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Human Gait Analysis Using Machine Learning

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ABSTRACT
Gait analysis, traditionally is a complex field due to the complex interplay of various data points which is being significantly transformed by machine learning coupled with biomechanics.This paper provides an overview into how machine learning can empowers researchers to effectively analyze walking patterns in humans.It explores the current research and practical applications implemented by experts. The focus lies on leveraging supervised machine learning algorithms to identify neurological problems, uneven gaits, gait disorders, specific gait events, and overall walking activities. Additionally, the paper emphasizes the effectiveness of these machine learning methods in diagnosing conditions, predicting recovery timelines, and improving clinical monitoring tools for better results.

Index Terms—Pattern Recognition, Machine Learning, Gait Analysis, Neural Networks,Motion Capture Technology.

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I. INTRODUCTION

Understanding human walking, or gait, involves complex calculations related to forces acting on the lower limbs. This analysis is crucial for identifying gait abnormalities and understanding posture problems, and monitoring rehabilita- tion progress.Traditional gait analysis faces challenges due to individual variations in walking patterns. Here, Artificial Intelligence (AI) offers a powerful solution. AI excels at handling large datasets of complex, time-series data, making it ideal for gait analysis.

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In healthcare, AI algorithms can analyze diverse patient data to diagnose conditions accurately and reliably. These algorithms continuously learn and improve their diagnostic abilities. Clinicians can leverage AI to gain deeper insights into patient health by analyzing vast amounts of data. Additionally, AI can analyze longitudinal health data to predict potential illnesses.

Beyond diagnosis and treatment selection, AI-driven tech- nologies like surgical robotics can streamline workflows and improve patient monitoring. However, early implementations of AI were hampered by poor data management, leading to limited effectiveness. Experiments were often confined to controlled lab settings, highlighting the need for real-time, high-precision data capture techniques.

While predictive methods in gait analysis are common, their ability to foresee unexpected outcomes is limited. A combined approach integrating biomedical engineering, computational analysis, and gait analysis expertise holds promise for over- coming these limitations.

Paper Objectives:

Identify key factors in research using machine learning (ML) for gait analysis and rehabilitation. Evaluate current gait analysis methods based on their effectiveness in detecting gait activities, events, disorders, asymmetries, and neurological patterns. Assess the most common ML methods used for gait analysis, performance evaluation, and rehabilitation.

II. MACHINE LEARNING AND GAIT ANALYSIS

Machine learning plays a crucial role in analyzing how our bodies move while walking. It does this by building mathematical relationships that help understand the connection between different types of data collected during walking (like muscle signals and body movements) and the resulting patterns. This process involves taking raw data from various sensors, organizing it into sets for training and testing, and then fine-tuning the model until it can accurately classify different walking patterns or detect any issues that might arise. There are different types of machine learning techniques used for this, including supervised learning, unsupervised learning, and reinforcement learning, each with its own approach to analyzing and interpreting the data.

A. Supervised Learning supervised learning requires data that has been labeled or categorized to understand the con- nection between different features and their labels. When it comes to analyzing walking patterns, algorithms using supervised learning use various methods like decision trees, neural networks, and support vector machines. Among these, support vector machines are particularly useful because they can handle both simple and complex problems, even with limited data. They work by separating different classes of data using a method called kernel methods, making them very effective for analyzing walking patterns and identifying different types of movements.

B. Unsupervised Learning

Unsupervised learning operates without labeled data, en- abling algorithms to discern relationships between various inputs to generate outputs. Most clustering techniques focus on the distance between vector features. However, these methods are now in progress in gait studies due to challenges in delineating learning targets and managing extensive feature vectors. Nonetheless, they prove beneficial in scenarios with unclear outcome relationships. Combining classification with dimensionality reduction methods proves advantageous for large datasets, facilitating unsupervised approaches in learning diverse patterns. Rigorous selection of distance metrics ensures accurate problem representation. C. Reinforcement Learning

