Study on Biomechanics of Human Body Motion

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Abstract—Central nervous system is one of the most intricate part in nature, however it plays a key role in day to day life. The motion executed by commands given by central nervous system are very precise. Today's technology is no match for CNS due to its agility, accuracy, ability to adapt to environment and quick decision making. This seminar deals with the model and the methods of computation, biomechanical analysis of human movement in real-time using inverse kinematic and dynamic analysis of muscle. Also deals with the force estimation technique, Sensors to estimate movement and forces. We use motion trackers to generate a record motion and further create a motion generating algorithm. This algorithm may help us to improve the machines. But no computational model has yet made it possible to generate an algorithm that is even close to CNS in terms of accuracy, agility and adaptability. Using various sensors, we synthesize a model to estimate its kinematics and dynamics and use various concepts of physics to compile the collected and calculated data. Hence helping us to select correct criteria for the synthesis of movement.

Index Terms—Movement analysis, Biomechanics, Parkour, Recording,Kinematics, Dynamics, Motion

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1 INTRODUCTION

The Biomechanics deals with the application of mechanical laws to the movement of living organisms to produce movement. The combination of muscles, bones, tendons, and ligaments work together to produce movements in leaving organisms. Biomechanics represents the broad interplay between mechanics and biological systems, from the Nanoscale to whole-body systems. It is helpful in understanding and embodies the attempts to design and develop mechanical devices that mimic, measure, improve, repair, or replace the function of living systems. Mathematical and computational models are required to understand the extreme complexity of leaving organisms. Creating models with such complexity to replicate leaving organisms is a difficult challenge. Biomechanics mainly has applications in improving the design of medical devices, robotics, athletic equipment, etc.

The techniques used for recording and recreating movement are movement of the body is given by the brain. The brain sends impulses to the spinal cord. There are Single nerve cells in the spinal cord, called motor neurons and these neurons are the only way the brain connects to muscles. These motor neurons inside the spinal cord pass the impulse received from the brain that goes to the muscles. Muscles are made of long fibers connected to each other by a ratchet mechanism, it is a kind of mechanism that allows the two muscles to slide past each other and then lock in a certain position. When the impulse from the motor neuron is received by muscle, it causes the muscle fibersto ratchet past each other, overlapping each other more, so that the muscle gets shorter and fatter moving the part in the desired position.

When the impulses from the motor nerve stop, the muscle fibers slide back to their original positions. Hence relaxing the body part and returning the muscles in a relaxed condition.

Computational model of human body is required for study. sensors, makers, and motion capture techniques to collect the data. Sensors were used to measure the displacement, angular displacement, acceleration, inertia, and force of the body while performing a movement. Accelerometers and gyroscopes are commonly used for motion capture. The body movement creates the electrical signal from the brain and these signals are captured using electromyography sensors. Some motion capture techniques use optical devices such as cameras. The optical motion capture system uses markers for data collection. Passive Markers are reflective and bounce light back at the cameras, whereas active markers use LEDs that shine a light toward the camera. Markers need placed closer to the skin, bone and joints in order to reproduce accurate movement.The technology used in motion capturing and analysis of human motions to enhance human physical capability, personalized bionics for dynamic gait, and mechatronic systems. The design of next-generation bionic ankles and knees to improve bionic actuators, range of motion, power density, bandwidth, and mass, while adopting a futuristic aesthetic. eses. Mechanical, electrical, and dynamic control systems recreate biological behavior with synthetic hardware

2 LITERATURE REVIEW

A study on dynamic human movement taking into account its variability, software and sensors to collect data from human body motions. Computing the kinematics and dynamics of human motion which allows us to explain motor control strategies in terms of performance variables. [1].Paper presents a method to estimate gait kinematics and kinetics directly from raw inertial sensor data performing a single dynamic optimization. The researcher formulated a control problem to track accelerometer and gyroscope data while minimizing muscular effort to ensure a unique solution with reduced error due to noise. Only inertial sensor data is

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considered for analysis. [2].study of Mechanical analysis of movement can play a significant role in the clinical management of neurological and orthopedic conditions. The researcher used a software system, named human body model (HBM) is used to compute joint kinematics and kinetics for a full-body model with 44 degrees of freedom, in real-time, and to estimate length changes and forces in 300 muscle elements. [3].

