3	-2.53913	-7.21874	3.539935	0.545431	0.154468	-0.74358
4	-2.53913	-7.21874	3.539935	0.545431	0.154468	-0.74358
5	-2.53913	-7.21874	3.539935	0.545431	0.154468	-0.74358
6	-1.79211	-8.26384	3.143682	0.067113	0.204536	-1.31458
7	-1.79211	-8.26384	3.143682	0.067113	0.204536	-1.31458
8	-0.02634	-8.55235	3.193962	0.320654	0.137423	-1.93564
9	-0.02634	-8.55235	3.193962	0.320654	0.137423	-1.93564
10	0.914613	-8.70079	2.403852	-0.34303	-0.29935	-2.50664
11	0.914613	-8.70079	2.403852	-0.34303	-0.29935	-2.50664
12	2.264983	-9.25148	2.09499	-1.23681	0.558215	-2.65472
13	2.264983	-9.25148	2.09499	-1.23681	0.558215	-2.65472
14	5.547534	-10.5983	1.777748	-2.2531	1.211242	-2.52475

Fig. 4. Example of Data set.

IV. Methodology

This section going to discuss the Data set collection and the proposed system.

A. System Overview

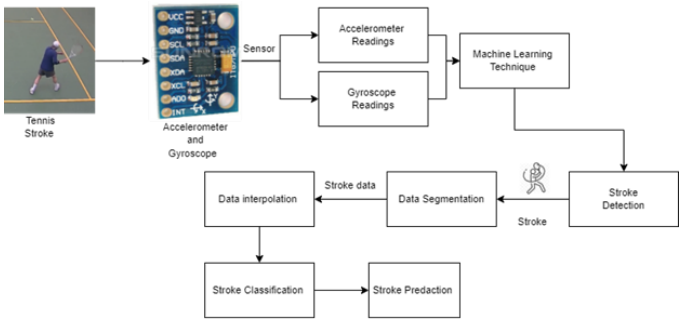

Fig. 5. System Overview.

As shown in Figure 5,the player wearing a sensor combining of accelerometer (a device that actions the vibration, or speed increase of movement of a design. The power brought about by vibration or an adjustment of movement [12]) and gyroscope

(a gadget that can measure and keep up with the direction and and precise speed of an object [13]). The sensor extracts x, y, z of accelerometer and x, y, z of gyroscope then put in CSV file combining them and as mentioned before each CSV file is a one stroke performed then take those CSV files of 3 strokes types put them in 2 arrays. An array consists of sensor readings and second array consists of the label of the stroke type. the label of the stroke is entered manually as each type of stroke is in separate folder. After that data scaling is done as there is a tremendous contrast in the reach say not many running in positive and barely any going in the negative, and it causes the fundamental supposition that higher going numbers to have superiority or the like. Then put it in ANN that will classify the stroke types after learning of the data then can predict what the stroke type if seen a new data incoming.

B. Data Preprocessing

Data were in mat lab (.mat) format and for transforming it for better use in machine learning made a python code to transform that data from (.mat) to CSV file (.csv). It does not contain the label of each column so for labeling it, while converting it into the top of the data put the label of each column. Data resampling for random forest classifier and data scaling before data is processed in the model.

C. Model Approaches

Afterward collecting the data as CSV files, it passed through 2 stages for approaching the stroke prediction. Essentially data preprocessing and it was not the hardest thing as it is just labeling the stroke type in the array while inserting it and labeling sensor principal axis in the CSV file to use it in the learning of the model. Along with data scaling because of differences between the numbers of the data as some of them are positive and others in negative which could cause a problem in understanding the data by the model which used data standardization to improve the way of analyzing the data.

ANN (Artificial Neural Network) is used for analyzing the data and working on it. After data has across data scaling it is entered in the ANN process of input, hidden and output layers. It comprises the number of layers, Elementary units. It additionally comprises of changeable Weight change system. The decision of the design decides the outcomes which will acquire. It is the most basic piece of the execution of a brain organization [14].

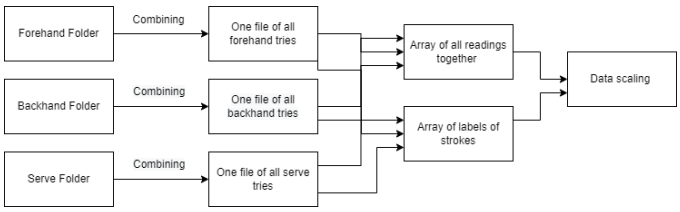

Fig. 6. Input of the data set.

