Computer Vision Applied to Sports: A Case Study for Evaluating the Accuracy of Poomsae Pyongwon

Abstract. This research addresses a constant problem in Poomsae competitions: the significant variation in accuracy ratings given by judges. We present the development of software based on artificial vision as a support tool for judges and competitors. The software integrates computer vision frameworks and specialized scoring algorithms to evaluate the accuracy of the Poomsae Pyongwon. In collaboration with the College of Referees of the State of Veracruz, we conducted a comparative evaluation of athletes throughout the Mexican Republic. In this evaluation, we contrast the scores assigned by human judges with those provided by the software. The results indicated that, in most cases, the software's ratings were close to the mean of the ratings the human judges gave, demonstrating that the software can provide ratings close to expert judgment.Additionally, the software tended to be stricter due to the precise mathematical calculations of angles and distances. The software allows you to standardize qualifications and support training, benefiting judges and competitors. Likewise, it contributes to the scientific community by providing public data sets with information relevant to Taekwondo.

Keywords: Poomsae, Artificial Vision, Taekwondo, Pyongwon, Artificial Intelligence.

1 Introduction

Taekwondo is one of the most practiced sports in Mexico [1], with a wide base of practitioners and numerous outstanding athletes who have represented the country in international competitions [2], [3]. Taekwondo is a traditional Korean martial art whose name means "the way of punch and kick." Practitioners in this discipline use hand and foot techniques for defense and attack [4]. Taekwondo is divided into two main categories: Kyorugi (sparring) and Poomsae (forms)[5]. Poomsae consists of a series of coordinated defense, attack, and posture movements that simulate imaginary combat against one or more adversaries. A common problem in Poomsae competitions is the variability in accuracy scores assigned by judges. This variability can be attributed to various factors related to practice and human perception [6]. The present research addresses the problem of variability in accuracy ratings in Poomsae using emerging technologies. A framework based on computer vision and a specialized algorithm is implemented as the proposed solution. A comparative evaluation was carried out to analyze the scores assigned by the judges and those generated by the proposed software.

The objective was to determine if the software could accurately and consistently evaluate the accuracy rating criterion of the Poomsae Pyongwon competitors participated in three categories: Youth, Under 30, and 40, both in the female and male branches. The results showed that, in most cases, the software scores were close to the mean of the scores assigned by the judges, although they were stricter 100% of the time. Specific movements were identified in which the software gave very accurate ratings, as well as others in which it disagreed with the judge's judgment.

2 Related works

A systematic literature review was carried out to identify previous studies that addressed problems like those proposed in this research. The systematic review included an exhaustive search in academic databases such as PubMed, IEEE Xplore, Scopus, and Google Scholar. Specific keywords and combinations of search terms were used such as: "*Pose Detection*", "*Poomsae*", "*Taekwondo*", "*Accuracy Rating*", "*Computer Vision*" and "*Technology in Taekwondo*". The inclusion criteria were established to select studies published in the last five years, written in English, and involving technological sports evaluations. Additional filters were applied to ensure the relevance and quality of the studies, excluding those that did not present empirical data or rigorous methodologies. The final selection included studies conducted primarily in Asia and Europe, providing a comprehensive overview of technological advances in Poomsae assessment and highlighting the paucity of research focused specifically on the issues addressed by this research.

Studies were identified that apply technology to martial arts, specifically Taekwondo. In [7], the relationship between weight categories and Taekwondo cross-kicks is investigated. The authors propose using artificial intelligence to analyze joint angles, movement time, displacement, and speed of 30 Korean athletes distributed in three weight categories: 58 kg, 68 kg, and 80 kg. The results show significant biomechanical differences between the categories, highlighting the effectiveness of artificial intelligence in the analysis and evaluation of sports techniques. On the other hand, [8] addresses the disadvantages of traditional Taekwondo teaching in educational institutions and proposes an evaluation model based on artificial intelligence algorithms to improve it. A set of support vector machine (SVM) algorithms is used to build a model that corrects students' movements by recognizing Taekwondo-specific features. This model guides movements and allows exercises to be carried out through simulations. A control experiment verified the model's effectiveness, showing its ability to detect errors and applicability in teaching Taekwondo. In other areas of martial arts, [9] proposes an interactive system that uses virtual reality and motion capture technology for interactive learning of Taichi in real-time. The system projects the practitioner's movements onto a virtual avatar and compares them to a reference model using a motion similarity matching algorithm to evaluate the quality of learning. The inertial sensors, which capture the position and orientation of 17 bone nodes, have no problems with light or body occlusion and are wireless, which places no burden on the student. This technology significantly improves the Taichi learning process without needing a physical instructor, accurately capturing the practitioner's position. At the same time, [10] proposes applying artificial intelligence technology in the educational management of martial arts. They use a deep learning-based target tracking algorithm to analyze the movement of practitioners, along with a coordinated regression pose estimation algorithm to predict key body points. This combination simplifies the prediction of key points and addresses the challenges associated with non-standardized movements of martial arts students.

