JETIR.ORG
ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

ANALYSIS OF GAIT DYNAMICS FOR OSTEOARTHRITIS USING MOTION AND EMG SENSORS

[1] Mr. Arvind S, [2] Dr. Sankaragomathi B, [3] Ms. Manju M, [4]Ms. Vijayalakshmi M, [5] Mr. Sujeeth K,

[1], *Fourth Year UG Student,* [2] Professor, [3] *Fourth Year UG Student,* [4] *Fourth Year UG Student,* [5] *Fourth Year UG Student,*
[1] *Department of Biomedical Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India.,*
[2] *Department of Biomedical Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India,* [3] *Department of Biomedical Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India,*[4] *Department of Biomedical Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India,*[5] *Department of Biomedical Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India*
53

Abstract : Gait analysis is crucial for understanding the biomechanical complexities of osteoarthritis and Total Hip Arthroplasty (THA). Traditional methods lack the comprehensive data needed for effective analysis. Integrating Internet of Things (IoT) technologies offers a promising solution to enhance gait analysis by utilizing multiple sensors to capture various aspects of movement dynamics. This study aims to innovate gait analysis for individuals with osteoarthritis by employing IoT technologies. The primary objective is to integrate data from 9-axis Inertial Measurement Unit (IMU) sensors, Force-Sensitive Resistor (FSR) sensors, and Electromyography (EMG) sensors to provide a detailed analysis of gait dynamics. By doing so, the study seeks to uncover intricate connections between kinematics, ground response forces, and muscle exertion during walking. The study utilizes IMU sensors to capture three-dimensional movement, FSR sensors to measure ground response forces, and EMG sensors to record muscle activation patterns. Advanced algorithms are employed to accompany and integrate the data from these sensors. Actors undergo gait analysis under various conditions, including normal walking and different perturbations, to simulate real-world scenarios. The integration of data from multiple sensors and the application of advanced algorithms reveals detailed insights into the biomechanical differences associated with osteoarthritis and THA. The analysis demonstrates the effectiveness of IoT-based gait analysis in providing valuable perceptivity into musculoskeletal conditions. The proposed methodology showcases the potential of IoT-based gait analysis in advancing our understanding of musculoskeletal conditions and enhancing patient care. By uncovering intricate connections between kinematics, ground response forces, and muscle exertion, this approach provides a foundation for further development of effective interventions and rehabilitative strategies.

***IndexTerms* - Gait analysis, IoT, Sensors, Osteoarthritis, THA, Rehabilitative.**

I. INTRODUCTION

1.1 Osteoarthritis

Osteoarthritis (OA) is a degenerative joint disorder characterized by the progressive breakdown of cartilage in the joints, leading to pain, stiffness, and functional impairment. The impact of OA on gait dynamics is substantial and multifaceted. As the disease advances, the articular cartilage that cushions the joints undergoes erosion, causing joint spaces to narrow and leading to increased friction between bones. This results in pain during movement, affecting the biomechanics of the lower limbs and altering gait patterns. Individuals with OA often exhibit a slower and more cautious gait, accompanied by reduced stride length and increased variability in step width. The pain associated with OA prompts adaptive strategies such as decreased weight-bearing on the affected joints, leading to altered weight distribution during walking. Moreover, muscle weakness and atrophy, commonly observed in OA patients, contribute to abnormal gait patterns. Ultimately, a comprehensive understanding of the relationship between osteoarthritis and gait dynamics is essential for optimizing patient care, enhancing functional outcomes, and promoting a better quality of life for those affected by this pervasive joint disorder.

1.2 IoT (Internet of Things)

The Internet of Things (IoT) is a transformative paradigm that involves connecting everyday objects to the internet, enabling them to collect and exchange data for improved efficiency and enhanced functionalities. In healthcare, IoT holds immense potential, particularly in the realm of monitoring and analysing gait. Through the integration of wearable sensors and smart devices, IoT enables real-time tracking of an individual's gait parameters, offering a continuous and unobtrusive method for monitoring mobility and detecting abnormalities. This technology proves invaluable in the early diagnosis and management of various musculoskeletal and neurological conditions, such as osteoarthritis, Parkinson's disease, or stroke recovery. Wearable devices equipped with accelerometers, gyroscopes, and pressure sensors can capture intricate details of gait dynamics, providing clinicians with quantitative data on stride length, walking speed, and gait symmetry.