- Input:It takes an array consists of the input variables which are accelerometer x,y,z axis and gyroscope x,y,z axis each CSV file consists of those 6 variables. Reading each file individually and then combining them into one big array of different types of strokes that the model can learn from it easier.
- Hidden: Apply given changes to the information values inside the organization. In this, approaching circular segments go from other secret hubs or input hubs associated with every hub. It associates with active bends to yield hubs or to other secret hubs. In the secret layer, the genuine handling is done through an arrangement of weighted 'associations'. There might be at least one secret layer. The qualities entering a secret hub are increased by loads, a bunch of foreordained numbers put away in the program. The weighted information sources are then added to create a solitary number.
- Output:After the ANN model works on the input variables and learns from them therefore the model can classify between the 3 classes of strokes (Forehand, Backhand and Serve) depending on the range of variables given of input.

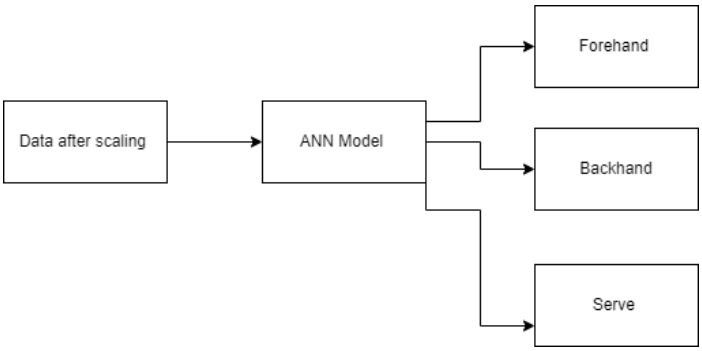

Fig. 7. Output classes after ANN model.

Data have been split into 70 % training and 30 % testing then this training data worked on a sequential model with flattening with 5 hidden layers between the input and output using" LeakyReLU" and the activation is" SoftMax". The model compiles with" categorical cross entropy". According to the past researches sequential model has been the simplest to use in machine learning as its components and mostly for more complex using other models and learning like deep learning and computer vision [15] but for trying to solve complex use and with the same result for that used basic sequential model.

D. Architecture

Firstly, the simple architecture shown in Figure 8 for the ANN model. The architecture of the model in which all the data set is used in it.

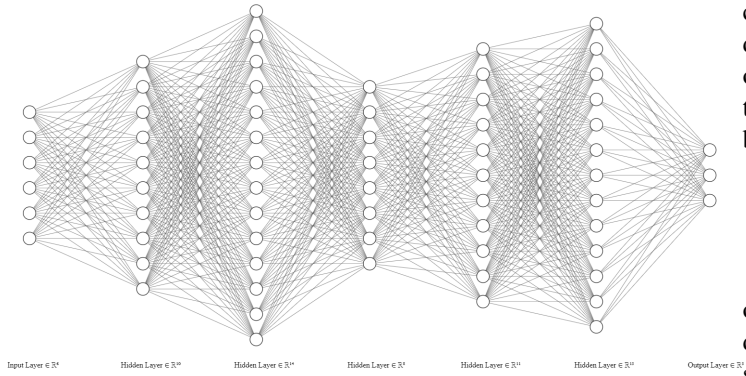

Fig. 8. Simple model of architecture.

Model architecture is shown in Figure 9 .

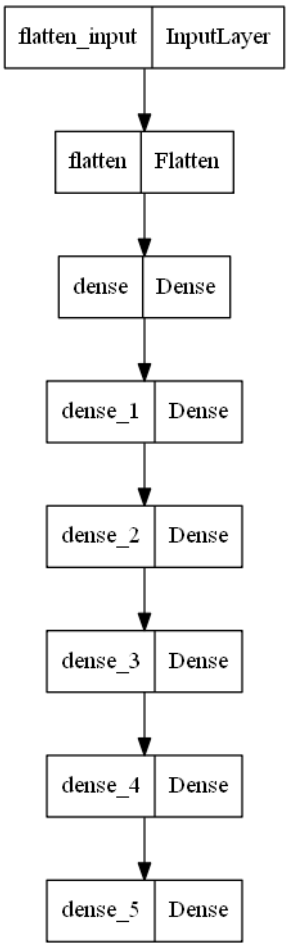

Fig. 9. Model architecture.

Each dense has been applied on it a" LeakyReLU" as its activation as it improves the data accuracy and increases the speed of training more efficiently and fixes the" ReLU" problem [15] with different number of neurons and after that finalized dense with" SoftMax" activation of the 3 outputs having in the model. In the model has been used categorical cross entropy as a loss function as of having multiple classes in data so was most suitable in the process. In addition, Adam's optimizer is used with the model as it is most satisfying for the model case. The number of epochs used is 100 with a batch size of 8.

