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Unveiling Patterns and Abnormalities of Human Gait: A Comprehensive Study

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***Abstract* - Varieties of serious mental and physical disorders are the cause of variations in gait. Gait analysis is extensively used in a variety of clinical applications to diagnose and monitor specific disorders. Sports, physical rehabilitation, clinical evaluation, surveillance, identification, modeling, and other industries all benefit from gait analysis. The study provides extensive information on characteristics, types, methodologies, limitations, applications, datasets, and tools used in gait analysis employing different sensor-based and vision-based approaches. A thorough study on gait analysis indicates a significant research gap in various elements of vision-based gait analysis. The field is either undiscovered or has received minimal attention in various scenarios, thus requiring emphasis on comprehensive analysis and exploration. This study will help analyze human walking patterns concerning clinical applications, rehabilitation, injury assessment, and fall risk assessment. It can provide important insights into various aspects of a person's gait.**
***Keywords:* Gait Analysis, Approaches, Parameter, Types, Applications, Limitation, Meta-Analysis**

I. INTRODUCTION

Walking is often seen as a natural attribute in humans, yet when investigated attentively, it reveals itself to be a complicated phenomenon. Gait is a key feature of human movement that includes the coordinated efforts of nerves, muscles, and the brain. Walking is intimately related to freedom and uniqueness in the arena of human existence, and any variation from the standard can have a substantial influence on life quality (Nutt *et al.,* 1993). Human gait is always measured subjectively through eye observation. However, as technology has advanced, empirical and objective examination of human gait has become available. Walking is a synchronized action of the lower limbs that is characterized by involuntary and periodic flexion-extension motions. The posture is combined with a pattern of locomotion (crawls, walks, runs, etc.) known as gait (Nutt. *et al.,* 1993).

In the gait pattern, the negative deviation is recognized by the gait analysis (systematic) technique and also determines their effects and reasons. The mechanism of human movement was revealed, through gait analysis by computing factors overriding the functionality of lower extremities. Human gait analysis is a combination of various uses, such as security, sports science, animation and medical diagnosis (Prakash *et al.,* 2015, Fuhrer *et al.,* 2014). In gait analysis, monitoring of patient responses for medical recovery is generally done by using an optical-based motion analyzer system. A gait cycle is bifurcated into two phases: the stance phase and the swing phase (Perry *et al.,* 1992).