In addition, works related to using technologies and detecting poses applied to sports were reviewed. Below is a table with summarized data of the relevant works for this research identified in the literature.

Table 1. Relevant works with the use of artificial intelligence technologies in sports

Year	Authors	Technologies used	Objective	Results
2022	Guo, Xiaoping [11].	Graph neural network	Develop a multi-individual human posture detection method for sports videos.	The algorithm outperforms other methods in estimating human posture in sports videos, demonstrating effective performance.
2022	Q. Wang [12].	Convolutional Neural Network (CNN)	Propose a CNN to improve the quality of athlete pose estimation in sports competition videos.	It was evaluated, demonstrating high precision and outperforming other methods, reducing errors and mitigating the influence of occlusion.
2021	Jiang y Tsai [13].	Sequential Minimal Optimization (SMO) algorithm, convolutional neural network, VLAD algorithm	Develop a model to improve the accuracy of training action recognition.	The model improves the recognition rate of sports actions and reduces the error recognition rate.
2021	R. Liu [14].	Multiple convolutional neural networks	Develop a method for accurate athlete posture estimation in sports game videos.	It achieves high precision, with percentages greater than 80%. Reduces the influence of occlusion on athlete posture estimation.
2021	L. Wang et al. [15].	Machine learning, spectral feature, computer vision.	Improve the efficiency of athlete gait recognition technologies.	The proposed method improves the number of types of recognition actions and gait accuracy.
2020	J.-A. Wang et al. [16].	Computer Vision, ResNet-50 v2	Develop a system for recognizing and identifying sports risks.	The system classifies and recognizes risks associated with sports practice at the university level.
2019	Kong et al. [17].	Support Vector Machines (SVM), Computer Vision.	Design a system for sports training using data from physiological indices of athletes.	The system showed an accuracy close to 98%, based on a badminton data set.

Table 1 presents the relevant works reviewed in this research, each with different approaches, from developing more precise methods to estimate the posture of athletes to implementing intelligent systems to recognize risks associated with sports practice. None of the reviewed works addresses the specific problem raised in this study, which indicates that the scientific community has little explored this area. Therefore, it is pertinent to propose the development of technological tools as a solution to the problem observed.

3 Methods and materials

Specific methodological steps were followed to develop the software: obtaining data and metrics for each Poomsae movement, choosing the technology, designing the scoring algorithm, and defining the software structure. It was implemented in Python to be compatible with MediaPipe, focusing on Pose Detection functionality. Human pose detection in video was carried out using the MediaPipe framework [18], offering a comprehensive solution. Specifically, the Pose Landmark Detection component [19], was implemented, specializing in estimating human poses by accurately identifying critical points on the body.

3.1 Data Collection

Several reference photographs of the 31-foot and hand movements were taken to collect data for each movement. These movements were categorized into three sections: performed correctly, partially correct (with a deduction error of 0.1), and incorrect (with a deduction of 0.3). This classification made it possible to evaluate ranges of correct and incorrect movements and measure the characteristic angles and distances of each movement. The expert judgment [20] used for evaluating the individual movements of the Poomsae was through a member of the State College of Taekwondo Referees of the state of Veracruz (COESAT Veracruz). Images of individual movements were categorized according to their corresponding section (Fig. 1). With this categorization and feedback on the causes of errors, a specific algorithm was developed to evaluate the accuracy of each movement. This algorithm considers factors such as joint angles, heights, and distances of movements in relation to the athlete's body and other relevant parameters to determine movement precision (Fig. 2).

Fig. 1. Comparison of the execution of arm movements.