V. Experiment and Results

Afterward finishing the model and trying different methodologies for fitting the best technique for the best effect on the data. There have been 2 experiments done on different data sets but have the same structure and methodology done on both of experiments for having a fair and equal accuracy on stroke detection.

- The First Experiment:

  Working on data set got published by paper named" Tennis stroke detection using inertial data of a smartwatch" [10]. Different techniques have been applied on the data for stroke classification to try the best result compared to other results and with the simplest technique as an important contribution in this work. Various players with different professionalism are included in the data set to get the full range of possible sets of actions. 32 actions are performed for each type of stroke and the action takes 38 seconds to be performed. Firstly, the random forest technique was applied on the data, but it did not get higher accuracy, it was using 70% training and 30% testing on data. Required data re sampling from 3D array to 2D array for using in random forest. For other trying ridge classifier was used and like a random forest in training and testing ratio but it did not quite improve than random forest. Other's classifiers did not improve the best accuracy. In the end, classical ANN was used as a sequential model with the same training and testing ratio on data. Just scaling is used on the data for implementation preprocessing as mentioned before in the data section. Data has been classified into 3 types of strokes depending on the range of motion performed. As shown in table I the best result acquired by ANN (sequential with 5 hidden layers of leaky rule activation function of total parameters: 2,132,883 which are all trainable. As shown in Figure 10 and Table I the best result of tried techniques.

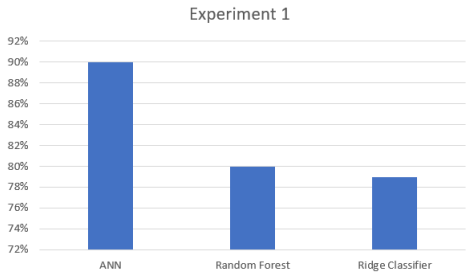

Fig. 10. Diagram 1 for the first experiment results.

TABLE I
EXPERIMENT 1 RESULTS

Accuracy	
Technique	Results
ANN(sequential)	90%
Random Forest	80%
Ridge classifier	79%

- The Second Experiment:

  The used data set which got published in a paper named" Tennis Ball Speed Estimation using a Racket-mounted Motion Sensor" [17] . On this data set it differs from the last one in size but has the same structure of CSV files (6 columns as 3 principal axes of each accelerometer and gyroscope). 1980 action was performed in this data set (1017 Forehand, 394 Backhand, 569 Serve) and each action toke in 100 seconds for a full range of motion for more accurate principal axes. For the experiment, 7 players have performed with different professionalism. Each player recorded some of the tennis strokes but not equally for all players. Random Forest has been applied on the data set with 70% training and 30% testing after data re sampling from 3D to 2D as in array but was not promising so much in results. The deep learning was applied on this data for better accuracy so BILSTM was chosen. Data has been flattened and 4 hidden layers was put with Leaky ReLU activation and sparse categorical cross entropy with Adam optimizer with sigmoid activation function. It improved so much from the previous techniques as deep learning is more specify than machine learning but was not the best result so far. So tried the classical ANN (sequential model) as it is simple and this one the important thing in this work and it was quite outstanding from the previous techniques as it is not mostly used but it had a higher accuracy so far . Just 5 hidden layers leaky rule activation function of trainable params: 2, 535, 315...As shown in Figure 11 and Table II the best result of tried techniques.

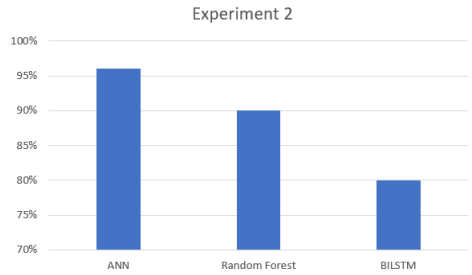

Fig. 11. Diagram 2 for the second experiment results.

TABLE II
EXPERIMENT 2 RESULTS

Accuracy	
Technique	Results
ANN(sequential)	96%
Random Forest	90%
BILSTM	80%

VI. DISCUSSION

According to the previous research, the achieved accuracy depends on 2 different factors. The first factor depends on the advanced complicated algorithms with small data sizes. Therefore, these algorithms may fail if the data size is increased in a massive amount. While the second factor depends on the specific expensive tools to receive the data or to monitor the player's performance. The proposed solution balances the 2 factors. It aimed to have simple algorithm with a simple gadget which is relatively cheaper. The gadget is accurate and captures the data needed for the simple ANN model. Differ from the most previous researches that have been used so much advanced machine learning and deep learning models and used too many sensors for gathering the data set which to quite important. So, for that only used only 2 sensors and getting same or just less than achieved accuracy. In addition to, a data set that is relatively bigger than the used data in the other research. The accuracy achieved by this technique is approximately 96%. While other techniques achieved 97% using enhanced tools and small data set.