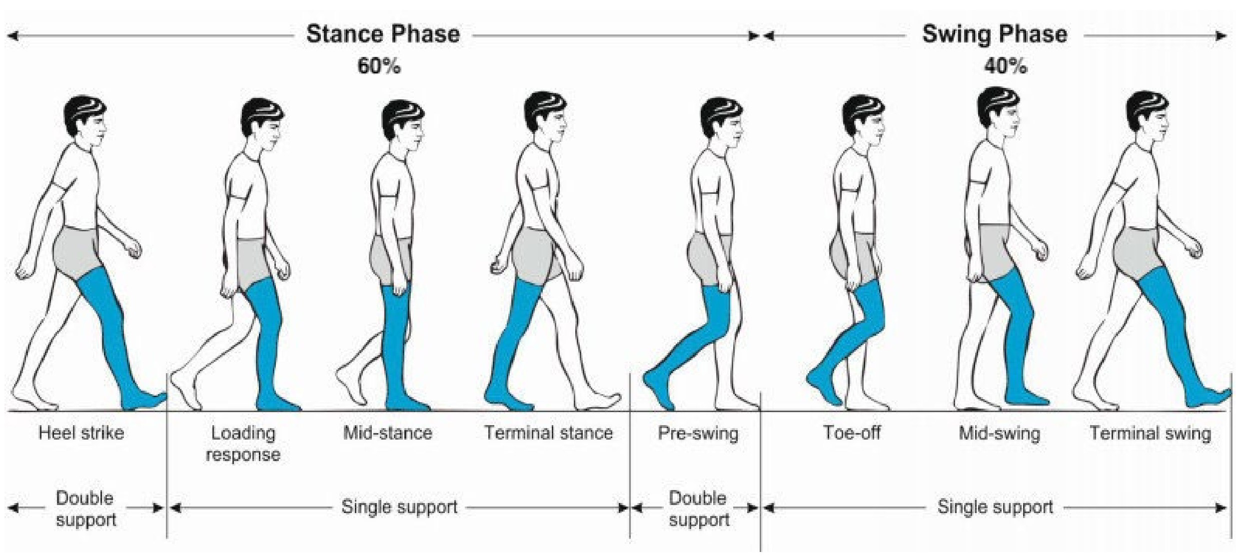

Fig. 1 The gait cycles

Phase 1: Inertial contact (IC), also known as heel strike, happens when the heel of the foot makes contact with the ground.
Phase 2: The loading reaction (LR) occurs when the reference foot persists until the other foot is raised for swing.
Phase 3: Mid-stance (MSt) is the moment at which the contra-lateral foot toes off and transitions to the reference foot with the COG.
Phase 4: A terminal stance (TSt) begins with the COG reference foot and ends with the contra-lateral foot.
Phase 5: PSW (pre-swing) starts initial contact of the contra-lateral toe and finishes with toe-off.
Phase 6: The initial swing (ISw) occurs while the hip's reference foot is flexed, and the comparable knee is flexed.
Phase 7: The flexion knee's reference foot is at the swing's extremity (MSw).

When in terminal swing (TSw), the tibia is perpendicular to the ground. It accounts for between 87 and 100 per cent of the total gait cycle.

Gait analysis can be done by Gait parameters which are bifurcated into two fundamental parameters used for specific measurements and other basic parameters used for common measurements of human walking. Eight types of gait abnormalities. Defines the methodologies that have been used for the gait analysis such as Sensor-based and Vision-based approaches and Machine Learning techniques. Sensor-based approaches are applied to gather the data using sensors, inertial systems, etc. from the subject body (such as EMG, force platform, inertial systems (GRF, foot pressure pattern distribution, accelerometer, gyroscope)). Vision-based or image processing approaches are used to gather the data in the form of images/frames or videos using human 3D motion capturing cameras and can be accomplished with two methods: marker-based (direct) and without marker-based (indirect). Equipment used to capture the gait analysis in vision-based is analogue or digital cameras.

Machine learning techniques and statistical techniques are used to classify and represent the gait data. Machine learning technique such as supervised, unsupervised, rule-based, reinforcement, etc. helps to improve performance, accuracy, and optimizations efficiently. In statistical techniques, LDA, PCA, etc. are used to form a linear relationship in gait data. Kinetics, Kinematics and Computational Intelligence are classified as the broad approaches for Gait Analysis. Kinematics mainly focus on the knee joint, hip joint, ankle joint and many other joints. Kinetics mainly focus on foot amputation related to ground reaction force, mass and movements, but it does not have a detailed knowledge of the position and orientation of the entity involved. Computational intelligence is the hybridization of kinematics and kinetics approaches with various machine- learning methods.

In every technology, there are some pros and cons that affect the results such as limited space to set up experiments, uncomfortable wear of sensors, results affected due to some muscle relaxants due to CNS, etc. There is a huge publicly available gait dataset for consistent evaluation and performance comparison for gait analysis (Collins *et al.,* 2002). The available datasets, in term of the walking environment, has a large diversity but are still insufficient for reliable gait analysis.

Data on gait is highly heterogeneous, temporal dependent, highly dimensional and variable in nature. Gait patterns cannot be generalized for a person, because till now there is insufficient data to mark a standard generalized gait pattern for a given age group and gender. The biometric dataset is very limited in comparison with biometric individuals such as fingerprint and face recognition. There are limited datasets related to gender and age and eight specific gait abnormalities.

Currently, various datasets have been opened for the researchers publicly related to genders and age, gait abnormalities, and many more to identify and classify the gait pattern, and various gait behaviour activities. The dataset consists of various musculoskeletal values related to kinetics and kinematics to identify various features in gait, body movements, pressure pattern distribution, clinical analysis, etc. A precise description of various gait analysis or musculoskeletal analyzer/simulator tools that have been used to gather the input and give the output with better performance and accuracy such as OpenSim, Anybody Tech and many more. Industrial applications of gait analysis have increased in the recent decade.

II. GAIT ANALYSIS PARAMETERS

The gait analysis parameter is broadly classified into two categories: Fundamental parameters and basic parameters that help to measure it. Table I shows the basic parameters that are used to measure the common measurement of human walking patterns.

Approaches to gait analysis are divided into three categories: kinematics, kinetics, and computational intelligence. While kinematics and kinetics are involved in categorizing human motion, computational intelligence plays a role by merging the concepts of kinematics and kinetics through the use of various artificial intelligence approaches.