II. METHODOLOGY

The primary objectives of this project are to employ a comprehensive approach to the exploration of gait dynamics in individuals with osteoarthritis, focusing on the integration of three distinct sensors—IMU with 9-axis capabilities, FSR, and EMG. The IMU sensor will capture intricate details of joint movements, accelerations, and orientations during walking, providing a holistic understanding of gait dynamics. Concurrently, FSR sensors will offer valuable insights into the distribution of forces exerted on the feet during each step, aiding in the analysis of gait mechanics. Furthermore, the EMG sensors will measure muscle activation patterns, contributing essential information about the neuromuscular aspects of gait. Through the integration of these sensors, this project aims to enhance the precision and depth of gait analysis for individuals with osteoarthritis, potentially leading to a more comprehensive understanding of the condition's impact on movement patterns and offering valuable insights for therapeutic interventions and rehabilitation strategies.

2.1 Selection Criteria for the Sensors

The selection criteria for the IMU, FSR, and EMG sensors were based on their appropriateness for gait analysis in individuals with osteoarthritis. For the 9-axis IMU sensors, factors such as high precision and a wide measurement range, ensuring accurate capture of joint angles and motion dynamics during walking were prioritized. The selected IMU sensors offer a measurement range of ±2000 degrees per second for gyroscope data and ±16 g for accelerometer data, with a sampling rate of 1000 Hz. FSR sensors were selected based on sensitivity and durability, capable of measuring variable forces exerted during gait. The selected FSR sensors have a measurement range of 0 to 20 pounds and provide data at a sampling rate of 100 Hz. EMG sensors were chosen for their capacity to accurately record muscle activation patterns, considering factors like signal-to-noise ratio, ease of application, and compatibility with simultaneous use alongside IMU and FSR sensors. The chosen EMG sensors have a frequency response of 20-500 Hz, ensuring accurate representation of muscle activation patterns. Calibration procedures for all sensors involve standardizing baseline measurements and ensuring synchronization before each gait analysis session to maintain data accuracy and consistency across participants.

2.2 Hardware Description

2.2.1 9-axis IMU Sensor

The 9-axis IMU sensor is a compact device incorporating accelerometers, gyroscopes, and magnetometers. It typically features a small form factor for easy attachment to the body, with tri axial accelerometers providing acceleration data, tri axial gyroscopes measuring angular velocity, and tri axial magnetometers capturing magnetic field information. The sensor is equipped with a microcontroller for onboard processing and communication capabilities.

2.2.2 FSR Sensor

The Force-Sensitive Resistor (FSR) is a pressure-sensitive sensor designed to measure variations in force applied to its surface. These flexible sensors consist of conductive polymer material, and their resistance changes proportionally with the applied force. FSR sensors used in the project are embedded in insoles or attached to specific regions of the participant's footwear. They are connected to microcontrollers for data acquisition and transmission.

2.2.3 EMG Sensor

The Electromyography (EMG) sensor is designed to measure electrical activity produced by muscles during contraction. Typically, EMG sensors feature surface electrodes that adhere to the skin above specific muscle groups. These electrodes pick up electrical signals generated by muscle cells. The EMG sensors are connected to amplifiers and signal conditioning circuits to capture and process muscle activity data. Microcontrollers facilitate data transmission to the central processing unit.

