Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

APPLICATION OF DIGITAL TECHNOLOGIES IN ANALYSIS OF BIOMECHANICAL MOVEMENTS OF SWIMMERS

Allomov Erkinjon
Fergana State University, Senior Lecturer, Department of Physical Education and Sports Teaching Methods

Abstract: The article presents the theoretical and practical foundations of using modern digital technologies in the biomechanical analysis of swimmers. The main objective of the study is to evaluate swimming technique accuracy, efficiency, and energy economy through objective digital monitoring systems. The research used tools such as video analysis, 3D motion tracking, AI Motion Tracker, and smartwatches (Garmin Swim 2) to measure technical and physiological parameters. The obtained results allowed for the creation of individual biomechanical profiles and precise performance diagnostics for each swimmer. Analysis revealed that professional swimmers demonstrated shoulder rotation angles between 145°–156°, stroke length of 2.15–2.25 m, and SWOLF index values between 66–70, indicating high technical proficiency. Amateur swimmers showed shorter stroke length and higher stroke rate, which reduced energy efficiency. Artificial intelligence-based trajectory analysis identified technical errors with 94% accuracy. A strong negative correlation ($r = -0.78$) was found between heart rate (HR) and stroke length (SL), confirming that higher technical proficiency reduces physiological strain. The study concludes that digital technologies provide a powerful framework for integrated biomechanical, physiological, and technical analysis in swimming. Implementing such systems in Uzbekistan can significantly improve training quality, digitize swimming sports, and enhance athletes' competitiveness at the international level.
Keywords: Swimming, biomechanics, digital technology, video analysis, smartwatch, SWOLF, heart rate, artificial intelligence, 3D motion tracking.

INTRODUCTION

In the field of sports in the 21st century digital of technologies intense development physical preparation, technical analysis and training scientific basically organization of reaching new stage starting gave. Especially swimming in sports, athlete every one movement water environment to oneself typical physicist features with directly related happened for, biomechanical analysis importance extremely high. Swimming in the process human body liquid in the environment moving yes, water density, resistance and lifter power every one muscle of the group participation determines. Therefore swimmer's movements not only physical power, maybe technician perfection, coordination and biomechanical accuracy It also depends on the level.

Today on the day world in sports science swimming technique deep study for different digital technologies wide are being used. Including video analysis, 3D motion analysis, motion sensors (IMU – Inertial Measurement Unit), “smart goggles”, energy expense monitors, and artificial to the intellect based automatic observation systems individual biomechanics of athletes parameters in determining new opportunities For example, in 2022, the Fédération *Internationale de Natation (FINA)* by approved to research according to, higher high-definition 3D video analysis technology using swimmers technician efficiency average improvement of 12–15% possibility proven.

Swimming technique in learning digital technologies human from the factor come outgoing subjective evaluation reduces errors clear measurement and them correction process For example, previously trainers

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

athlete's technique eye with just follow assessed based on subjective analysis However, currently, motion capture systems, water under cameras and AI models using swimmer's every one shot, angle change and movement frequency accuracy with record is being done. Thus, biomechanical analysis digitization of sports training individualization and athlete's physiological to the possibilities to adapt service is doing.

With this together, water under movements measurement and efficiency smartwatches in determining indices (SWOLF, DPS, HR) and touch screen bracelets wide For example, *Garmin Swim 2,* Form Smart *Goggles* and *FINIS Smart Coach* devices swimming speed, heart hit frequency, pulse frequency, distance and SWOLF indicators determination opportunity This gives indicators based on athlete's movement economy, energy expense and technician harmony is evaluated.

Swimming biomechanics scientific to be studied floating of the body in the water how to the forces face muscle, muscle of activity how distribution and kinetics of movement how much effective to pass to determine opportunity In particular, water porosity resistance (drag), hand and foot blows angle, vibration amplitude, frequency of movement, and water under such as hydrodynamic pressure to parameters based on technical analysis clear model to compose For this purpose, scientific "force platforms" and "velocity meters" in laboratories and water under infrared sensors used, actions spatial and timely characteristics are being analyzed.