The author tries to find the motor plan to be effective, it must be adapted in response to environmental changes. the main objective of this paper was to understand how people adapt motor plans of center of mass (COM) trajectory during goal-directed walking in response to a consistent change in environmental dynamics [4].Paper provides recommendations for training and evaluating machine learning models and discusses the potential of several underutilized approaches, such as deep learning, to generate new knowledge about human movement. the author believes that cross-training biomechanists in data science and a cultural shift toward the sharing of data and tools are essential to maximize the impact of biomechanics research [5].The kinematic model in HBM consists of 16 rigid body segments that are coupled by joints, with a total of 44 kinematic degrees of freedom. Subject-specific joint centers and axes are calculated from 3D coordinates of markers attached to anatomical landmarks, while the subject is in an initialization pose. Details can be found in ''Supplemental Material''. Inertial properties for all body segments are estimated during initialization from segment lengths and total body mass using published regression equations [6].

Author investigated that how people adapt motor plans of COM trajectory during goal-directed walking to a novel and consistent environment. He hypothesized that when performing a goal-directed walking task in the novel and consistent force field, people would adapt by forming an internal model of their COM trajectory within the new environment [7]. Clinicians and physical therapists could benefit from a real-time visualization and quantification of specific motion variables, as well as from having additional information about internal forces and moments which would remain otherwise fundamentally invisible. Furthermore, such biomechanical data can also be presented to the patient in real-time, to help them perform therapeutic exercises more effectively than could be done with verbal or tactile feedback from a physical therapist [8].

Machine learning approaches show promising results for estimating specific gait parameters. However, the collection of representative training data is time-consuming and sometimes infeasible. Unlike data-driven approaches, musculoskeletal simulation yields interpretable results providing insights into muscular control and mechanical characteristics of movement [9,10]. The most extensive kinematic and kinetic gait analysis based on IMUs and musculoskeletal modelling was carried out. They obtained segment positions and orientations from the Xsens system with 17 IMUs and computed kinematics by constrained optimization. Afterwards, they solved a static optimization problem to obtain the muscle reaction forces for the given computed motion trajectory by minimizing muscle activity subject to dynamic equilibrium constraints. [11]. static optimization cannot account for time-dependent interactions like muscle activation-deactivation dynamics and elastic energy storage in the tendons [12]

The above literature review reveals that the present technology used for capturing motions and their analysis for studying the effect of type of motion and forces acting on human parts. Several authors have presented the tools and techniques used in the kinematic and dynamic analysis of motions of bone and skeletal together. This seminar deals with the detailed case study carried out to analyze the motions of parkour and its effects on the body.

3METHODOLOGY

This section discusses motion capture techniques and data processing in detail and how the models were created for further study and also understand the kinematics and dynamics role in biomechanics. The entire process of biomechanics of human body motion is explained through a case study.

3.1 Motion capture

Motion capture is sometimes referred to as "Mo Cap" and it is a process of recording the movement of people using digital technology. The recorded motion is used for the quantitative analysis of the motion. The moments of the body can be tracked using various methods which are discussed further in detail one by one. This seminar deals with the human motion tracking techniques using various methods, some of the popular motion capturing techniques, modules and the entire process.

3.1.1 Optical motion capture(OMC)

Optical motion capture uses cameras to record the body posture of the performer. OMC utilizes more than one camera to capture the movement of the body. Optical motion capture has some advantages over other systems like the markers are not heavy and the person can move more freely and also clean, neat, and detailed data is captured. But It also has some disadvantages, like it is affected by light interference or the markers can get hidden by another person or object. OMC uses active and passive type of markers to capture the movement of the body.

Active markers use LEDs to triangulate the position of the body. LED lights are light up with the help of the software to identify them by their relative positions. The inverse square law tells us that one quarter the power at two times the distance, which helps in increasing the distances and volume for capture and also enables high signal-to-noise ratio, low marker jitter and provides the result with high measurement resolution of 0.1 mm within the calibrated volume. Sometimes active systems use infra-red active markers with light-emitting diodes stimulated in a predefined sequence. Instead of relying on an external light source for emitting the active markers produce light internally.