A. Kinematics

The major focus is on human motion analysis. The participant must walk normally while being watched under controlled settings, enabling for three-dimensional study of their full body movement. Kinematics can be further classified as qualitative or quantitative. It is largely concerned with the upper section of the body (trunk), where force is not a defining feature. The study focuses on obtaining information on temporal and spatial factors, different joint angles, and movement in the sagittal, frontal, and transverse planes.

TABLE I BASIC GAIT ANALYSIS PARAMETER DESCRIPTION

Basic Gait Parameters	Description
Stride velocity	Body cover distance in unit time, velocity of stride
Step length	Short step, successive steps contact.
Stride length	Long step of heel contact of the same foot
Cadence	No. of steps per unit time
Swing time	Time between lifting the foot off the floor.
Stance time	Time from heel touches the floor
Step width	Linear equivalent Distance between both foot
Step angle	Direction of foot step per unit
Step time	Time of short step per unit
Gait autonomy	Maximum number of persons can walk, taken from start and stop
Accumulated altitude	Height difference between drop and rise
Joint angles	Angle between the two relative segments on either side of joint (such as hip, knee, ankle) calculated in degree
Body segment orientation	Fixed line with respect to reference, segmentation should be in same direction
Ground Reaction Force	Force that is up thrust from ground
Muscle force	Force applied using part of the body such as arm or leg. This can be measured or generated by electromyography (EMG)
Body posture	Correct alignment of body parts supported by centre of gravity such as standing, bending or symmetry
Phases	Walking in a repetitive component such as swing and stance phases.
Event	Foot strike (contact of foot with ground) and toe-off (foot is off the ground)

B. Kinetics

It is largely concerned with analyzing ground reaction forces. Gait analysis is most commonly used in instances involving foot amputation. Study of mass, force, acceleration, and motions without a full understanding of the analyzed entity's location or orientation. A force platform is often used in gait analysis to quantify the force exerted beneath the foot when walking. The force platform, on the other hand, does not offer information regarding the position or angles of the limbs or joints. Kinetics is the study of the lower half of the body (locomotor system), which is dominated by force.

C. Computational Intelligence

It combines kinetics and kinematics principles with artificial intelligence techniques. This fusion allows for the detection of probable gait abnormality outcomes without the requirement for therapeutic intervention. In this hybrid environment, useful insights are achieved by utilizing automated parameter-based illness estimates and forecasting the potential impact of various rehabilitation programmes. This domain can also be subdivided into methodologies such as clustering and recognition/identification.

1. Clustering

This method falls under the category of unsupervised learning, which uses datasets with unlabeled data as input. Clustering, in particular, is the problem of grouping like items together and isolating different objects. It requires determining the metrics of similarity and dissimilarity between collections of things. Clustering approaches help in the extraction of useful information such as gait patterns and gait profile scores in gait analysis. Table II displays a sample of clustering surveys focusing on gait data.

2. Identification/Recognition

Gait Recognition is a sort of biometric technology used to track and identify persons. This visual-based system captures recordings of body motions such as the shoulder, knee, and foot using video cameras such as RGB depth-sensing cameras. Similar to previous pattern recognition algorithms, these movies are then analyzed to automatically extract human motion patterns, allowing the verification of human identification. As a biometric technology, gait recognition has various benefits, one of which is its capacity to operate with distance for possible recognition, making it a cost-effective option [Nutt *et al.,* 1993]. Pose estimate is critical in gait recognition. Pose estimation entails identifying the camera's location and orientation to the person relation or item being analyzed. Pose estimation is further divided into two types: 2D pose estimation, and 3D pose estimation. Table III summarises some previous surveys in the field of posture estimation for gait identification.

TABLE II CLUSTERING APPROACHES TO GAIT (VB-VISION-BASED AND SB- SENSOR-BASED)