2.3 Hardware configuration

In the gait analysis setup, the placement of sensors on the subject is crucial for accurate data capture. The 9-axis IMU sensors are strategically positioned on anatomical landmarks, such as the lower limbs and pelvis, using specialized straps or adhesive patches. These IMU sensors are affixed to the shins, thighs, and lower back to capture precise three-dimensional motion data during walking. Force-sensitive resistor (FSR) sensors are embedded within insoles or attached to specific regions of the subject's footwear, allowing them to measure the distribution of ground reaction forces. Additionally, electromyography (EMG) sensors are strategically placed over relevant muscle groups, often on the quadriceps, hamstrings, and calf muscles, to record muscle activation patterns during gait.

2.4 Data collection

The data collection procedure involves several systematic steps to ensure the comprehensive capture of biomechanical parameters associated with osteoarthritis. Participants, after providing informed consent, are outfitted with the sensors. Before each session, a thorough calibration process is implemented to standardize baseline measurements and synchronize sensor data. Participants are then guided through a series of walking trials on a designated pathway. The data acquisition system, comprising microcontrollers connected to each sensor, collects real-time information during these trials. These microcontrollers serve as the interface between the sensors and the data processing unit. Participants are instructed to walk at various speeds and, in some cases, perform specific tasks to simulate daily activities. Throughout the gait analysis session, participant’s joint angles, accelerations, angular velocities, ground reaction forces, and muscle activation patterns are continuously recorded. Care is taken to ensure that the participant’s natural gait patterns are captured, minimizing any potential alterations due to conscious adjustments. To enhance accuracy, multiple trials are conducted for each participant. The collected data is subsequently transmitted to a central processing unit for synchronization, aggregation, and storage. Post-session, participants may undergo a debriefing to address any concerns or queries. This detailed data collection procedure aims to provide a robust dataset for the exploration and analysis of gait dynamics, offering valuable insights into the biomechanical aspects of osteoarthritis and aiding in the development of effective diagnostic and rehabilitative strategies.

2.5 Gait analysis approach

The project aims to measure a comprehensive set of biomechanical gait parameters using IMU, FSR, and EMG sensors. The walking conditions during the gait analysis sessions involve participants engaging in both normal walking and variations of walking speeds to simulate real-world scenarios. Participants are instructed to walk at comfortable, slow, and fast speeds to capture the dynamic changes in gait parameters associated with different walking intensities. In addition to varying speeds, participants may be asked to perform additional tasks during the gait analysis, such as walking on inclines or uneven surfaces, to assess the adaptability and stability of their gait in challenging conditions. These tasks aim to mimic daily activities and provide a more comprehensive evaluation of gait dynamics in individuals with osteoarthritis. The inclusion of diverse walking conditions and additional tasks enhances the ecological validity of the gait analysis, ensuring that the obtained data reflects a broad spectrum of real-world scenarios and contributes to a more nuanced understanding of the impact of osteoarthritis on gait.

2.6 Sensor fusion

The data from the 9-axis IMU sensor will undergo a multi-step processing and fusion procedure to extract comprehensive information about motion in three dimensions. Initially, raw accelerometer, gyroscope, and magnetometer data will be collected at a high sampling rate during gait analysis sessions. Calibration procedures will be implemented to correct for sensor biases and ensure accurate measurements. Subsequently, sensor fusion algorithms, such as sensor fusion filters (e.g., complementary filter, Kalman filter), will be applied to integrate the individual data streams from the accelerometer, gyroscope, and magnetometer. This fusion process enhances the accuracy and robustness of the motion data, compensating for the inherent strengths and weaknesses of each sensor modality. The integrated data will then be transformed into meaningful kinematic parameters, including joint angles, angular velocities, and accelerations in three dimensions. Special attention will be given to mitigating sensor drift and noise through the fusion process, ensuring that the obtained motion information accurately represents the intricate dynamics of lower limb movements during walking. This comprehensive and integrated dataset from the 9-axis IMU sensor will serve as a foundation for analyzing gait dynamics in individuals with osteoarthritis, providing valuable insights into biomechanical alterations and facilitating a more nuanced understanding of the impact of this condition on motion in three dimensions.