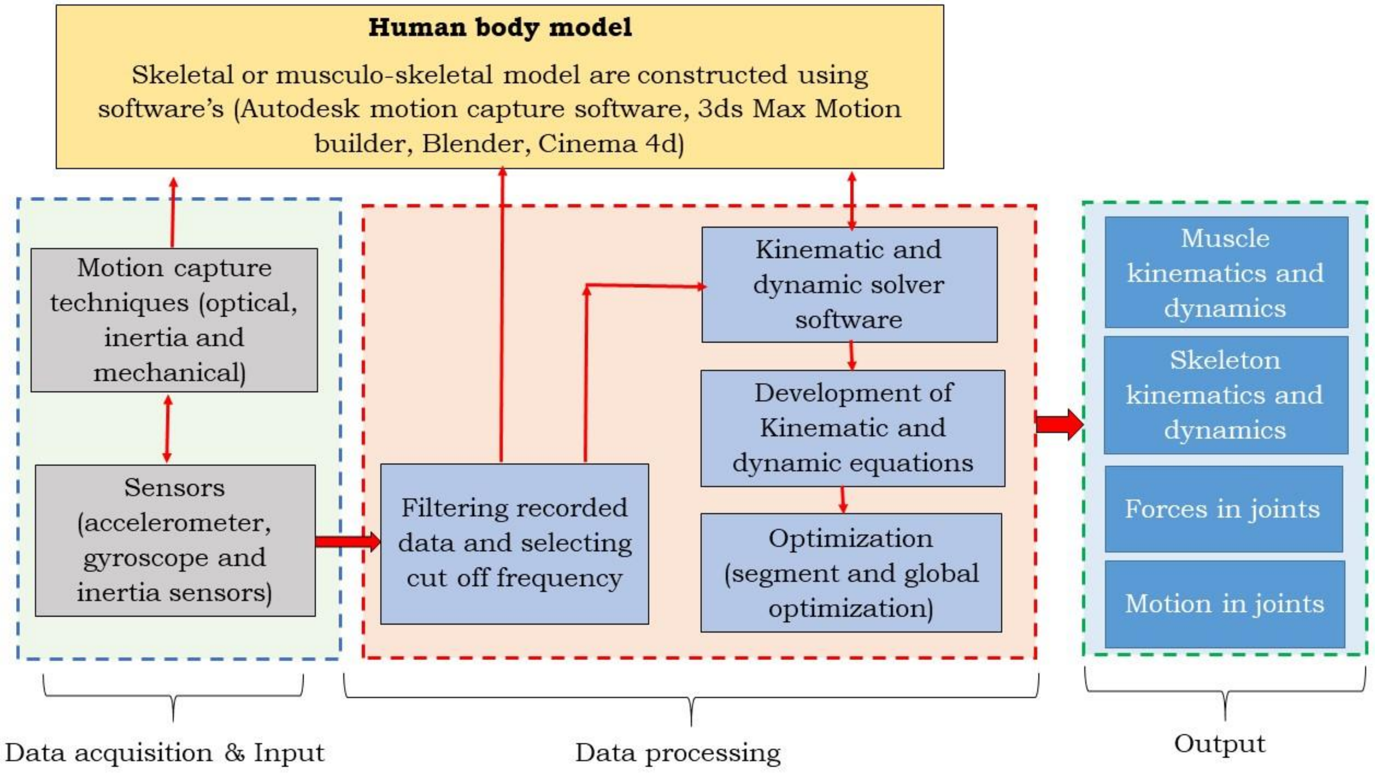

Fig. 1: Process of Biomechanics

Passive markers use external light sources for getting output and these are coated with a retroreflective material to reflect light which is then generated near the camera lens. The camera's threshold is adjusted so that the bright reflective markers will be sampled, ignoring skin and fabric glaring. An object with a known position is used to calibrate the cameras and to obtain their positions. Then the lens distortion of each camera is measured. The 3-dimensional fix can be obtained if two calibrated cameras can see a marker.

