Application of Computer Vision Technologies to Reduce Injuries in the Athletes' Training

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Abstract. Computer vision technologies can be used to track the movements of an athlete while performing diagnostic or training exercises. Through the analysis of this data, coaches and medical professionals can identify potential problems in athletes' movements, such as incorrect movements, overloads, and imbalances. This allows to capture deviations in the athlete's musculoskeletal system, develop individual training plans, and adjust technique to prevent injury and improve performance. Computer vision can be used to monitor the condition of athletes in real-time. Such systems can detect fatigue and stress in athletes and alert coaches and medical staff on possible problems. At this stage, the development of computer vision technologies for diagnosing athletes and preventing injuries should not replace professional medical care and consultation with specialists. It is a tool that can help coaches and medical staff make better-informed decisions and improve athlete performance.

Keywords: computer vision · musculoskeletal system · athletes · diagnosis

1 Introduction

The physiological result of the training process is the body's adaptation to the load, causing certain morphological and functional changes, including in the athlete's musculoskeletal system. These changes are not always positive - they often lead to significant compensatory changes - somatic dysfunctions [4].

One of the most common reasons for leaving sports is the presence of an injury caused by disorders of the musculoskeletal system.

The knee joint is most often affected (more than 50% of all disorders of the musculoskeletal system). The joints of the upper limbs (shoulder, elbow, hand - 20%), the ankle joint (10%), the lumbar spine (10%), and the thoracic spine (10%) are in the high-risk zone. These percentages vary greatly depending on the specific sport.

The most common cause of injury is a constant excessive load, leading to link deformations: thickening, stretching, compaction, wear, etc. [2].

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So, for example, in figure skaters, the load on the knee joint when landing after a jump is up to 300 kg (five times the weight of the athlete himself). In the case of a slight distortion of the technique under this load, the athlete is likely to receive an injury of varying severity: from sprain and micro tear, to complete separation of the cruciate or rupture of the collateral ligament.

Another consequence of constantly occurring loads is the appearance of motor asymmetries caused by the specifics of the sport (fencing, tennis and table tennis, throwing sports, etc.). In this case, as a result of overstrain of the leading limbs and insufficient loading of the subdominant ones, dissimilation processes are activated and lead to increased fatigue and irrational energy consumption of each limb, which increases the risk of injury.

It is also necessary to take into account external injuries in sports: for example, in ice hockey, the situation with injuries is aggravated by the influence of environmental factors (temperature, ice, opposition from an opponent, stick strikes, puck hits, etc.), so any violations in the musculoskeletal system significantly increase the risk of the injury itself [9].

But the problems described above are associated not only with sports activities but also with the everyday life of a child and an adult. The increased volume of receiving and processing information through a computer makes a person spend most of their working time in a sitting position in front of a computer, in a position that allows them to see the monitor screen and type text on the keyboard. This position significantly aggravates the condition of the muscles of the musculoskeletal system.

Also, the problem of muscle dysfunction is exacerbated by the sedentary lifestyle of a person of the 21st century - so after a sedentary job, a person moves home by car in a sitting position and often spends the evening at home in front of the TV while sitting. All this leads to active growth of spinal diseases, osteochondrosis, exacerbation of chronic pathologies, muscle atrophy also starts, strength decreases, and the transmission of neuromuscular signals is disrupted. With hypodynamia, the muscles stop responding quickly to brain commands, and severe discoordination develops.

The most common consequence of a sedentary lifestyle is degenerative diseases of the spine. With prolonged work in a sitting position, the load on the back increases by 50–60% [10].

According to the observations of neurologists, every second office employee under the age of 50 complains of cervical osteochondrosis, scoliosis or spondylosis. Diseases develop gradually, they are associated with improper redistribution of the load on the vertebrae, insufficient intake of calcium into bone tissue, and slowing of blood circulation [12].

When a particular disease occurs, a person often goes to the doctor for a long way of examinations and drug treatment, after which one way or another there are consequences in the form of pathologies.

These facts make the problem of finding and substantiating methods for the prevention of sports and domestic injuries in the early stages relevant.

2 Diagnosis of the Musculoskeletal System Through Exercises

Diagnosis of the musculoskeletal system is possible with the help of exercises that are usually performed under the guidance of a specialist. It includes exercises that help assess the functional state of muscles, joints and ligaments.

One such exercise is the overhead squat. This exercise allows you to evaluate the strength, flexibility, coordination and stability of the body. It involves lifting a dumbbell or other object overhead and then doing a squat. A person is required to use many muscle groups and joints, including the shoulder, elbow, wrist, hip, knee and ankle.