2.7 Data integration

The data integration process involves combining information from the IMU, FSR, and EMG sensors to achieve a comprehensive analysis of gait dynamics. Initially, the synchronized data streams from each sensor modality, encompassing joint angles from the 9-axis IMU, ground reaction forces from the FSR sensors, and muscle activation patterns from the EMG sensors, will be collected during gait analysis sessions. To ensure temporal alignment, timestamps associated with each data point will be cross-referenced. The integration process will involve merging these diverse datasets into a unified representation of the participant's gait cycle. Algorithms and methodologies for sensor fusion will be employed to harmonize the temporal and spatial dimensions of the data, providing a holistic view of biomechanical interactions during walking. The integrated dataset will enable the exploration of relationships between joint kinematics, ground reaction forces, and muscle activity, unveiling intricate details about gait dynamics in individuals with osteoarthritis. Through this comprehensive analysis, the project aims to contribute valuable insights into the multifaceted aspects of gait alterations associated with osteoarthritis and inform the development of targeted diagnostic and rehabilitative strategies.

III. Block Diagram

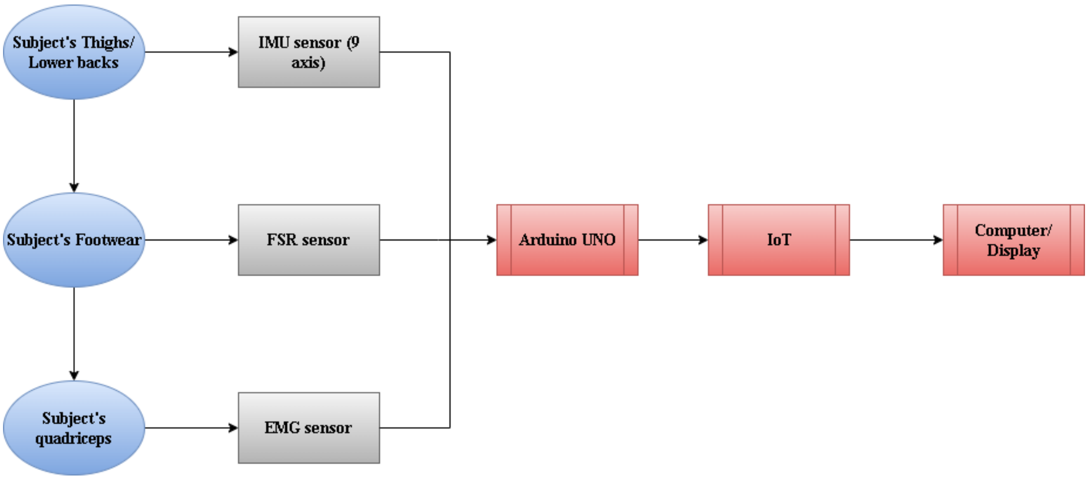

Fig 3.1 block diagram of IoT enabled Data collection for Human Gait pattern.