Author	Methodologies	VB	SB
Malley *et al.,* 1997	The fuzzy clustering approaches is demonstrated on temporal-distance parameters with pre and post-operative test data subjects.	No	Yes
Prakesh *et al.,* 2018	Nature-inspired algorithm is explored for automated system. Optimal number of gait profile score are identified based on the voting from various clustering majors.	No	Yes
Carriero *et al.,* 2009	PCAfor dimensionality reductions of parameters. Fuzzy C-mean cluster analysis was performed to plot the first three principal component that account 61% of total variability.	No	No
Xu *et al.,* 2006	Using clustering-based approaches such as k-means and hierarchical clustering to investigate the gait pattern mining and cluster quality is validated by cluster majors.	No	No
Toro *et al.,* 2007	Identification of homogenous gait types using hierarchical clustering analysis on sagittal kinematic gait data.	No	No
Phinyomark *et al.,* 2015	Principle component analysis is used to reduce the dimensionality of entire waveform of gait, consists the three-dimensional kinematic data from ankle, hip and knee joints.	No	No
Vaughan *et al.,* 2005	Compare and characterized the dynamic similarity of neuromuscular function, a gait nomogram is developed which help to identify the pre and post-operative data using a statically fuzzy clustering to measures the clusters and help in improving neuromuscular functions.	No	No
Zhang *et al.,* 2014	Multiscale signature points extraction, newly signature points are encoded for sparse representation scheme and collection of signature point series for classifying spares-code. These are used to avoid the explicit step-cycle detection, inter-cycle phase misalignment and cycle detection failure.	No	Yes
Nguyen *et al.,* 2019	Under unsupervised learning various clustering methods are used to identify the gait clusters in constant and non-constant parameters of Parkinson disease patients.	No	Yes
Kuntze *et al.,* 2018	K-means method is used to determine the analysis of kinematics barefoot walking and clusterned into spatic diplegic CP using multi-joints without prior data reduction. This is validated by the cluster quality test using silhouette coefficient and Kruskal-Wallis H test.	No	Yes

TABLE III GAIT RECOGNITION APPROACHES ON GAIT (VB-VISION-BASED AND SB- SENSOR-BASED)

Author	Methodologies	VB	SB
Chattopadhyay *et al.,* 2013	Gait energy volume (GEV) is initiated to gather the features of the frontal gait recognition using depth images frame through kinetic. A novel feature is derived known as pose depth volume through partial volume reconstruction of frontal surface for each silhouette.	No	Yes
Chattopadhyay *et al.,* 2014	The depth da-ta of kinetic that presents the essential pose-based gait detection technique yields skeleton joint information. The picture of the skeleton is taken and mapped using 3D geometric transformation. It may generate gait characteristic for a certain key pose with more accuracy using key pose.	No	Yes
Chattopadhyay *et al.,* 2014	RGB-D camera is used to capture the combine feature view of front and back using proposed hierarchical classification strategy. This helps in identifying the frontal gait recognition using partial gait cycle information.	No	Yes
Roy *et al.,* 2015	Particle swarm optimization methodology is for parameter estimation that process the desired level of occlusion. The occlusion model is proposed on the basis of position and pose uncertainties of moving subject in videos.	No	Yes
Chattopadhyay *et al.,* 2015	Fast frontal gait recognition method is proposed using kinetic depth data to focuses the problem of frontal gait recognition occlusion along with the contour of silhouette.	No	Yes
Chattopadhyay *et al.,* 2014	Depth stream from kinetic can be utilizes by the proposed method known as key pose-based gait recognition. Coordinate system transformation arrange the frontal parallel silhouette in sequence.	No	Yes
Chattopadhyay *et al.,* 2015	Fully automated gait recognition method is proposed by multiple kinetic RGB-D cameras (frontal and back view both) that captured the depth information.	No	Yes

III. GAIT TYPES

The gait is bifurcated into eight pathological gaits that are attributed to neurological conditions. Diagnosis of these gaits helps to provide information regarding musculoskeletal conditions/disorders.

These are the gait abnormalities that can form various deformities in the body while walking in a deformed posture. In Fig.2 the bifurcation of gaits is shown.

A. Hemiplegic Gait

A swing arm and modest circumduction from normal mobility may result in hemiplegic gait problems. The patient has unilateral weakness and stiffness on the afflicted side, which is influenced by the arm, flexed, internally rotated, and adducted. It involves more than 50% - 60% of metabolic energy to walk and match with normal participant walking velocity. Gait analysis approaches of Kinematic, Kinetics and computational intelligence in Hemiplegic gait are shown in Table IV.