When performing an overhead squat, the specialist pays attention to several key aspects that may indicate problems in the musculoskeletal system [13]:

- stability and balance. If a person has difficulty maintaining balance during an exercise, this may indicate problems with coordination and stability;
- flexibility. If a person has limited flexibility in the joints, then this can lead to incorrect body position, which can lead to injury;
- strength. If a person has difficulty lifting a dumbbell or other object above their head, this may indicate insufficient strength in the muscles of the shoulder girdle and arms;
- coordination. If a person has problems with the coordination of movements, then this may indicate problems in the nervous system;
- pain or discomfort. If a person has pain or discomfort in the joints, this may indicate the presence of injuries or diseases of the musculoskeletal system.

Analysis of the musculoskeletal system without the appropriate instrumentation can be significantly difficult. Although physicians and specialists can make some assessment of the musculoskeletal system with eyes and touch, without the use of appropriate instruments and additional studies, the analysis may be incomplete and inaccurate [11].

3 Computer Vision for Analysis of the Musculoskeletal System

ML Kit Pose Detection is the most common development tool provided by Google that uses machine learning to detect the posture and movements of the human body. This tool can be used to create a digital twin of the musculoskeletal system.

ML Kit Pose Detection detects a person's pose in an image and recognizes 33 key points on the human body. These points include the upper and lower body, as well as the arms, legs, and head.

The key points that ML Kit Pose Detection recognizes include: right and left ear, right and left eye, nose, right and left shoulder, right and left elbow, right and left wrist, right and left shoulder blade, right and left thigh, right and left knee, right and left leg, right and left foot, right and left hand, right and left fingers.

Each of these points has *(x, y)* coordinates, which represent the position of the point in the image. These coordinates can be used to analyze a person's posture and movements, as well as to create a digital twin of the musculoskeletal system [8] (Fig. 1).

To build vectors between key points, you can use their coordinates. Each vector will have a starting point at one of the key points and an endpoint at the other key point [14].

For example, consider a vector that connects the left shoulder and the left elbow. This vector will have a starting point at *(x1, y1)* coordinates that represent the left shoulder

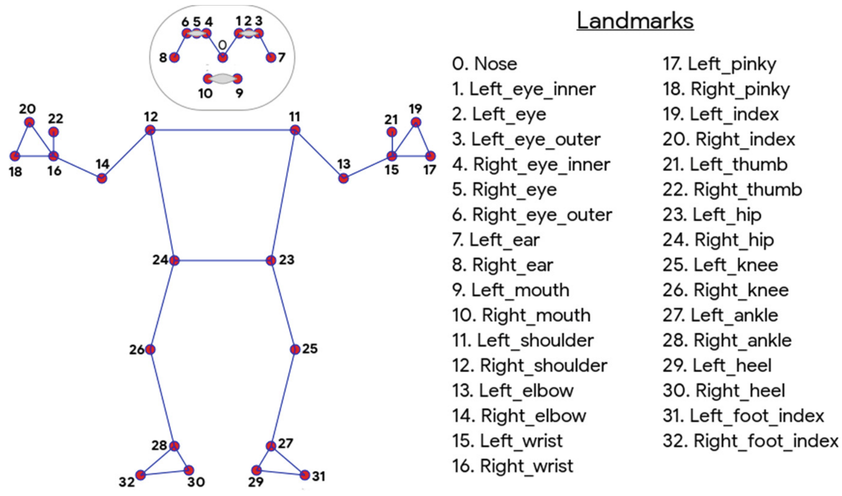

Fig. 1. ML Kit Pose Detection key points.

position and an endpoint at *(x2, y2)* coordinates that represent the left elbow position. To build a vector between these points, you need to calculate the difference between the x and y coordinates for each point:

$$x2 - x1 = dx$$

$$y2 - y1 = dy$$

These values will be the coordinates of the vector that connects the left shoulder and the left elbow. Next, you can calculate the length of the vector using the formula:

$$len = sqrt(dx^\wedge 2 + dy^\wedge 2)$$

This formula calculates the distance between the start and end points of a vector. You can also calculate the angle between the vector and the x-axis using the formula:

$$angle = a\,tan2(dy, dx)$$

This formula calculates the angle between the vector and the x-axis in radians.

By using vectors between key points, additional information about the person's posture and movements can be obtained. For example, you can calculate the angles between vectors to determine which parts of the body are in a certain position. You can also calculate the speed and direction of movement of body parts [3].

4 Specialized Software for Computer Vision Aided Analysis of the Musculoskeletal System

Specialized software was developed using a software-instrumental environment based on the ontological approach, in which the domain ontology is represented as a meta-associative graph.