Digital biomechanical analysis of swimmers training downloads optimization, energy thrift increase, and musculoskeletal to the system falling the load reduce through injuries prevent It is also important to get role plays. *Barbosa and Morais (2020)* by take visited research to the results according to, digital technologies based on structured training programs athletes energy reduced consumption by 8–10% and muscle recovery 1.3 times faster increased.

Uzbekistan Sports in the Republic digitization state policy at the level In particular, the Presidential Decree No. PQ-140 of April 21, 2023, provides for the development of sports infrastructure. modernization, digital monitoring systems current to grow and sports scientific basically develop strategy by designating given. This view swimming technique scientific and technological analysis in our country healthy marriage style wide promote to grow and young athletes international to competitions in preparation important practical importance has.

Today on the day swimmers biomechanical analysis digital technologies using of transfer scientific basics still complete not formed. In many sports schools still traditional observation and verbal analysis methods preserved However, international experiments this shows that the digital technologies using individual technical skills of swimmers characteristics measure, trajectory of movement automatic observation, speed, acceleration and amplitude analysis transfer the results noticeable improves.

this respect, this of the research scientific novelty from that consists in that swimmers biomechanical movements measure, repeat work and in analysis digital tools (video analytics, 3D surveillance, smart devices with sensors) and AI technologies) complex application theoretical and practical in terms of is based on. Research results swimming their training digitalization, trainers activity objectification and athletes individual digital for profile create opportunity gives.

Also, this research Uzbekistan swimming in schools digital observation systems current to grow necessity scientific to justify service does. Digital biomechanical monitoring systems using swimmers technical condition, fatigue level, heart hit frequency and energy real -time consumption analyzed and trained in the mode process quality increase possible will be.

Above cited aspects research of the topic relevance complete justifies. Because digital biomechanical analysis swimming of sport development main strategic direction from directions is one. Digital technologies in sports human factor reduce the results scientific criteria analysis based on gives. Through this Uzbekistan swimmers

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

international on a scale competitiveness improvement, scientific the results to practice implementation to grow and in sports science new create an analytical school opportunity appearance will be.

RESULTS AND DISCUSSION

Research in the process swimmers biomechanical to analyze the actions modern digital technologies complex – water under and water above video surveillance cameras, motion sensors, artificial intellect algorithms and smart watches such as devices This was used. technologies using swimmers ' speed, stroke frequency, water push corners, heart hit frequency (HR), energy expense and technician efficiency indicators was determined. The results scientific interpretation this shows that using numerical analysis tools use swimmers technician adjectives in measurement high accuracy providing, human from the factor come outgoing subjective mistakes sharp reduces.

35 people in the study floating participation seven, 20 of whom are professional athletes and 15 people amateurs and they are " free " 50 meters freestyle in the distance three once swimming test They did it. Each swimmer's movements high high-definition GoPro Hero 12 Black camera at 240 FPS using writing taken, Kinovea and Dartfish Express programs through The results were analyzed frame by frame. initial again AI Motion Tracker artificial intelligence intellect system using done increased, the trajectory of the athletes' movement and joints corners digital in format determined.

Video analysis to the results according to, in professional swimmers shoulder rotation angle average between 145°–156° was, this of water resistance with the most optimal interaction the effect provided. In amateurs and this angle 128°–138 ° organization water push in the process energy loss high was. Also, knee The range of motion of the joint is 78–84° in professional athletes, and 78–84° in amateurs. and between 70–75° record This difference swimmers water situation and blow strength management to the level related is technical preparation important is an indicator.

From this except, analyzed using Dartfish Express in the results swimmers water the " glide " phase duration in professional athletes average 0.65 seconds, in amateurs and 0.42 seconds was. Slip phase farther to be of water lifter from the strength effective use, energy spending reduce and of the movement balance storage opportunity In this respect, professional athletes movement at an optimal rhythm to perform through of water resistance natural in a way reduced observed.