Learning Model	Applications	Complexity	Pros	Cons
Supervised	Activity, Incidents, Illness, Asymmetry, Neurology.	Moderate	*Neural Network*	
			Functions in handcrafting, No need for feature detection.	Lack of explain ability.
			Support Vector Machine	
			The potential for generalization, Stability.	Kernel role selection, Scaling of function
			Random Forest	
			Many decision trees together with a probabilistic method, Quick training.	The memory requirement is heavy for massive datasets, No hyperparameter modification.
			Decision Tree	
			Probable solution.	Lack of continuous characteristics predictability, Non-Stabilization.
			Fuzzy Logic	
			Rules-based, Less complexity.	Membership function selection, many linguistic characteristics.
			kNN	
			Learning based on instances.	Scaling of function, Responsive to environmental factors.
Unsupervised	Gait operation determination, Detection of asymmetry, Disorder clustering.	Moderate	Facility to incorporate, Implementation is easy.	Much time-consuming.
Reinforcement	Restoration, Helping systems, Automation.	Moderate	Learn continuously, No learning model	Learning is limited.

Fig. 1. MACHINE LEARNING MODELS SUMMARY

Reinforcement learning acts as pivot in rehabilitation settings, such as exoskeletons, enabling systems to interact and navigate dynamically. Various control strategies for rehabilitation have emerged,with reinforcement learning and deep neural networks widely adopted for their adaptability to participate heterogeneity and task simplification according to specific conditions.

III. LITERATURE REVIEW

In this section, we dig deep into a various studies conducted by various scholars in the past, focusing on the application of new computer training methods in gait analysis.

A. Detection of Gait Activity

Researchers have explored the recognition of normal gait for different activities, employing machine learning techniques. This involves discerning various motions, such as walking on flat surfaces, standing still, and navigating uneven terrain, using inertial sensors and motion capture devices. Studies conducted on both pathological and healthy populations highlight the significance of tracking activity for patient outcomes. For instance, Lau et al.'s analysis identified support vector machines as the most effective method for gait activity classification. Sensors placed on either the foot or shank which accurately identify different activities, aiding in robotics, rehabilitation and exoskeleton control. Several studies have focused on reducing data size to enhance recognition performance, with optimization models developed
to aid clinicians in selecting key pathological parameters.

B. Detection of Gait Event

Gait event detection (GED) is fundamental in classifying gait phases and sub-phases, such as swing, pull, push, terminal swing, and loading. Precise identification of these phases is crucial for avoiding injury in rehabilitation robotics and assessing gas recovery, orthotic reliability, and functional electrical stimulation. Electromyography signaling plays a vital role in defining the gait process by capturing muscle contraction and relaxation. Studies utilizing neural network recognition processes have explored stroke therapy in robotic exoskeleton patients and identified the relationship between motion changes and knee arthritis. Observational approaches with group learning models have been developed to categorize patterns for gait phase recognition. Functional electrical stimulation, along with supervised and reinforcement learning methods, aids in understanding human gait and achieving automatic detection of gait phases for recovery.

C. Detection of Gait Disorder

Gait, the walking pattern of humans, relies on muscle balance and stabilization. Disorders may arise from brain, orthopedic, or psychological issues, leading to anomalies in walking patterns. Previous studies have used parameters such as the normalcy index to assess degraded gait, emphasizing the importance of variance in diagnostic conditions. Multimodal identification methods offer qualitative and quantitative assessment of gait defects, proving more effective than single-model approaches. Disorders like knee arthritis, rheumatoid arthritis, and patellofemoral pain syndrome contribute to antalgic behaviors and weight-bearing mechanism alterations. Machine learning models, such as support vector machines (SVM) and NN, aid in identifying and quantifying biomechanical variables associated with knee pathology and arthritis.

D. Detection of Gait Asymmetry

Minor differences between lower limb movements contribute to asymmetric gait, affecting balance and posture control. Assessing asymmetries is crucial for rehabilitation, disease identification, and evaluation. Studies combining fuzzy logic with other classifications have attempted to assess ligament healing stages, employing neuromuscular and kinetic signals. Machine learning models aid in patient care and healing by physiatrists, physiotherapists, and physicians. Research efforts utilizing SVM and long short-term memory (LSTM) networks have achieved high accuracy in gait asymmetry detection.