VII. CONCLUSION AND FUTURE WORK

The neural network contribution in tennis strokes analysis has taken an effective impact in this era as tennis becoming an important sport compared to others so researchers focus on analyzing data acquired from the sensors that player wear while playing in the game or training. The analysis will make it easier for players to develop as they can track their progress continuously with accurate statistical percentages and can detect which stroke is more week than the other. The player should wear a sensor that consists of an accelerometer and gyroscope. Hence, the readings taken from the sensor will be processed by the proposed system. Because of the success of the proposed system, the next step is to analyze different types of more difficult strokes. The strokes have multiple types such as lob shot, slice shot, and volley shot. Also, this analysis can be beneficial for predicting the best shot the player should have taken to improve his skills not only monitor his performance.

REFERENCES

[1] Kos, M., & Kramberger, I. (2019). Smart wearables for tennis game performance analysis. Proceedings of the Sports Science and Human Health-Different Approaches, 1-18.

[2] Benages Pardo, L., Buldain Perez, D., Orrite Uruñuela, C. (2019). Detection of tennis activities with wearable sensors. Sensors, 19(22), 5004.

[3] Stănescu*, R. (2019). The Role of Video Analysis Method in Tennis Performance.In V. Grigore, M. Stanescu, M. Paunescu (Eds.), Physical Education, Sport and Kinetotherapy - ICPESK 2017, vol 36. European Proceedings of Social and Behavioural Sciences (pp. 277-282).Future Academy .https://doi.org/10.15405/epsbs.2018.03.37.

[4] Liu, X. (2020). Tennis Stroke Recognition: Stroke classification using inertial measuring unit and machine learning algorithm in Tennis.

[5] Ha, S., Choi, S. (2016, July). Convolutional neural networks for human activity recognition using multiple accelerometer and gyroscope sensors. In 2016 International Joint Conference on Neural Networks (IJCNN) (pp. 381-388). IEEE.

[6] Liu, X. (2020). Tennis Stroke Recognition: Stroke classification using inertial measuring unit and machine learning algorithm in Tennis.

[7] Connaghan, D., Kelly, P., O'Connor, N. E., Gaffney, M., Walsh, M., O'Mathuna, C. (2011, October). Multi-sensor classification of tennis strokes. In SENSORS, 2011 IEEE (pp. 1437-1440). IEEE.
[8] Dibua, V. C. O. Action Recognition in Tennis Using Deep Neural Networks.
[9] Ganser A, Hollaus B, Stabinger S. Classification of Tennis Shots with a Neural Network Approach. Sensors (Basel). 2021;21(17):5703. Published 2021 Aug 24. doi:10.3390/s21175703
[10] Sankararaman, G., & Buddhiraju, S. Tennis Shot Recognition through Spatiotemporal Deep Neural Networks.
[11] Taghavi, S., Davari, F., Malazi, H. T., Abin, A. A. (2019, October). Tennis stroke detection using inertial data of a smartwatch. In 2019 9th International Conference on Computer and Knowledge Engineering (ICCKE) (pp.466-474). IEEE.
[12] Troiano, R. P., Berrigan, D., Dodd, K. W., Masse, L. C., Tilert, T., McDowell, M. (2008). Physical activity in the United States measured by accelerometer. Medicine and science in sports and exercise, 40(1), 181.
[13] Scarborough, J. B. (1958). The Gyroscope. Interscience Publ..
[14] Zupan, J. (1994). Introduction to artificial neural network (ANN) methods: what they are and how to use them. Acta Chimica Slovenica, 41, 327-327.
[15] Vinyes Mora, S., Knottenbelt, W. J. (2017). Deep learning for domain-specific action recognition in tennis. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops (pp. 114-122).
[16] Mastromichalakis, S. (2020). ALReLU: A different approach on Leaky ReLU activation function to improve Neural Networks Performance. arXiv preprint arXiv:2012.07564.
[17] Zhao, H., Wang, S., Zhou, G., Jung, W. (2019, April). TennisEye: tennis ball speed estimation using a racket-mounted motion sensor. In Proceedings of the 18th International Conference on Information Processing in Sensor Networks (pp. 241-252).