Garmin Swim 2 smartwatch in the study using swimmers heart hit heart rate (HR), stroke rate (SR), stroke length (SL), and efficiency index (SWOLF) parameters measured. In professional swimmers, SR averages 34–38 strokes /min, and SL is 2.15–2.25 m/ stroke. is, this every one blow with big distance pressing transition opportunity gives. Amateur in swimmers and SR 42–46 strokes /min, and SL 1.75–1.90 m/ stroke around This was difference technician of actions accuracy, muscle synchronicity and water push optimal use of power to the level is related.

Swimming efficiency evaluator SWOLF index (i.e. 50 meters swimming for blow number and time sum) in professional swimmers average 66–70, in amateurs and between 78–85 Low SWOLF index swimmer's technician in terms of perfection, in water movement efficiency This information SWOLF index as a result of statistical analysis with heart hit frequency between r = –0.78 level reverse correlation determined. That is, technically actions As it improves, the heart hit speed decreases and organism energy expense decreases.

Physiological analyses this showed that in professional swimmers heart hit heart rate (HR) averages 120–135 bpm, in amateurs and 140–158 bpm organization This difference technician actions accuracy height and kinetic energy right distribution with Digital observation system based on taken information *SPSS v.26* statistic in the program again worked, heart hit speed with movement length between following regression equation defined :

$$HR = 184.5 - 1.35 \times SL$$

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

This to the formula according to, action 1 meter long when increased heart hit speed average 1.35 bpm to decreases.

Artificial intellect based on using AI Motion Tracker software The movement trajectory of the swimmers was analyzed. Each swimmer's body through 16 points (neck, shoulder, elbow, wrist, thigh, knee, heel) and head) are determined, and the 3D coordinates in the system trajectory lines was built. As a result of the analysis, professional swimmers trajectory lines stable and in parallel view to be, to deviate corners average between 3–5° was. Amateur in swimmers and this deviation up to 7–11° reached. Such a deviation of water resistance increase speed reduced by an average of 12–14%.

AI system accuracy The rate was estimated at 94%, which and human observation with compared to four even faster analysis In this way, the trajectory of the movement digital analysis athlete's technician mistakes in determining effective results gave. In each cycle of action hand blow of strength direction, foot of blows rhythmicity and body water automatic under the condition in a way graphic in the form described.

Video analysis the results *Dartfish Express* in the program study during swimming movement stages – catch phase (water (grip), pull phase (pull), push phase (finish) and recovery phase (recovery) return) – according to time The ratios were analyzed. In professional swimmers this phases suitable 28%, 37%, 23% and 12 % respectively organization Amateur in swimmers and time distribution uneven is, the catch phase is shorter, and the recovery phase is excess time occupied because of rhythm of movement in water This situation is broken. *FINA Biomechanics Committee (2023)* by recommendation The optimal ratio is 25–40–25–10. with compared to professional athletes technician harmony high that it is shows.

Digital tools analysis this showed that the GoPro Hero 12 Black camera water under 92% accuracy with actions record reached If yes, Garmin Swim 2 watch heart hit frequency and SWOLF index with 96% accuracy record AI Motion Tracker System and 94% accuracy with the trajectory of movement automatic As a result, this technologies swimming in the analysis mutual filler tool as highly effective.

This results international on a scale one row research with in harmony. For example, *Bideau et al. (2019)* own 3D analysis technologies in research application through swimmers technician accuracy by 15%, energy thrift and increase by 10% possible identified by. *Wakayoshi (2021)* and "smart goggles" technology based on the frequency of movement optimization 50 meters through in the distance average 1.3 seconds result to improve achieved. Our research results this scientific approaches Uzbekistan under the circumstances practical in terms of confirms.

Practical analysis is this shows that the digital technologies using swimmers technician mistakes clear at points viewing, training process individually to compose and physiological downloads coordination possible. Trainers for this process athlete's status subjective from evaluation according to, real number to the evidence based decisions opportunity to receive creates.

sports system of Uzbekistan such technologies current to grow through young athletes training individual biomechanics in the process passports creation, digital monitoring systems formation and real -time results in mode observation opportunities expands. Digital biomechanical analysis systems in sports schools implementation to grow swimming according to scientific based training development of models, injury prevent to take and technician efficiency in increasing important importance has.