An ontological structure has been created to provide the possibility of storing, modifying and processing data on diagnostic exercises, athletes and the state of their musculoskeletal system [1, 7] (Fig. 2).

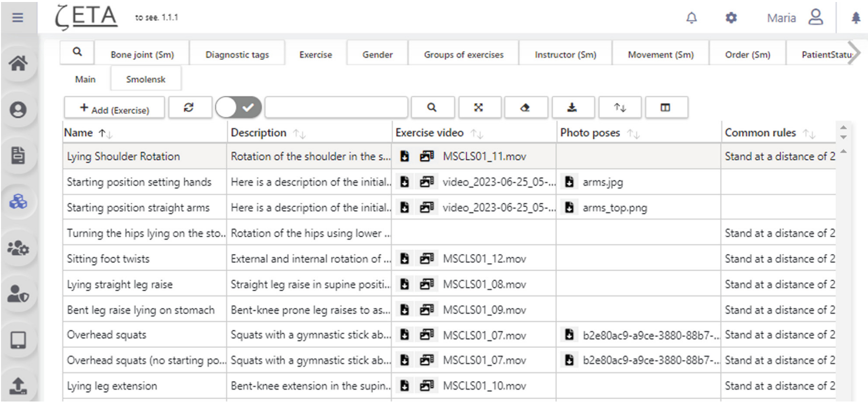

Fig. 2. Diagnostic exercises list.

Using the software, it is possible to develop sets of rules for each exercise, allowing you to track the relative position of the vectors connecting the key points of the musculoskeletal system (Fig. 3).

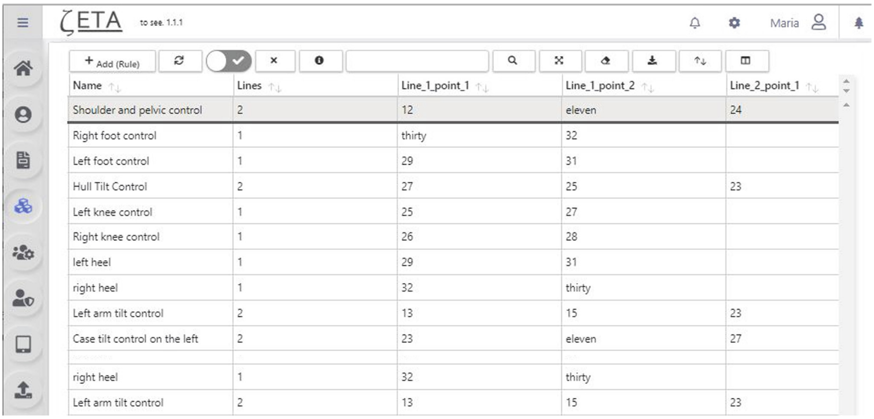

Fig. 3. Overhead squat rules list.

The following settings are available for each rule (Fig. 4):

- controlled vectors (number and key points connected by them);
- control zone (left side, right side, left and right sides, front, back, front and back, all sides)

- whether it is necessary to control repetitions with fixation of the maximum or minimum angle.

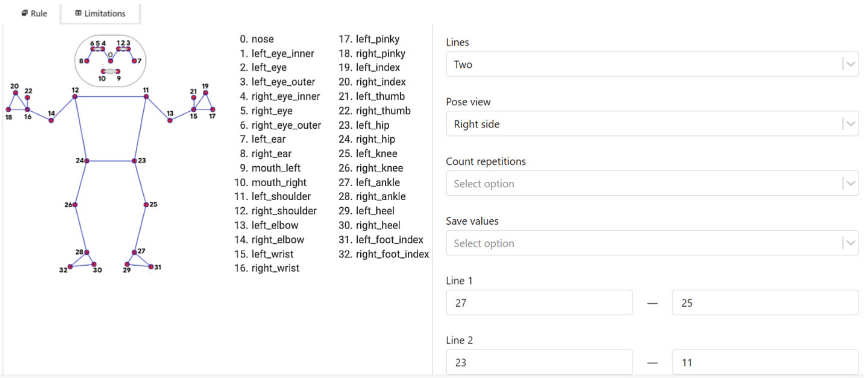

Fig. 4. Rule settings.

In addition, each rule can be configured to highlight situations when the values of the angles between vectors are in areas of increased attention for a specialist. Getting into such a zone is automatically fixed in the form of a preliminary diagnosis and proposed recommendations (Fig. 5).