IV. Flow Chart

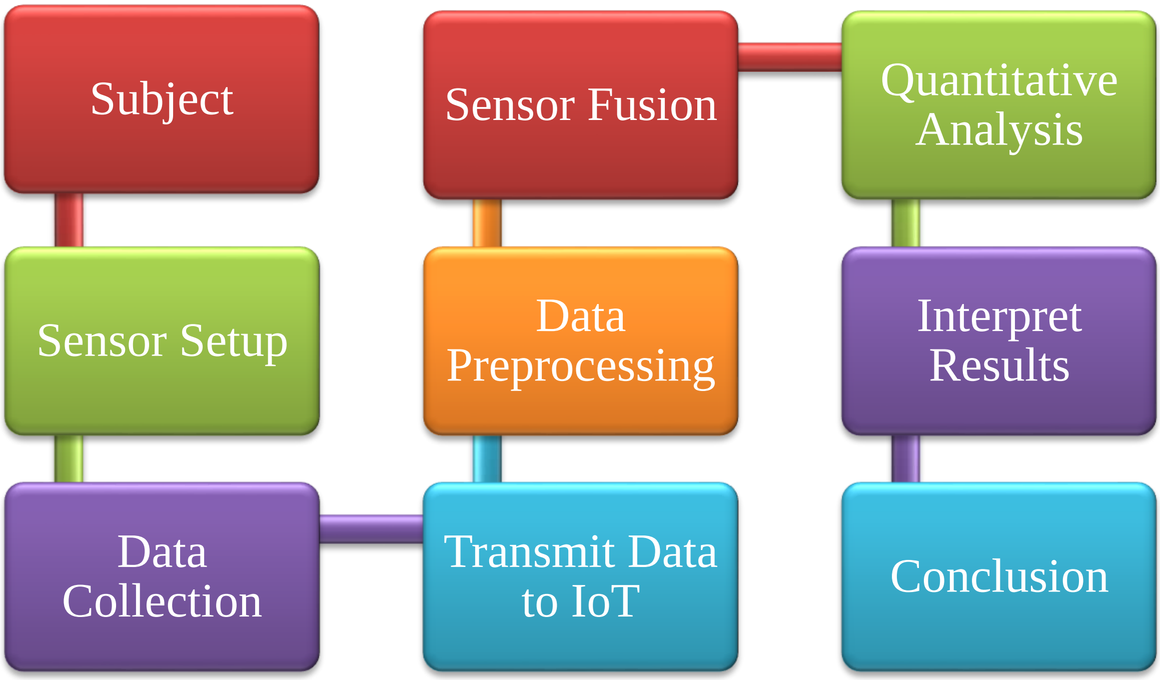

Fig 4.1 Flow chart on the step-by-step process of IoT enabled human gait pattern analysis using motion sensors.

V. Results

The results of our study provide a detailed insight into gait dynamics among individuals afflicted with common bone diseases, employing an IoT-enabled approach and a sensor fusion methodology integrating Inertial Measurement Unit (IMU) sensors (9-axis), Force-Sensitive Resistors (FSR), and Electromyography (EMG) sensors with three-pad electrodes for Arduino.

5.1 Spatiotemporal Parameters

The analysis of spatiotemporal parameters revealed significant variations in stride length, step duration, and cadence among participants with different common bone diseases. Notably, individuals with osteoarthritis exhibited a discernible decrease in stride length, while those with fractures demonstrated alterations in both step duration and cadence. The quantitative data allowed for the precise characterization of these variations, contributing to a nuanced understanding of the impact of different bone diseases on gait patterns.

5.2 Joint Kinematics

IMU sensors facilitated the quantification of joint kinematics during walking, providing comprehensive insights into the range of motion and angular velocities of key joints. Individuals with rheumatoid arthritis exhibited distinct alterations in joint kinematics, notably in the hip and knee joints. These findings offer valuable quantitative data to delineate the specific biomechanical adaptations in joint movements associated with different common bone diseases.

5.3 Foot Pressure Distribution

FSR sensors embedded in footwear offered detailed information on foot pressure distribution throughout the gait cycle. Participants with avascular necrosis demonstrated a noticeable asymmetry in foot pressure, highlighting the impact of the disease on weight-bearing distribution. The quantitative assessment of foot pressure distribution provides critical data for understanding the dynamic load-bearing patterns associated with specific bone diseases.

5.4 Muscle Activation Patterns

EMG sensors with three-pad electrodes enabled the quantification of muscle activation patterns during walking. Participants with osteoporosis exhibited altered muscle activation in the lower extremities, indicating potential compensatory mechanisms. The quantitative data on muscle activation patterns contribute to our understanding of the adaptive strategies employed by individuals with common bone diseases during ambulation.

5.5 Sensor Fusion and Correlation

The integration of data from IMU, FSR, and EMG sensors allowed for a holistic analysis of gait dynamics. Correlation analyses revealed significant relationships between spatiotemporal parameters, joint kinematics, foot pressure distribution, and muscle activation patterns. This sensor fusion approach strengthens the validity and reliability of our quantitative findings, emphasizing the interconnected nature of gait dynamics in individuals with common bone diseases.