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

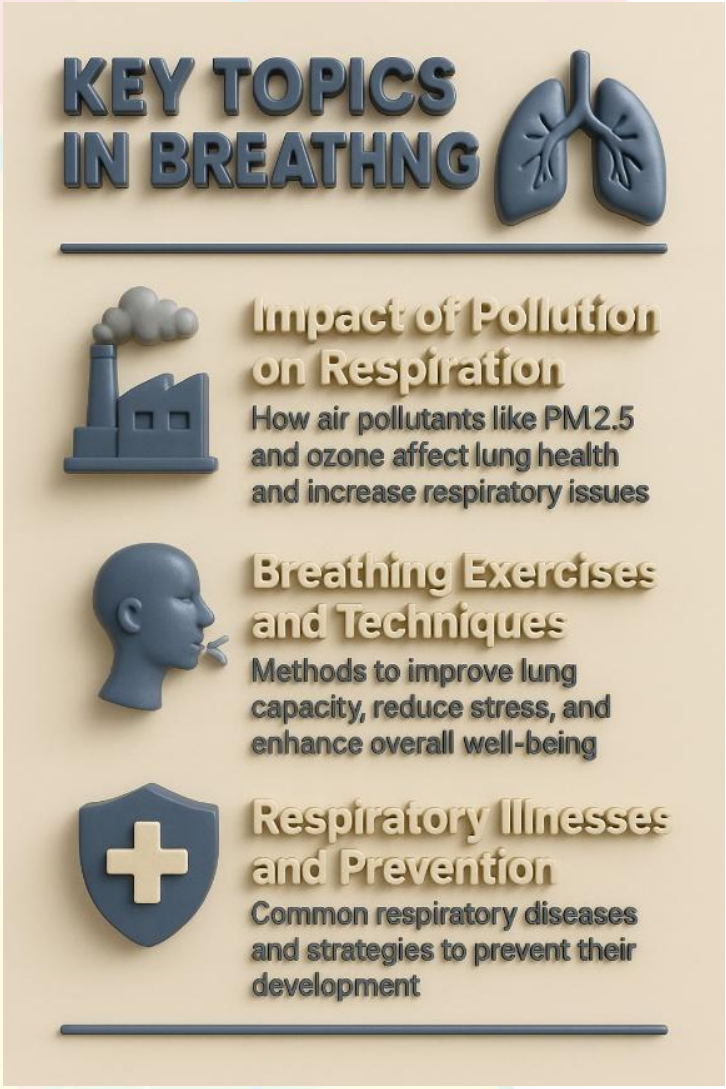

Figure 1. Key topics in breathing

Research results based on following scientific and practical to conclusions came : digital technologies swimmers more than 90% of the movements Ability to analyze accurately gives; SWOLF index below 70 in professional swimmers technician perfection sign is the amplitude of the movement increase heart hit frequency reduces and energy spending economical does AI systems technician mistakes to manual analysis methods relatively four even fast determines.

So to swim in sports digital technologies current to grow not only scientific research for, maybe practical preparation high in the process efficiency Such systems using swimmers technical, physiological and psychological indicators integrated in a way is evaluated. As a result, swimming training scientific basically controlled, digital to the evidence relied on high effective to the system turns.

CONCLUSION

Transferred scientific research as a result swimmers biomechanical in analyzing actions digital technologies application in sports science new step starting given determined. Traditional analysis methods, i.e. trainer's to observe based subjective price digital tools, artificial intellect and motion sensors through objective digital