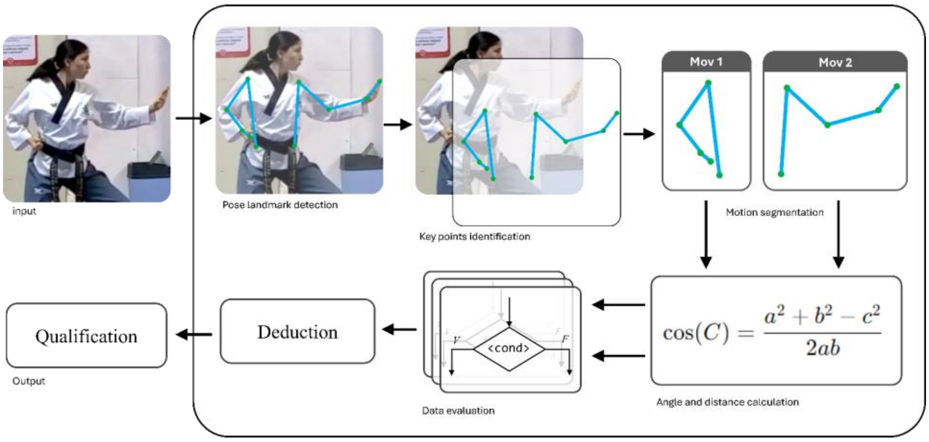

Fig. 2. Diagram of the phases of the grading algorithms

3.2 Software development process

The software is organized into classes and methods that facilitate the sequential execution of the steps necessary for evaluation. This structure guarantees systematic management of each stage of the Poomsae and the evaluation process. Each class and method play a specific role, contributing to the comprehensive functioning of the program and the fulfillment of the evaluation objectives of Poomsae Pyongwon (Fig. 3). Due to the complexity of Poomsae, it has been subdivided into stages, which are divided into sequences of movements or Poom. The Poomsae Pyongwon consists of 31 Poom, each made up of one or more movements of the feet and hands, subdivided into several moments according to their particularities (Fig. 4).

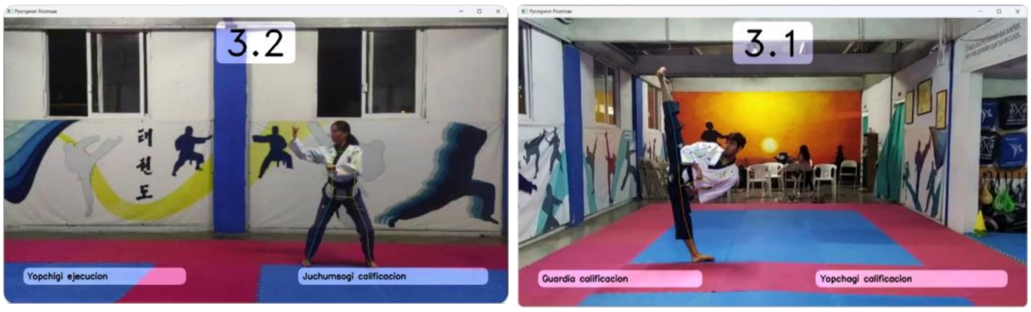

Fig. 3. Running software

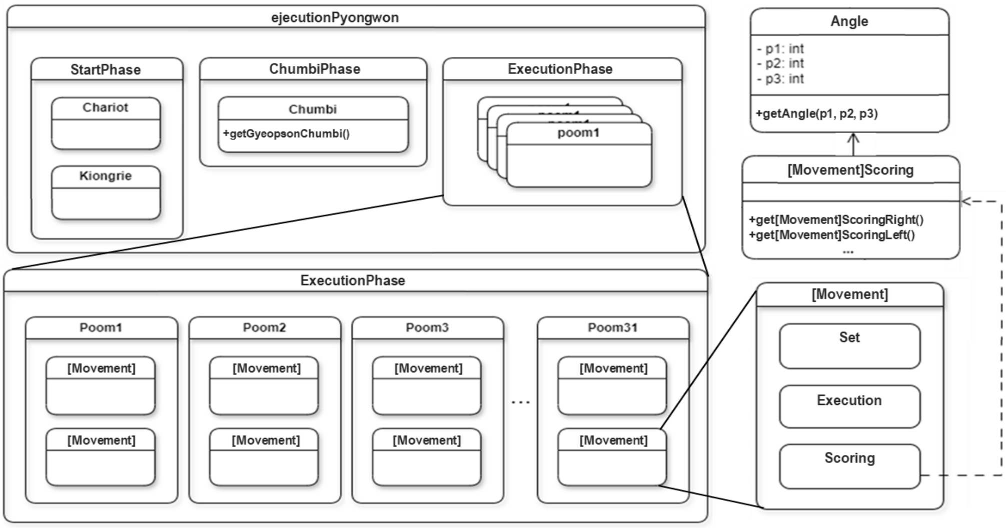

Fig. 4. Software structure diagram.