3.1.2 Mechanical Motion Capture

Mechanical motion capture systems are used to track body joint angles and are often referred to as exoskeleton motion capture systems. In this technique, the person wears structured body suits which are known as an exoskeleton. The suit has a sensor on all the joints which provides the position accurately of that joint. It has an advantage over optical motion capture because it has no limited range and is not affected by interference from light or magnetic fields. But it has some downsides like the sensors make noise which provides data that contains errors and the equipment has to be calibrated frequently.

3.1.3 Inertial Motion Capture

Inertial motion capture technology is based on miniature inertial sensors, biomechanical models, and sensor fusion algorithms. The data from the inertial sensors are often transmitted wirelessly to a computer, where the motion is recorded or viewed. Inertial measurement units (IMUs) are mostly used inertial systems containing a combination of gyroscope, magnetometer, and accelerometer, to measure rotational rates. These rotations are translated to a skeleton in the software. More IMU sensors are used for more data. No external cameras, emitters or markers are needed for relative motions, although they are required to give the absolute position of the user if desired. the full six degrees of freedom body motion of a human can be captured by Inertial motion capture systems in real-time and can give limited direction information if they include a magnetic bearing sensor, although these are much lower resolution and susceptible to electromagnetic noise.

Benefits of using Inertial systems include: capturing in a variety of environments including tight spaces, no solving, portability, and large capture areas. Disadvantages include lower positional accuracy and positional drift which can compound over time. They can accurately measure the direction to the ground to within a degree.

3.2 DATA PROCESSING

Sensors are used in extensively used in biomechanics and motion capture for data collection from a subject while performing a movement. Sensors can be used for correcting the abnormality in the data recorded using motion capture techniques. Various sensors are used in motion capture like accelerometers, gyroscope, and inertial sensors. An accelerometer is an electromechanical device used to measure acceleration forces. Such forces may be static, like the continuous force of gravity or, as is the case with many mobile devices, dynamic to sense movement or vibrations. An accelerometer can also be used as a tool to measures proper acceleration is the acceleration of a body in its own instantaneous rest frame. Accelerometers are tiny, accurate, and low-cost Micro Electro Mechanical Systems (MEMS) devices. These properties make them ideal for a wearable system.

A gyroscope is a device used for measuring or maintaining orientation and angular velocity Gyroscope consists of a wheel or disc mounted so that it can spin rapidly about an axis which is itself free to alter in direction. The orientation of the axis is not affected by the tilting of the mounting, so gyroscopes can be used to provide stability or maintain a reference direction in navigation systems, automatic pilots, and stabilizers. For the motion capture A gyroscope is a sensor that can detect the rotational angular velocity. So it is fit for measuring the rotational motion like human arm's.

Inertial sensors are sensors based on inertia and relevant measuring principles. These range from Micro Electro Mechanical Systems (MEMS) inertial sensors, measuring only a few mm, up to ring laser gyroscopes that are high-precision devices with a size of up to 50cm. An Inertial Measurement Unit, commonly known as an IMU, is an electronic device that measures and reports orientation, velocity, and gravitational forces through the use of accelerometers and gyroscopes and often magnetometers.The data from motion capture is recorded and then processed. This process is known as data reconstruction. Data reconstruction mainly involves labelling markers and interpolation their positions. Reconstructed data may contain noise therefore before using the data is filtered. For filtering the reconstructed data different people use different methods like low-pass Butterworth digital filter applied in a zero-phase, Kalman filter using sensor fusion. While filtering the signal the cut off frequency is considered. cut-off frequency is chosen to avoid inconsistencies with inverse dynamics computations (inverse dynamics and inverse kinematics).