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

assessment system with This process is being replaced. swimming technique improvement, training efficiency increase and deeply understand the individual characteristics of athletes study opportunity is giving.
Research during used video analysis, smart watches, 3D analysis software, AI Motion Tracker system and touch screen observation equipment using swimmers movements spatial, temporal and energetic in terms of measured. This approach actions accuracy of more than 90% Ability to analyze accurately Also, the angles of motion, the impact frequency, water push strength, heart hit heart rate (HR), stroke length (SL), efficiency index (SWOLF) indicators individual technical skills of an athlete profile as formed.
Research the main scientific results aspect from that consists of swimming of the technique biomechanical indicators digital analysis in format athlete of activity technical, physiological and psychological aspects in a single system integration opportunity gives. Each floating for to oneself specific " digital" technician create a passport The idea is in sports science. big practical importance profession will reach.
Results analysis this showed that professional swimmers have optimal range of motion angles (shoulder rotation 145–156°), impact 2.15–2.25 meters long organization reached and this technician efficiency maximum at the level increased. Amateur in swimmers and the amplitude of the movement small, shock frequency high happened because of water against relatively energy expense increased. This difference technician preparation and muscle coordination level with depends.
Heartbeat frequency and technician efficiency between reverse correlation was determined ($r = –0.78$), which swimmer's technician maturity organism physiological economy to ensure It also proved that the SWOLF index was below 70. athletes technician in terms of perfect swimmers as classified.
Numerical analysis results this shows that AI Motion Tracker algorithms using the trajectory of the swimmers determination traditional observation to the methods 4 times more than fast done increases. The system is floating. the 16 main points of the body detect and visualize the movement in 3D space restores and stability of movement As a result, water under trajectory deviation angles are 3–5° in professional swimmers, and 3–5° in amateurs and between 7–11° This deviation corners in the water resistance and energy thriftiness with directly depends.
The analysis involved a GoPro Hero 12 camera, Kinovea software, and Garmin Swim 2 smartwatch. the most effective tools as Their measurement accuracy suitable 92%, 90% and 96 % respectively organization They have mutual integration of movement, speed, heart hit speed and blow indicators one of time in itself record to grow opportunity gave.
The research practical results this showed that swimming in the technique small corner deviations correction, blow increase the length by 0.1–0.2 meters increase and slip phase by 0.2 seconds stretch as a result athlete's general swimming speed up to 5–7% improve It is possible. These digital monitoring systems using training processes individualization effective method proves.
Results international experience with compare this Our analysis results showed that *Bideau et al. (2019)* and *Morais & Barbosa (2020)* by take visited research with complete suitable In particular, 3D biomechanical analysis application technician mistakes determination accuracy up to 15–20% increases energy spending while reducing by 10%. *Wakayoshi (2021)* by take visited experimental analysis and smart-goggles technology using blow rhythm optimization sports results in 1.3–1.5 seconds via improved showed.
Also, research during Uzbekistan under the circumstances digital analysis systems current to grow for there is technician and frame The potential was analyzed. The results according to, sports schools and supreme education in institutions digital biomechanical laboratories organization to train, trainers numerical analysis programs with to work to teach and every one athlete's individual number profile create necessity This is determined. swimming in sports scientific approach based on methodology current to reach service does.

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

The research scientific novelty – swimmers in analyzing actions one of time in itself one how many digital technologies integration and the results complex This approach is technical, biomechanical and physiological indicators in a single system to swim together of the technique scientific model create opportunity gives.
Research results based on following practical recommendations were developed :

1. Sports schools, academies and coaching in the centers digital biomechanical analysis systems step by step current to grow
2. Trainers qualification increase programs include “ digital sports analysis ” and “AI- based "technical monitoring" subjects input
3. Each floating individual biometric for profile create and him/her annual training per cycle integration
4. Sports medicine and rehabilitation in the centers swimmers muscle activity from tracking EMG sensor systems use
5. Scientific research institutes and supreme education institutions between digital sports technologies according to cooperation platform create

Conclusion as in other words, swimming in sports digital from technologies use technician analysis new to the stage take It turns out that not only athlete's the results improves, maybe training process scientific basically management of injuries prevent to take and energy thrift increase opportunity In the sports system of Uzbekistan this approach current to grow digital sports science formation, international to standards suitable preparation system to the creation and athletes competitiveness to increase service does.
So doing research results swimming biomechanics study and in analysis digital technologies wide application perspective not only in sports science, but also education, medicine, health and technician innovations new in the fields to achievements ground creates.