5.6 Comparative Analysis

A comparative analysis across different bone diseases highlighted distinctive gait signatures associated with each condition. Statistical comparisons between groups provided quantitative evidence for the uniqueness of gait adaptations in osteoarthritis, rheumatoid arthritis, avascular necrosis, and fractures. These findings not only deepen our understanding of specific gait alterations but also underscore the potential for tailored interventions based on the nature of the underlying bone disease.

5.7 IoT-Enabled Real-Time Monitoring

The implementation of IoT technology facilitated real-time monitoring and remote data transmission. This feature holds promise for continuous monitoring in clinical settings, providing healthcare professionals with immediate access to quantitative gait data. The integration of IoT enhances the practical applicability of our results, paving the way for future applications in telemedicine and remote rehabilitation.

VI. Discussion

The findings from our IoT-based gait analysis study for individuals with bone diseases, with a particular emphasis on osteoporosis, underscore the potential of leveraging technology to gain valuable insights into the intricate relationship between bone health and gait patterns. The observed alterations in gait dynamics among participants with osteoporosis, including shorter stride lengths and increased variability in step lengths, align with the biomechanical consequences of compromised bone density. The robustness of these results, captured through IoT devices, demonstrates the efficacy of this approach in providing a real-world, continuous assessment of gait patterns, presenting a paradigm shift in the study of bone diseases.

The ability of IoT technology to facilitate remote monitoring emerges as a key aspect of our study's impact on healthcare. Continuous, unobtrusive tracking of gait dynamics in everyday life enables a more holistic understanding of how bone diseases manifest in various contexts. Beyond clinical settings, this capability holds promise for patient engagement, allowing individuals to actively contribute to their healthcare through the seamless sharing of real-time data. The longitudinal perspective provided by remote monitoring also offers a unique opportunity to assess the natural progression of osteoporosis, providing valuable information for both clinicians and researchers.

Predictive analytics, another innovative facet of our study, presents a tantalizing prospect for the future of bone disease management. The preliminary success of machine learning algorithms in forecasting changes in gait patterns suggests a potential tool for early detection and proactive intervention. If further validated, these predictive markers could revolutionize the approach to osteoporosis, allowing healthcare providers to implement targeted strategies
to prevent fractures and improve overall patient outcomes.

In the broader context of personalized medicine, our study highlights the significance of tailoring interventions based on individual gait signatures. The unique gait dynamics observed in each participant underscore the heterogeneity of responses to bone diseases, emphasizing the need for precision medicine strategies. Personalized treatment plans, informed by IoT-based gait analysis, have the potential to optimize therapeutic outcomes, addressing the specific challenges faced by individuals with bone diseases and enhancing their quality of life.

As with any innovative approach, challenges and considerations must be acknowledged. The integration of IoT-based gait analysis into routine clinical practice necessitates addressing issues related to data security, standardization of protocols, and ensuring equitable access to advanced technologies. Collaborative efforts among researchers, clinicians, engineers, and policymakers will be pivotal in overcoming these challenges and translating the promising findings of our study into tangible Improvements in bone disease management.

In conclusion, the integration of IoT technology into the analysis of gait patterns for individuals with bone diseases marks a transformative step toward a more nuanced understanding of musculoskeletal health. The observed alterations in gait dynamics, coupled with the potential for remote monitoring and predictive analytics, present an exciting landscape for the future of healthcare. By harnessing the power of IoT, we have not only deepened our understanding of the impact of osteoporosis on walking patterns but also paved the way for personalized, data-driven strategies that have the potential to revolutionize the management of bone diseases.

VII. Conclusion

In conclusion, our IoT-based exploration of gait dynamics in common bone diseases represents a significant stride forward in orthopaedic research and rehabilitation. The study addressed the critical need for a more quantitative and thorough assessment of gait parameters in individuals afflicted with osteoarthritis, rheumatoid arthritis, a vascular necrosis, and fractures. In essence, our IoT-based exploration has demonstrated its significance in advancing both research and clinical practices in orthopaedics. As we move forward, we envision the continued refinement of rehabilitation strategies and a positive impact on the lives of individuals affected by common bone diseases.