For the selection of cut-off frequency for filtering a signal, two types of analyses are commonly performed are power spectral analysis and residual analysis. The power spectral analysis is a technique in which the power of the recorded signals can be studied in the frequency domain. Based on this analysis, it is decided that if the frequencies are to be accepted or rejected from the signals. Whereas residual analysis is used to evaluate noise by comparing the difference between the unfiltered signals and the signals filtered at different cut-off frequencies. After the data has been filtered, body joint and center of rotation can be estimated from marker's trajectory. Three methods are used namely, virtual models, regression tables, and functional methods. In general, the center of rotation of ball-modelled joints such as the shoulder and the hip are computed by using functional methods. The Functional methods can be used to determine the optimal axes of joint rotations. Other joint center can be computed based on regression tables or based on a virtual model. The data processing and reconstruction is an important step because it helps to create a musculoskeletal model for measurement of kinematics and dynamics of the movement.

3.4 INVERSE KINEMATICS AND INVERSE DYNAMICS

A common step in analyzing a movement is to compute the joint angles and joint moments of the subject during movement. Inverse kinematics is used to compute joint angles whereas Inverse dynamics is used to compute net joint reaction forces and net joint moments. Inverse kinematics is the mathematical process of calculating the variable joint parameters needed to place the end of a kinematic chain, such as a robot manipulator or animation character's skeleton, in a given position and orientation relative to the start of the chain. *Inverse dynamics* is a technique in which measured kinematics and, possibly, external forces are used to calculate net joint torques in a rigid body linked segment model. However, kinematics and forces are usually not consistent due to incorrect modelling assumptions and measurement errors.

3.5.1 Inverse Kinematics

Generally, we use forward kinematics in day to day life. In Forward kinematics, joint angles are taken as input and the Cartesian position and orientation of the end effector is calculated. On the contrary while using the data from the sensors used for tracking a human body we get Cartesian coordinates, position, and orientation of body as input. Therefore, Inverse kinematics takes the Cartesian end-effector position and orientation as input and calculates joint angles. Inverse kinematics is also used for trajectory planning. Inverse kinematics is also used for converting experimental marker positions into joint angles by minimizing the error coming from the reconstructed motion and the soft tissue artifact" STA". STA corresponds to the relative motion of tissue with regards to the underlying bones. Two methods are commonly used to calculate 3D angles: segment optimization and global optimization

The segment optimization procedures are typically used for minimizing the under- and over-segmentation to increase the efficiency and accuracy of a technique. Segmentation is an iterative process, where an overall analysis may contain several segmentation stages of different types and for different purposes. In segment optimization, a reference frame is positioned and oriented on each modelled body segment according to the ISB (international society of biomechanics) recommendations. Angles can be calculated by following Euler angle sequences by computing the optimal bone pose from a marker cluster. The global optimization methods are usually referred to as "Inverse Kinematics", and are also be used to calculate joint angles. Global optimization makes it possible to add physically realistic joint constraints while taking into account the whole kinematic chain structure, and joint ranges of motion.

3.5.2 Inverse dynamics

Inverse Dynamics is used much more often than Forward Dynamics for biomechanical modeling. Usually Forward Dynamics uses joint torques/forces to predict resultant motions. Whereas inverse dynamics helps us in determining internal forces and joint torques from a given motion. Mainly Three formalisms are available to compute inverse dynamics: Hamiltonian, Euler-Lagrange, and Newton-Euler. In particular, Newton-Euler formulation expresses dynamic equations for each link and performs calculations recursively by propagating reaction forces and applying Newton's third law of motion. Euler's first and second equations of motion form the so-called Newton-Euler equations.Euler's first equation (2) states that the sum of external forces equals the variation of linear momentum.

$$\sum f_{ext} = \frac{d}{dt}(mv) = ma \qquad (2)$$

Where "m" is the mass of the body and "a" its the center of mass acceleration. Euler's second equation (3) states that the sum of external torques equals the variation of angular momentum at the center of mass (CoM).

$$\sum \tau_{ext} = \frac{d}{dt}(I_G\omega) = I_G\dot{\omega} + \omega * I_G\omega \qquad (3)$$

where IG is the inertia, ω and ω˙ are respectively the body inertia, angular velocity and angular acceleration expressed at the CoM. Eq. (2) and Eq. (3) are commonly propagated at each joint using a bottom-up approach.