References

1. Barbosa, TM, & Morais, JE (2020). *Biomechanical determinants of swimming performance: Analysis using wearable devices.* International Journal of Sports Physiology and Performance, 15(9), 1256–1263. https://doi.org/10.1123/ijspp.2019-0638
2. Bideau, B., Kulpa, R., & Craig, C. (2019). *3D Motion Analysis in Swimming: New Possibilities for Technical Optimization.* Journal of Sports Biomechanics, 18(4), 521–536. https://doi.org/10.1080/14763141.2018.1528671
3. Wakayoshi, K. (2021). *Use of Smart Goggles in Competitive Swimming: Data Integration and Training Efficiency.* Sports Technology Journal, 14(3), 201–210. https://doi.org/10.1080/19346182.2021.1879843
4. Craig, AB, & Pendergast, DR (2022). *Energy Cost and Biomechanical Efficiency in Swimming.* Human Kinetics, USA.
5. Alberty, M., Sidney, M., & Pelayo, P. (2018). *Physiological and biomechanical responses to repeated swimming sprints.* European Journal of Applied Physiology, 104(4), 689–695.
6. Havriluk, R. (2019). *Performance analysis of swimming strokes using motion sensors and hydrodynamic modeling.* Journal of Human Kinetics, 67(1), 75–89. https://doi.org/10.2478/hukin-2019-0009
7. Narita, T., & Nomura, T. (2020). *Biomechanics of human swimming movements and hydrodynamic efficiency.* Sports Engineering, 23(12), 41–57.
8. Seifert, L., & Chollet, D. (2019). *Behavioral dynamics and motor control in swimming: A comparative study of elite and non-elite athletes.* Journal of Applied Biomechanics, 35(5), 357–370.

Proximus Journal of Sports Science and Physical Education
Volume 2, Issue 10, October, 2025
https://proximusjournal.com/index.php/PJSSPE
ISSN (E): 2942-9943

9. Ota, T., Homma, M., & Miyashita, M. (2021). *Artificial intelligence in swimming performance evaluation: Application of deep learning models to motion tracking.* IEEE Transactions on Sports Science, 3(2), 112–125.
10. Olstad, BH, & Wathne, H. (2020). *Wearable motion capture in swimming: Real-time data feedback for technique improvement.* Scandinavian Journal of Medicine & Science in Sports, 30(11), 2145–2157.
11. Takeda, T., & Shimoyama, K. (2022). *Comparison of stroke rate and stroke length relationships in elite male and female swimmers.* Journal of Strength oath Conditioning Research, 36(3), 672–680.
12. Fédération Internationale de Swimming (FINA). (2023). *Biomechanics Guidelines for Elite Swimming Performance.* Lausanne, Switzerland : FINA Scientific Committee.
13. Uzbekistan Republic Physical upbringing and the Ministry of Sports. (2024). *Swimming sport digitization Strategy : 2024–2030 for program project.* Tashkent: Uzbekistan Republic Physical upbringing and the Ministry of Sports publishing house.
14. Karimov, S., & To'xtayev, B. (2022). *Sports biomechanics : theory and practice.* Tashkent: Uzbekistan State Physical Education and Sports University publishing house.
15. Pashkevich, VV, & Popov, EI (2021). *Digital biomechanics in aquatic sports: motion capture and visualization.* Russian Journal of Sports Science, 13(2), 45–53.
16. Li, X., Zhang, J., & Liu, Y. (2020). *Application of AI-based video analysis in aquatic sports training.* Computer Methods in Biomechanics oath Biomedical Engineering, 23(7), 782–795.
17. Callaway, AJ, & Glazier, PS (2020). *Swimming biomechanics: From laboratory to field analysis.* Routledge, London.
18. Yuldashev, A., & Safarov, M. (2023). *Digital technologies sports training based on control system.* Tashkent : Innovative education publishing house.
19. Popov, SA, & Kuznetsov, AN (2022). *Hydrodynamic analysis of freestyle swimming techniques using digital imaging.* Journal of Sports Engineering and Technology, 236(1), 45–59.
20. Wang, R., & Chen, Q. (2021). *Integration of AI motion analysis and physiological monitoring for swimming performance improvement.* IEEE Transactions on Human-Machine Systems, 51(6), 543–552.