Counter	Angle from	Angle to	Color	Text	Goal
1	-5	5	#a4dd00		
2	-6	-15	#fcdc00	Moderate forward tilt	
3	-16	-90	#f44e3b	Strong forward tilt	
4	6	15	#fcdc00	Moderate lean back	
5	16	90	#f44e3b	Strong deviation of the body back	

Fig. 5. Highlight settings.

5 The Example of an Athlete's Diagnosis

The video of a female volleyball player was analyzed while performing an overhead squat exercise (Fig. 6).

The software detected the following deviations in the musculoskeletal system:

- a strong tilt of the body forward - shortened or clogged hip flexors;
- blockage of the hands - insufficient mobility of the thoracic region, muscles are clogged or shortened: pectoralis major and minor, latissimus dorsi;
- valgus of the knee joints - clogged or shortened adductors of the thigh, weak gluteus medius;

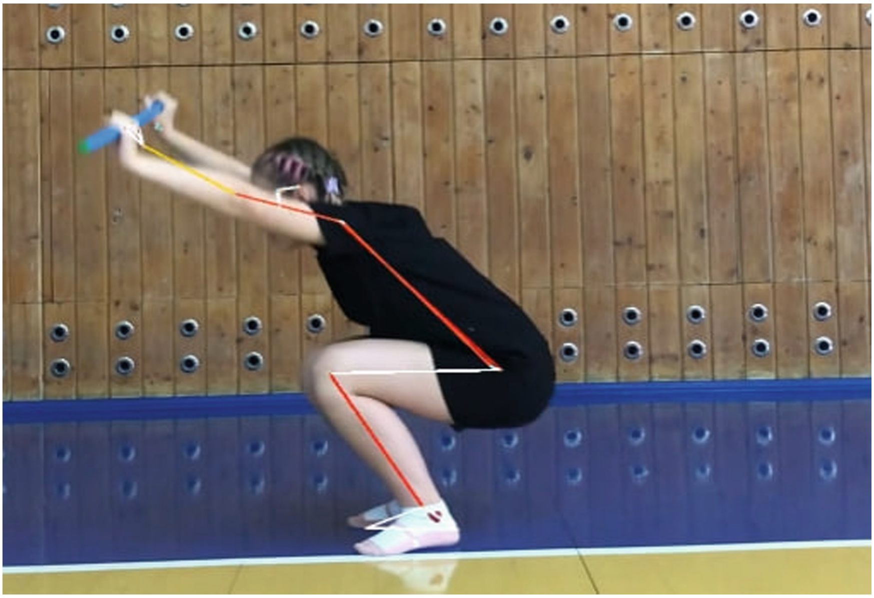

Fig. 6. Female volleyball player video screenshot.

- outward abduction - clogged or shortened: hamstring, soleus, piriformis;
- a nod of the pelvis - weak longitudinal muscles of the back, muscles of the hip flexors are shortened, muscles of the press are spasmodic.

Based on the internal rules (angle-dependent ones) the software proposed the following recommendations based on the athlete's checkup:

- reducing the power developing load (general, maximum, explosive strength);
- decreased game load (volleyball) - minimum jumps;
- the use of MFR on the muscles of the back and lower extremities after training and in the evening before going to bed;
- eccentric load on the abductor muscles of the thigh, longitudinal muscles of the back, collateral ligaments of the knee and ligaments of the ankle;
- increased proprioception of the cortex and foot through activation exercises;
- activation and eccentric are used at every workout in the warm-up (preparatory) complex;
- under the condition of 3 workouts per week, one workout is completely dedicated to increasing joint mobility through articular gymnastics and dynamic stretching;
- the term of restrictions and changes in the training process is determined individually based on the results of the test once a week.

6 Further Development

Key point trajectories of the musculoskeletal system received from ML Kit Pose Detection are currently stored in the software database and linked to each video file.

Currently, more than 1000 files with athletes performing diagnostic exercises have been loaded into the system. It is planned to expand the database to at least 10,000 files.

In cooperation with orthopedists and rehabilitation specialists, it is planned to review the video files in the system and compare each file with a diagnosis or a set of diagnoses.

After analyzing the downloaded files, it is planned to create and train a neural or neuro-fuzzy network, the input of which will be the trajectories of the key points of the musculoskeletal system, and the output will be compared with the diagnosis established by the orthopedist or rehabilitation specialist [5, 6].

In addition, it is planned to use neural networks based on unsupervised learning algorithms to cluster athletes according to the characteristics of the musculoskeletal system within one training group, which will allow the coach to individualize the approach to athletes and provide a more appropriate load for each identified cluster.