4 Experiment

4.1 Sample Selection

Purposive non-probability sampling [21] was used to select athletes to participate in the benchmarking. This choice is based on several key aspects: the competitive Poomsae community in Mexico is specific and relatively limited. This type of sample selects individuals based on specific criteria and their availability. Furthermore, it is a procedure that allows for the selection of characteristic cases of the population, limiting the sample to these cases. Given the specific nature of the target population and limited resources, this sample allows for a more efficient and faster selection of participants.

4.2 Comparative Evaluation

A comparative evaluation was carried out on the scores given by human judges and the software in which each athlete performed the Poomsae Pyongwon. Through a call and simultaneous evaluation of videos provided by the athletes, we sought to corroborate the software's ability to objectively and consistently evaluate the accuracy of the Poomsae, comparing it with the qualifications of specialized judges. This work was carried out in collaboration with the State College of Taekwondo Referees of the state of Veracruz, which provided a body of five judges with extensive experience in Poomsae events recognized nationally.

Fig. 5. Promotional poster and guidelines for recording the video.

A call was prepared that included all the necessary guidelines and guidelines for participation in the evaluation, as well as the requirements that competitors had to follow for recording the Poomsae video (Fig. 5). The categories requested for the comparative evaluation were Youth (2007-2009), Less than 30 (1994-2006) and less than 40 (1984-1993), both in the men's and women's branches. The procedure for evaluating the athletes' Poomsae by the human judges followed the standard used in conventional recognized Poomsae competitions. The judges evaluated the precision of the execution during the performance of the Poomsae, assigning scores according to predefined criteria. In parallel, the developed software also evaluated the accuracy of the Poomsae during its execution in an automated manner, using previously established parameters and algorithms. Once the scores were obtained from both sides, both those assigned by the human judges and those by the software, they were recorded in a control sheet for subsequent analysis.

5 Results

Once the benchmarking was completed, the judges' and software ratings were collected. From the scores assigned by the judges, those corresponding to accuracy were selected and averaged, and the range of variation (VR) was calculated to know the difference between the highest and lowest scores.

Table 2. Accuracy ratings from human judges

No.	J 1	J 2	J 3	J 4	J 5	AVG	VR
1	2.8	2.4	2.8	2.6	2.7	2.66	0.4
2	2.6	2.1	1.3	1.5	2.4	1.98	1.3
3	2.5	1.7	2.2	2.0	2.6	2.20	0.9
4	2.7	2.4	1.8	1.9	2.3	2.22	0.9
5	3.0	2.9	2.9	3.0	3.0	2.96	0.1
6	0.7	1.6	0.9	1.0	1.0	1.04	0.9
7	3.1	3.0	2.9	3.1	3.1	3.04	0.2
8	1.3	1.6	0.5	0.8	1.1	1.06	1.1
9	1.7	1.7	2.6	2.5	2.0	2.10	0.9
10	2.0	2.3	2.7	2.5	2.1	2.32	0.7
11	3.1	2.7	2.7	2.9	2.9	2.86	0.4

The initial data revealed a discrepancy in the scores given to competitors 1 to 4 and 9 to 11. Of the 11 participants, only 4 obtained similar scores, highlighting the problems observed and the need to implement support mechanisms to standardize evaluations (Fig. 6).