E. Analysis of Neurological Gait

Neurological gait studies focus on evaluating cognitive mechanisms, decoding cortical mechanisms, and recognizing gait intentions. Gait interventions now consider cognitive functions alongside motor functions, recognizing the impact of emotional function loss on gait dysfunction. Machine learning tools measure cognitive mechanisms' impact on rehabilitation approaches. Electroencephalogram signals play a crucial role in activation and cessation of gait, aiding in designing assistive devices for motor impairments. Integrating machine learning, gait, and cognitive mechanisms can improve the development of recovery devices, exoskeleton prototypes, and real-time clinical diagnoses. However, challenges remain in modeling neuronal networks accurately using electroencephalogram data, highlighting the need for specific data collection for robust function engineering systems.

IV. FUTURE ASPECTS

The collaboration between machine learning and biomedical engineering holds promising opportunities in gait identifica- tion, encompassing behavioral recognition, event detection, disruption detection, asymmetry detection, and remediation systems control. Emphasis on model construction lies in data, algorithms, models, and learning theory. The primary objective is to streamline hospital arrangements and long-term treat- ments by saving time. Methodological approaches addressing noise or lack of evidence, as suggested by Devanne and Berretti's review, are crucial for ensuring reliability. Integrating both traditional and innovative angles suitable for gait diag- nosis can enhance instrumentation. Overcoming the challenge of the black box factor's relevance in the environment is vital for further integration of machine learning and gait disorders. Although further analysis of classifier consistencies is war- ranted, domain-specific knowledge is essential for effective feature engineering in gait analysis. Gait analysis presents unique challenges due to its transient, non-stationary, and complex nature. Recent advancements in pathology diagnosis necessitate a high degree of power to accommodate participant heterogeneity at various stages. Many experiments employ at- tribute analysis methods and incorporate simple biomechanics estimation in learning models.

Deep learning shows promise in simplifying complex en- gineering practices and refining decision-making processes. Ongoing research focuses on identifying the best grouping for specific datasets. Significant progress has been made in gait analysis over recent decades.

The transition from offline analytics to real-time tests, facilitating efficient, intelligent clinician applications, is im- perative. Treating patients' gait abnormalities requires fun- damental awareness, paving the way for anomaly detection. The widespread adoption of models for various conditions, population levels, and transfer-learning is anticipated, enabling repeated applications in patients with similar impairments before training completion. Short-term benefits of AI include disease forecasting, disease progression monitoring, recovery rate prediction, and optimization of rehabilitation equipment control mechanisms.

Technological advancements, particularly sensor-based techniques, offer cost-effective solutions for maneuvering test- ing areas, continuous monitoring, and portability. These ap- proaches facilitate long-term data processing, patient manage-ment, rehabilitation module implementation, and systematic data storage for learning strategies. Clinicians can leverage these techniques to detect and manage gait pathologies effec- tively, aiding physiotherapists in addressing diverse situations and demands in clinical procedures.

V. CONCLUSION

In recent years, there has been significant growth in gait studies using AI applications. This is largely due to the effectiveness of machine learning techniques in analyzing gait, which can quickly and accurately classify different walk- ing patterns by extracting simpler functions from complex biomechanical data. Compared to traditional methods, dy- namic strategies driven by machine learning are more flexible and adaptable, simplifying the process of evaluating walking patterns. Traditional methods relying on human observation are subjective and lack reliability and accuracy.

Based on our analysis, the precision rates for detecting various aspects of gait range from 85% to 100% for behavior recognition, 95% to 98% for incident identification, around 80% to 85% for asymmetry detection, and 67% to 96% for neurological gait. These tests were conducted using different methods and in various settings. For example, accelerometers can detect physical activities with a precision of 85% to 95% , while combining gyroscopic data improves reliability, especially for binary classifications like climbing up and down. Future of gait analysis lies in continuous monitor- ing, regular diagnostics, and real-time testing, facilitating not only rehabilitation but also empowering medical professionals with valuable insights for personalized patient care. Further research is warranted to explore the integration of machine learning and inertial sensors into routine clinical practice, with the aim of establishing them as standard diagnostic tools for gait analysis. This ongoing exploration promises to revolu- tionize healthcare by enabling more accurate, efficient, and personalized approaches to gait assessment and rehabilitation. In the future, continuous monitoring, regular diagnostics, and real-time testing will be essential for gait analysis. This not only aids in recovery but also provides valuable information to medical professionals and patients. Further research is needed to explore the use of machine learning and inertial sensors as standard clinical diagnostic tools.

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