3.5 HUMAN BODY MODEL

The processed data is used for calculating kinematics and dynamics of human body composed of muscles and bones. In order to compute the kinematics and dynamics, a physical model is needed for representing the skeletal or musculoskeletal systems. While generating a model an assumption is made that the human body can be described by a collection of rigid bodies representing bones or a combination of them. The bones model (skeletal model) is considered for analysis as it is comparatively simpler than the musculoskeletal model. In musculoskeletal model bones and muscles, are considered together, it is much more complex than the skeletal model. the model is used to estimate the properties of the human body segments such as segment lengths, inertia matrices, and center of mass positions. While modelling anthropometry is also considered for scaling. Anthropometry is a scientific study of the measurements and proportions of the human body. For estimating human anthropometry cadaver studies mathematical modeling, scanning, and imaging techniques, kinematic measurements, or motion-capture-based identification with kinetic measurements, can be used.

The experimental marker data from static trials are used to scale the anthropometry of the recorded participant using the regression equations provided by cadaver studies or by fitting these data with a virtual skeletal model. A modelling is an effective tool for analyzing and visualizing body movement. For building a 3D-model following points to be considered:

1. The model should contain the description of the kinematic chain including joint types and ranges of motion of joint.
2. Segment data should provide specifications like physical characteristics of the body such as masses, inertia matrices, and positions of the center of mass of each segment.
3. Virtual models contain the position of the markers placed on the body of the model. a minimum of 3 markers per segment is needed for 3D analysis.

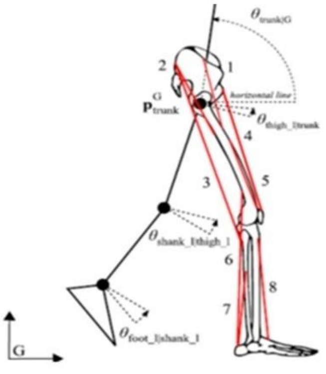

Fig. 2: A planar musculoskeletal model

A planar musculoskeletal model is shown in figure 2, it consists of seven rigid segments, one segment representing the head, arms, and torso denoted as the trunk, and three segments for each lower extremity. While considering the segment masses, lengths, center of mass locations, and moments of inertia were estimated based on the subject's heights and body masses by using the regression equations of Winter. The model has a total of nine kinematic degrees of freedom summarized as generalized coordinates in vector.

$$q = [P^G_{trunk}, \theta_{trunk\,|G}, \theta_{thigh\_r|trunk}, \theta_{shank\_r|thigh_r}, \theta_{foot\_r|shank_r} \\ \theta_{thigh\_1|trunk}, \theta_{shank\_1|thigh_1}, \theta_{foot\_1|shank\_1}]^T$$

In the above equation G is the 2D position of the trunk in the global frame. The time derivative of q is generalized as velocities v. When the subject moves from its position the reading from the sensors helps us to measure their displacement. Which can be further used for calculation of kinematics and dynamics.

5 RESULT AND DISCUSSION

The results ofinverse kinematics method of biomechanics generated motions present strong similaritieswith hierarchical task control., especially when comparing the motion of the lower body.The difference between the ranges of motion (RoM) of the human group and the simulation model for the principal segments in the motion during each phase. Take off results at the beginning of the motion, linear momentum values were different between the humans and the model. Throughout the motion, the linear momentum was similar in the medial-lateral component while the anteroposterior and vertical component of the linear momentum behaved differently. But angular momentum behaved similarly in the humans and the model in the sequel. It is also onservedthat the angular and linear momentum decreases foe all three positions but the anterio posterior and vertical biomechanics of parknour during take off shows initially it inceraese and then it dectreases.

The motion obtained from left and right legs for take-off, flight, and landing are Neck-head flexion-extension, Trunk flexion-extension, Upper arm flexion-extension, Upper arm abduction-adduction, Upper arm rotation, Forearm flexion-extension, Thigh flexion-extension, Thigh abduction-adduction, Thigh rotation, Shank flexion momenta profiles of the humans (± SD) simulation model during the take-off phase. The results of the medial-lateral, antero-posterior and vertical components of the linear momentum normalized by the body weight revealed that
angular momentum normalized by the body weight and height, about the the medial-lateral, antero-posterior and vertical axis.
The components of the linear momentum for medial-lateral reveals different behavior whereas antero-posterior and vertical it behaves differently.