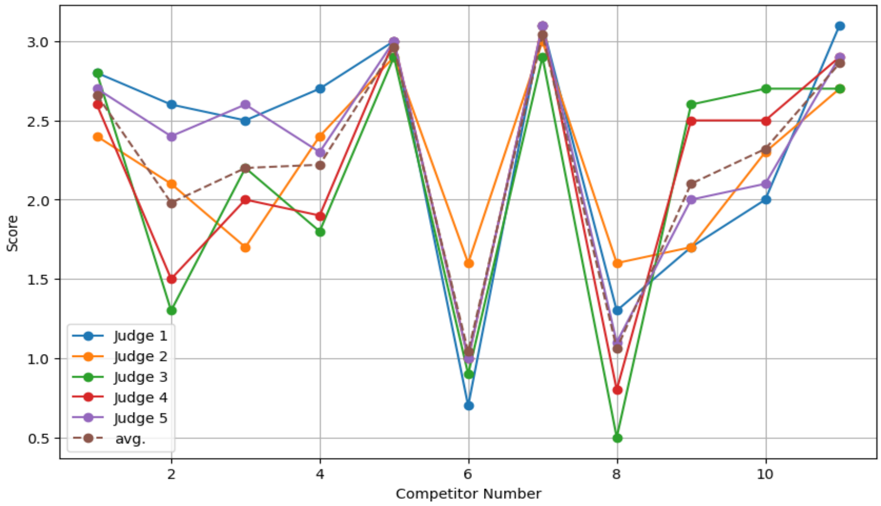

Fig. 6. Accuracy ratings from human judges

The ratings provided by the software were tabulated. A table is presented with the average of the scores given by the judges, the range of values of these scores, the software scores, and the difference between these and the judges' average. The table shows that, in all cases, the software scores were lower than the judges' average due to the efficient heuristics used to evaluate each Poomsae move. These heuristics evaluate the execution angles and distances from the body based on the criteria established in the recognized Poomsae competition regulations[22].

Table 3. Comparison of the average grades of judges and software.

No.	AVG	VR	Software	Difference
1	2.66	0.4	2.2	0.5
2	1.98	1.3	1.4	0.6
3	2.20	0.9	1.6	0.6
4	2.22	0.9	1.2	1.0
5	2.96	0.1	2.5	0.5
6	1.04	0.9	0.4	0.6
7	3.04	0.2	2.7	0.3
8	1.06	1.1	0.7	0.4
9	2.10	0.9	1.8	0.3
10	2.32	0.7	1.9	0.4
11	2.86	0.4	2.5	0.4

The gap between the scores of the human judges and the software is not considered far because it falls within the common ranges of variation of accuracy scores (Fig. 7).

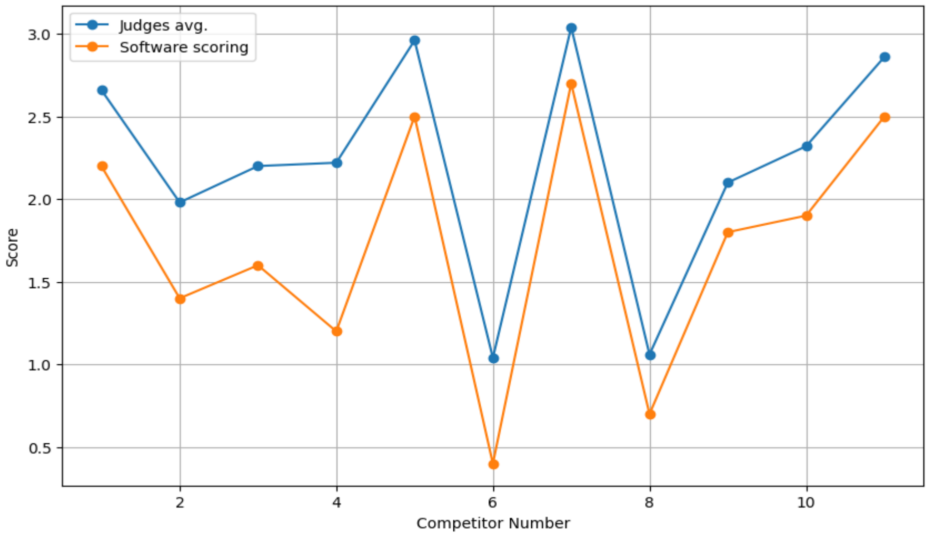

Fig. 7. Comparison of the average grades of judges and software

The software also detects all errors the competitor makes simultaneously, which often escapes the judges. However, the software scores were within an acceptable range of variation compared to the judges' scores.

The following table presents the average of the judges' scores, the highest and lowest scores, the range of values of these scores, the software scores, and the difference between the judges' lowest scores and the software scores.