7 Conclusion

The application of computer vision technologies has shown great potential in reducing injuries in athletes during training. With the ability to analyze multiple aspects of an athlete's movement in real time, these technologies can detect and assess injury risks that might otherwise go unnoticed.

By providing coaches and trainers with valuable insights into an athlete's biomechanics and movement patterns, computer vision technologies can help them make informed decisions about training regimens, equipment modifications, and injury prevention strategies.

While there are certainly challenges to be addressed, the benefits of computer vision technologies in sports training are undeniable. As these technologies continue to evolve and become more accessible, we can expect to see even more innovative applications in the field of sports medicine, ultimately leading to safer and more effective training practices for athletes.

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References

1. Borisov, V.V., Misnik, A.E.: Ontological Engineering of interrelated processes in complex cyber-physical systems. In: Kovalev, S., Sukhanov, A., Akperov, I., Ozdemir, S. (eds.) Proceedings of the Sixth International Scientific Conference Intelligent Information Technologies for Industry (IITI'22). IITI 2022. Lecture Notes in Networks and Systems, vol. 566. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-19620-1_39
2. Bugaeva, K.D.: Musculoskeletal disorders in athletes of various specializations/K.D. Bugaeva Symbol Sci. **11**(2), 16–19 (2015)
3. Das, A., et al.: Computer vision syndrome, musculoskeletal, and stress-related problems among visual display terminal users in Nepal. PLoS One **17**(7), e0268356 (2022). https://doi.org/10.1371/journal.pone.0268356.PMID:35853006;PMCID:PMC9295968

4. Mints, E.I.: Physiological and biomechanical analysis of the functional state of the musculoskeletal system in athletes: disscand. Biol. Sci. 03.00.13/Mints Evgeny Ilyich. – Krasnodar, 169 (2000)
5. Misnik, A., Krutalevich, S., Prakapenka, S., Borovykh, P., Vasiliev, M.: Impact analysis of additional input parameters on neural network cryptocurrency price prediction. In: 2019 XXI International Conference Complex Systems: Control and Modeling Problems (CSCMP), Samara, Russia, pp. 163–167 (2019). https://doi.org/10.1109/CSCMP45713.2019.8976486
6. Misnik, A., Krutalevich, S., Prakapenka, S.: Neural network approximation precision change analysis on cryptocurrency price prediction. In: Fuzzy Technologies in the Industry - FTI 2018: Proceedings of the II International Scientific and Practical Conference, Ulyanovsk, October23–25 2018 – Ulyanovsk (2018)
7. Misnik, A.E.: Ontological engineering on metagraphs basis. In: 2022 VI International Conference on Information Technologies in Engineering Education (Inforino), pp. 1–6 (2022). https://doi.org/10.1109/Inforino53888.2022.9782909
8. ML Kit Pose Detection Model card. https://developers.google.com/ml-kit/images/vision/pose-detection/pose_model_card.pdf. Accessed 02 Apr 2023
9. Puchko, A.A., Yasyukevich, A.S., Gulevich, N.P., Maslov, O.V.: Analysis of the level and structure of injuries of the knee joint in various sports. Appl. Sports Sci. **1**(9), 65–75 (2019)
10. Sedochenko, S.V., Chernykh, A.V.: The study of electroneuromyographic parameters of the asymmetry of the lower limbs of young fencers news of TulGU. Phys. Cult. Sport. **4**, 162–168 (2015)
11. Soshnikov, D.: Software toolkit for building embedded and distributed knowledge-based systems. In: Proceedings of the 2nd International Workshop on Computer Science and Information Technologies CSIT´ 2000. Ufa, pp. 103–111 (2000)
12. Tamozhnikova, I.S., Customsnikov, D.V., Davydov, S.A., Gladkikh, A.S.: Chronic microtrauma as a predictor of acute, chronic diseases and injuries of the musculoskeletal system of athletes. Theory Pract. Phys. Cult. **11**, 14 (2020)
13. Tarasov, A.V., Belichenko, O.I., Smolensky, A.V.: Injuries and diseases of the musculoskeletal system of athletes. Therapist. (5), 4–14 (2019)
14. Zakharova, A.A., Zakharchenkov, K.V., Vaynilovich, Y.V.: Integrated system approach to improving the efficiency of IT projects management based on evolutionary modeling. In: CPT 2020 The 8th International Scientific Conference on Computing in Physics and Technology Proceedings. – Nizhny Novgorod, Russia. November 09–13, 2020. pp. 309–314. https://doi.org/10.30987/conferencearticle_5fce27732298c9.93530561. http://ceur-ws.org/Vol-2763/CPT2020_paper_s7-5.pdf. Accessed 02 Apr 2023