4 CONCLUSION

The conclusions drawn from the study of Biomechanics of Human Body Motion that a physical model is suitable for analyzing and generating required motion. Whereas experimental protocol can be established for recording and analyzing the human motion. The identifying and understanding the performance, it is necessary to organize the tasks in a hierarchical manner according to their importance in the execution of the motion. A stack of tasks can be created and information is gathered from humans control strategies. By weighing these information,the controller input to the robot can be further parameterized. This information obtained from biomechanical study the artificial motion can begenerated and compared using the same physical model created for analyzing the motion.

REFERENCES

[1] E. Halilaj, A. Rajagopal, M. Fiterau, J.L. Hicks, T.J. Hastie, S.L. Delp, Machine Learning in Human Movement Biomechanics: Best Practices, Common Pitfalls, and New opportunities, Journal of Biomechanics (2018), vol(issue), pp – –, doi.org/10.1016/j.jbiomech.2018.09.009

[2] E. Dorschky, M. Nitschke, A. Seifer, J. Bogert, B. M. Eskofier, Estimation of gait kinematics and kinetics from inertial sensor data using optimal control of musculoskeletal models, Journal of Biomechanics, (2019), 95-109278, pp1-8, doi.org/10.1016/j.jbiomech.2019.07.022

[3] Mary A. Bucklin, Mengnan Mary Wu, Geoffrey Brown, Keith E. Gordon, Adaptive motor planning of center-of-mass trajectory during goal-directed walking in novel environments, Journal of Biomechanics, (2019), 94, pp 5–12, doi.org/10.21985/N2WJ4M.

[4] Galo Maldonado, Philippe Souères, Bruno Watier. From Biomechanics to Robotics. Biomechanics of Anthropomorphic Systems, (2018), Star 124. hal-02002519.

[5] Antonie J. van den Bogert, Thomas Geijtenbeek, Oshri Even-Zohar, FransSteenbrink, Elizabeth C. Hardin, A real-time system for biomechanical analysis of human movement and muscle function, Med. Biol. Eng. Comput. (2013) 51, pp1069–1077, doi:/10.1007/s11517-013-1076-z

[6] L., P., De, Adjustments to Zatsiorsky–Seluyanov's segment inertia parameters. J Biomech, 29 (1996), pp1223–1230.

[7] R., Shadmehr, F.A., Mussa-Ivaldi, Biological Learning and Control: How the Brain Builds Representations, Predicts Event, and Makes Decisions. MIT Press Scholarship, (2012), pp – –.

[8] Geijtenbeek T, Steenbrink F, Otten B, Even-Zohar O D-flow: immersive virtual reality and real-time feedback for rehabilitation. In: Proceedings of the 10th international conference on virtual reality continuum and its applications in industry (VRCAI '11). ACM, New York, (2011), Vol(), pp 201–208

[9] Hannink, J., Kautz, T., Pasluosta, C.F., Gamann, K.-G., Klucken, J., Eskofier, B.M., Sensor-based gait parameter extraction with deep convolutional neural networks. IEEE J. Biomed. Health Informat., (2016), Vol(issue), pp 1–8.

[10] Wouda, F.J., Giuberti, M., Bellusci, G., Maartens, E., Reenalda, J., van Beijnum, B.J.F., Veltink, P.H., Estimation of vertical ground reaction forces and sagittal knee kinematics during running using three inertial sensors. Front. Physiol. (2018), 9, pp 1–14.

[11] A. Karatsidis, M., Jung, H.M., Schepers, Bellusci, G., de Zee, M., Veltink, P.H., Andersen, M.S., Predicting kinetics using musculoskeletal modeling and inertial motion capture. arXiv preprint arXiv: 1801.01668, (2018), pp – -

[12] B.I., Prilutsky, V.M., Zatsiorsky, Optimization-based models of muscle coordination. Exerc. Sport Sci. Rev. (2002), 30 (1), pp 32–38.