Table 4. Comparison: minimum range of judges' and software's ratings

No.	AVG	Max R	Min R	VR	Software	Difference
1	2.66	2.8	2.4	0.4	2.2	0.2
2	1.98	2.6	1.3	1.3	1.4	-0.1
3	2.20	2.6	1.7	0.9	1.6	0.1
4	2.22	2.7	1.8	0.9	1.2	0.6
5	2.96	3.0	2.9	0.1	2.5	0.4
6	1.04	1.6	0.7	0.9	0.4	0.3
7	3.04	3.1	2.9	0.2	2.7	0.2
8	1.06	1.6	0.5	1.1	0.7	-0.2
9	2.10	2.6	1.7	0.9	1.8	-0.1
10	2.32	2.7	2.0	0.7	1.9	0.1
11	2.86	3.1	2.7	0.4	2.5	0.2

The difference between the judges' lowest rating and that of the software demonstrates that the software's ratings are within the ranges of those assigned by the judges, with variations equal to or less than between the judges themselves. This indicates that the developed software provides ratings that approximate the expert judgment of the judges, being objective, consistent, and impartial (Fig. 8).

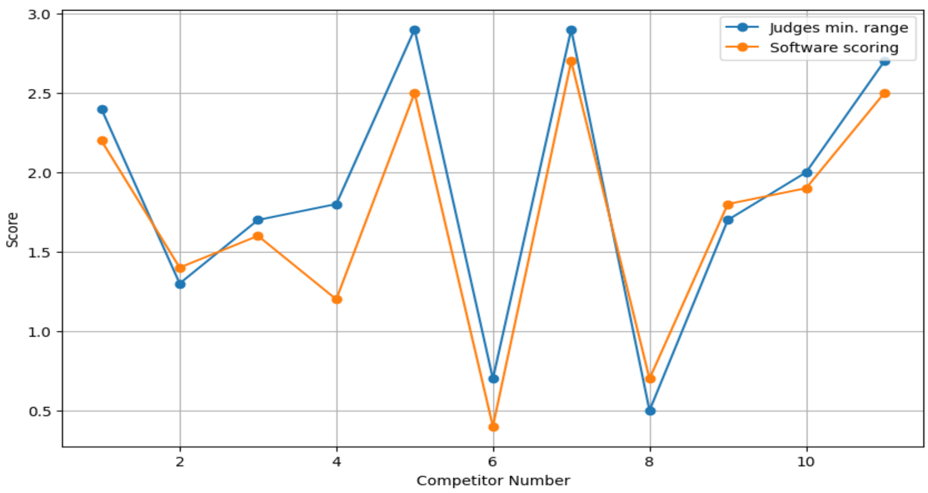

Fig. 8. Comparison: minimum range of judges' and software's ratings

In parallel, the software generated a set of data for each Poomsae evaluated, recording the coordinates of each point of articulation, the phase of the Poomsae, the movement executed (both feet and hands), the phase of the movement, and the deductions granted.

Analysis of the ratings showed that, in most cases, the software presented ratings close to the average of those the human judges gave.

The software excelled at identifying minor errors, such as optimal angles and distances of arm and leg movements, outperforming human judges. He also accurately scored solid movements and defenses or static positions, where the competitor remains motionless for an extended period. However, the software was less accurate in scoring movements with notable occlusion, especially in transient leg movements and some positions.

6 Discussion

Our research proposes software that uses a computer vision framework and specialized algorithms to score Poomsae Pyongwon accurately. The results of the experiment showed that the ratings given by the software were close to those of human judges, reaching expert judgment with precision and effectiveness. The software gave stricter ratings due to the heuristics used in the algorithms, which efficiently process running angles, distances, and lengths. In addition, the software stood out for its ability to quickly rate Poomsae movements and for not omitting errors, which sometimes go unnoticed by human judges.

This work is novel since the systematic literature review revealed that this area is little explored, with few studies addressing the problem raised. Compared to works in other places, the software stands out for its positive results in posture detection, as presented in [12] and [13]. Furthermore, pose detection is proposed, unlike [11], which uses a graph neural network, and [8], which uses support vector machines to build the model. However, given how little the topic has been explored, it would be valuable to explore the possibility of obtaining similar or superior results using artificial vision techniques that are alternative to those used in this research. The software presents high precision by using not only the artificial vision framework for posture detection but also a series of specialized algorithms for the individual qualification of each movement, unlike the reviewed works, which are mainly based on simulation models. Artificial intelligence, some of them pre-trained, for pose recognition and evaluation.