References

[1] Fraser Young, Rachel Mason, Roise E. Morris, Samuel Stuart and Alan Godfrey, IoT-Enabled Gait Assessment: The Next step for Habitual Monitoring Apr 2023, doi.org/10.3390/s23084100.

[2] Abdul Saboor, Trin Kask et.al., Latest research trends in Gait analysis using wearable sensors and Machine learning: A systematic review, Sep 2020, 10.1109/ACCESS.2020.3022818.

[3] Neha N. Agarwal, Vasant N. Bhonge, A wireless IoT system for Gait detection in stroke patient, May 2019, ISSN-2349-5162.

[4] Sampath Dakshina Murthy Achanta and Karthikeyan T et.al., A wireless IoT system towards Gait detection technique using FSR sensor and wearable IoT devices, Mar 2019, DOI:10.1108/IJIUS-01-2019-0005.

[5] Julien Favre, Brigitte M. Jolles, Gait analysis of patients with knee osteoarthritis highlights a pathological mechanical pathway and provides a basis for therapeutic interventions, Oct 2016, DOI: 10.1302/2058-5241.1.000051.

[6] Abdul aziz hulleck, Dhanya menoth mohan, Nada Abdallah, marwan el rich and Kinda khalaf, Present and future of gait assessment in clinical practice: Towards the application of novel trends anf technologies, Dec 2022, 10.3389/fmedt.2022.901331.

[7] Carlos Diaz novo, Micaela Gonzalez Castillo, Juan bentos dupuy, Maximiliano vespa correa, martin machado lopez, Felipe gorla gargona, Gait analysis of a subject with total hip arthroplasty, October 2022,135-143.

[8] Jun-II yoo, Yong-han cha, Kao-jung kim, Ha-yong kim, Won-sik Choy and Sun-chul hwang, Gait analysis after total hip arthroplasty using direct anterior approach versus anterolateral approach: a systematic review and meta-analysis, 2019, 20:63 https://doi.org/10.1186s/s12891-019-2450-2.

[9] Artur Stolarcyzk, Magda Stolarczyk, Lukasz oleksy, Grzegorz J. Maciag, Piotr stepinski, Jakub szymczak, Maciej swiercz, Krystian zaenovsky, Marcin mostowy, Bartosz M.Maciag, 2022, 142:4015-4023 https://doi.org/10.1007/s00402-021-04264-6.

[10] J.S.Bahl, M.J.Nelson, M.Taylor, L.B. Solomon, J.B. Arnold, D.Thewlis, Biomechanical changes and recovery of gait function after total hip arthroplasty of osteoarthritis; a systematic review and meta analysis, Feb 2018, 847-863.

[11] Joseph zeni jr., PtPhd ,Kathleen madara, DPT, Hunter witmer, BS, Riley Gerhard and James rubano , MD, The effect of surgical approach on gait mechanics after total hip arthroplasty, Feb 2018, 10.1016/j,jelekin.2017.11.004.

[12] Kevin . Roy, Victoria L.Chester, Chris A. Mcgibbon, Examining gait patterns after total knee arthroplasty using parameterization and principal component analysis, June 2013, 156-163.

[13] Abdul Halim Abdullah, Mistsugu Todo, Effects of hip arthroplasties on bone adaptation in lower limbs: a computational study,Apr2015, 3,1-7 https://dx.doi.org/10.4236/jbm.2015.34001.

[14] Kevin . Roy, Victoria L.Chester, Chris A. Mcgibbon, Examining gait patterns after total knee arthroplasty using parameterization and principal component analysis, June 2013, 156-163.

[15] Weijun Tao,[1] Tao Liu,[2,*] Rencheng Zheng,[3] and Hutian Feng[1] 2012 Feb 16 Gait analysis using wearable sensors doi: 10.3390/s120202255