It is not pertinent to compare the works detected in Taekwondo since they focus on different discipline areas, such as kicking metrics in combat, speed, or the effectiveness of movements in the Kyrougi modality. Although they belong to the same discipline, our research has a closer relationship with studies that evaluate specific postures and movements. This reinforces the relevance and need for our contribution in this particular area.

The systematic review of the literature revealed a notable lack, or even non-existence, of specialized and freely accessible data sets that could be used to train artificial intelligence models in the specific scope of this research. This lack of publicly available data represents a significant obstacle to developing and continuously improving tools based on artificial intelligence applied to Poomsae.

Therefore, in addition to evaluating the accuracy of the Poomsae Pyongwon, a dataset (currently in the process of copyright registration for subsequent release in a public repository) has been generated for each Poomsae evaluated, including detailed and relevant information for future technological developments. The availability of these data sets is crucial to fostering research and progress in this field, allowing other researchers to validate and compare their results and develop new applications and methodological approaches.

This initiative drives the growth of the academic and scientific community and provides a foundation for creating more precise and practical tools for evaluating and training Poomsae.

Finally, this research aims to raise the technical level in Mexico by providing public access tools to the competitive Poomsae community. In contrast, the articles reviewed did not show a similar intention to share their developments with the community in their respective areas of study. This approach highlights the commitment to developing and democratizing knowledge and promoting equitable access to advanced technological resources to improve the practice and evaluation of Poomsae in the competitive field.

7 Conclusions and future work

The software proposed in this research rates the accuracy of the Poomsae Pyongwon with ratings close to those of human judges, closely aligning with expert judgment and being unbiased. It meets the objective of guaranteeing fair competition and demonstrated good performance when evaluating videos that met specific recommendations of the call.

The software promises to be a valuable tool for judges, coaches, and athletes. It offers impartial qualifications based on Poomsae guidelines, standardizes evaluations, and serves as a reference for training new judges, improving consistency and transparency in qualifications. It also acts as an ally in training, providing accurate ratings that allow coaches and athletes to identify and correct technical errors, improving athletes' performance and autonomy. This approach democratizes access to high-quality training, allowing athletes to fix technical errors.

This initiative also benefits scientific research by providing detailed data sets for developing machine learning models, data analysis, and other technological advances. These resources significantly boost research in Poomsae, expanding existing knowledge. By encouraging the generation and exchange of data and results, we contribute to the growth of specialized literature in an understudied area, promoting its study and continuous improvement.

This research aims to lay the foundation for future developments in the field, promoting innovation and significant contributions to both sports and scientific research in computer vision and machine learning.

References

[1] R. Fuentes, “Deporte: guerra de cifras - Grupo Milenio,” Grupo Milenio. Accessed: Nov. 10, 2022. [Online]. Available: https://www.milenio.com/opinion/roberto-fuentes-vivar/las-otras-competencias/deporte-guerra-de-cifras_2

[2] TaekwondoData, “Taekwondo Data: World’s largest Taekwondo Database,” Taekwondo Data. Accessed: Oct. 25, 2023. [Online]. Available: https://www.taekwondodata.com/resultlist_country.html?tgid=12

[3] TaekwondoPoomsae, "Mexico Data," Nov. 2023. doi: 10.07.1988.
[4] IOC, "Taekwondo - Noticias, atletas, resúmenes y más," International Olympic Committee. Accessed: Nov. 02, 2022. [Online]. Available: https://olympics.com/es/deportes/taekwondo/#discipline-history-of
[5] P. de R. Añorbe, "Taekwondo: Origen y Evolución," Jul. 2017. Accessed: Jul. 31, 2019. [Online]. Available: https://buleria.unileon.es/bitstream/handle/10612/7963/RUFINO%20A%C3%91ORBE_PEDRO%20DE_JULIO_2017.pdf?sequence=1&isAllowed=y
[6] A. M. Osório-Costa, "Performance Evaluation: Subjectivity, Bias and Judgement Style in Sport Data," *SSRN Electronic Journal*, Jan. 2019, doi: 10.2139/SSRN.3321838.
[7] W. Lu and X. Lin, "Application and Analysis of Taekwondo Techniques, Tactics, and Movement Trajectories Based on Multi-Intelligent Decision Making.," *Math Probl Eng*, pp. 1–8, Mar. 2022, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=asn&AN=156056370&lang=es&site=ehost-live
[8] L. Hailong, "Role of artificial intelligence algorithm for taekwondo teaching effect evaluation model.," *Journal of Intelligent & Fuzzy Systems*, pp. 1–12, Sep. 2020, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=bth&AN=147565143&lang=es&site=ehost-live
[9] J. Liu, Y. Zheng, K. Wang, Y. Bian, W. Gai, and D. Gao, "A Real-time Interactive Tai Chi Learning System Based on VR and Motion Capture Technology," *Procedia Comput Sci*, vol. 174, pp. 712–719, Jan. 2020, doi: 10.1016/J.PROCS.2020.06.147.
[10] W. Ye, S. Li, S. Liu, and Y. Zhou, "Application of Artificial Intelligence Technology in Martial Arts Education Governance.," *Discrete Dyn Nat Soc*, pp. 1–13, Aug. 2022, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=asn&AN=158785234&lang=es&site=ehost-live
[11] X. Guo, "Research on Multiplayer Posture Estimation Technology of Sports Competition Video Based on Graph Neural Network Algorithm.," *Comput Intell Neurosci*, pp. 1–12, Apr. 2022, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=asn&AN=156079873&lang=es&site=ehost-live
[12] Q. Wang, "Application of Human Posture Recognition Based on the Convolutional Neural Network in Physical Training Guidance," *Comput Intell Neurosci*, vol. 2022, 2022, doi: 10.1155/2022/5277157.
[13] H. Jiang and S.-B. Tsai, "An Empirical Study on Sports Combination Training Action Recognition Based on SMO Algorithm Optimization Model and Artificial Intelligence.," *Math Probl Eng*, pp. 1–11, Jul. 2021, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=asn&AN=151367500&lang=es&site=ehost-live
[14] R. Liu, "A Study of Athlete Pose Estimation Techniques in Sports Game Videos Combining Multiresidual Module Convolutional Neural Networks," *Comput Intell Neurosci*, vol. 2021, 2021, doi: 10.1155/2021/4367875.

[15] L. Wang, A. Paul, S. K. S. Cheung, C. C. Ho, and S. Din, "Simulation of athlete gait recognition based on spectral features and machine learning.," *Journal of Intelligent & Fuzzy Systems*, vol. 40, no. 4, pp. 7459–7470, Apr. 2021, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=bth&AN=151821578&lang=es&site=ehost-live
[16] J.-A. Wang, S. Liu, and X. Zhang, "Application of artificial intelligence in university sports risk recognition and identification.," *Journal of Intelligent & Fuzzy Systems*, pp. 1–12, Oct. 2020, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=asn&AN=147566023&lang=es&site=ehost-live
[17] F. Kong, Y. Wang, T. Guarda, I. Lopes, and Á. Rocha, "Design of computer interactive system for sports training based on artificial intelligence and improved support vector.," *Journal of Intelligent & Fuzzy Systems*, vol. 37, no. 5, pp. 6165–6175, Nov. 2019, [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,url,uid,cookie&db=asn&AN=139809151&lang=es&site=ehost-live
[18] C. Lugaresi *et al.*, "MediaPipe: A Framework for Building Perception Pipelines," *Google Research*, Jun. 2019, Accessed: Nov. 16, 2023. [Online]. Available: https://arxiv.org/abs/1906.08172v1
[19] Google, "MediaPipe Framework," Google for Developers. Accessed: Nov. 16, 2023. [Online]. Available: https://developers.google.com/mediapipe/framework
[20] J. Escobar-Pérez and A. Cuervo-Martínez, "Validez de contenido y juicio de expertos: una aproximación a su utilización," *Avances en medición*, vol. 6, no. 1, pp. 27–36, 2008.
[21] R. M. Flores-Rodriguez, *Fundamentos de la metodología de la Investigación*, 1st ed., vol. 1. Madrid, 2014. Accessed: Mar. 12, 2024. [Online]. Available: https://www.google.com.mx/books/edition/Fundamentos_de_la_metodolog_a_de_la_Inve/0gmGDwAAQBAJ?hl=es-419&gbpv=0
[22] WT and FMTKD, "Reglamento de competencia e interpretación Poomsae," May 2019.