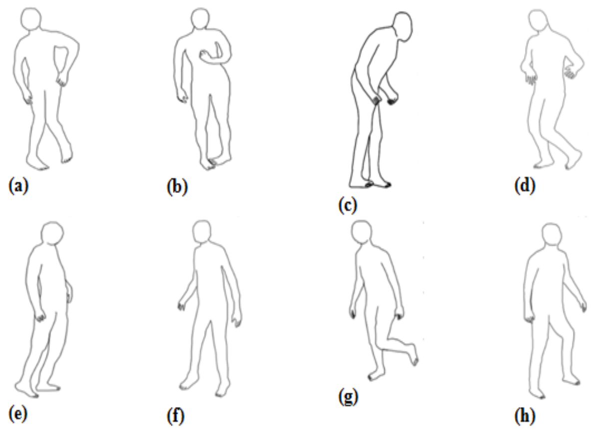

Fig. 2 Gait disorders include (a) diplegic gait,(b) hemiplegic gait, (c) Parkinsonian gait, (d) myopathic gait, (e) choreeiform gait, (f) ataxic gait, (g) neuropathic gait,and (h) sensory gait

B. Diplegic Gait

A patient with spasticity in the minor limbs that is worse than in the upper extremities. The patient walks with an unnatural scrape of the toes, dragging both legs and a narrow base in this case. As evidenced by bilateral periventricular lesions, this gait is present in cerebral palsy.

Hips and knees are stretched and internally rotated, while the ankles are flexed and adducted. Scissor gait is characterised by excessive tension in the hip adductors, causing the leg to cross in the midline. Cerebral palsy patients may benefit from hip adductor release surgery to reduce scissoring. Table V depicts Gait Analysis Approaches of Kinematics, Kinetics, and Computational Intelligence in Diplegic Gait.

TABLE IV HEMIPLEGIC GAIT ASSOCIATED WITH KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE (VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Cha *et al.,* 2018	Randomization, Rehabilitation therapy and gait intervention with or without auditory feedback	No	Yes
Titus *et al.,* 2018	Spatio-temporal parameters and PiG (Plugin-gait) model	Yes	Yes
Patikas *et al.,* 2005	EMG (Electromyography)	No	Yes
Molloy *et al.,* 2010	Gross Motor Function Measure	No	Yes
Churchill *et al.,* 2002	Rivermead video-based clinical gait analysis	Yes	No
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Bensoussan *et al.,* 2006	AMTI for Kinetic analysis and ELITE for kinematic analysis optoelectronic system	No	Yes
Dixon *et al.,* 2012	Oxford foot model and Plugin gait model with one-segment foot model	Yes	Yes
Jagadamma *et al.,* 2010	AFOFC (Ankle-foot orthosis footwear combination)	No	Yes
Ko *et al.,* 2011	Gait initiation used to examine effect of symmetrical weight bearing	No	Yes
Segal *et al.,* 2019	Multi-segment foot model used to examine the biomechanical adaptation of the foot and ankle joints	No	Yes
Zelik *et al.,* 2018	Rigid body segment	No	Yes
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Koktas *et al.,* 2010	Multi-layer perceptron approach is used	No	Yes
Safizadeh *et al.,* 2011	Assistive robotic leg (lower extremity exoskeleton) validated by kinematic motion	No	Yes
Coste *et al.,* 2015	Functional electrical simulation (FES) and body are network (BAN) embedding with sensors and actuators	No	Yes
Cutti *et al.,* 2010	Measure thorax-pelvis & lower limb using IMMS (Inertial and Magnetic measurement system)	No	Yes
Hansen *et al.,* 2008	Peripheral nerve activity is used for correction of foot drop. The simulation was recorded by telelinks, implanted devices. Detection can be done by adaptive logic network for controlling time.	No	Yes
Pogorelc *et al.,* 2012	Used motion capture systems and wall mount sensors with k-nearest neighbor and neural network algorithm	Yes	Yes

C. *Neuropathic Gait*

The gait is most frequent in people with peripheral nerve disease when the distal lower extremity is most affected by foot dorsiflexion (foot drop) weakness. The patient attempts to lift the leg high (high stepping gait) to avoid dragging the foot (toe) on the ground when walking. Unilateral causation is seen in peroneal nerve palsy and L5 radiculopathy. Many peripheral neuropathies associated with uncontrolled diabetes (such as Charcot-Marie-Tooth disease and amyotrophic lateral sclerosis) are included due to their bidirectional character. Table VI depicts Gait Analysis Approaches of Kinematics, Kinetics, and Computational Intelligence in Neuro-pathic Gait.

TABLE V DIPLEGIC GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE (VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Attias *et al.,* 2015	Gross motor function classification used and analyzed by Kruskal-Wallis and post hoc test	No	Yes
Heyrman *et al.,* 2013	Trunk profile score was proposed, and gross motor function classification system used	No	Yes
Heyrman *et al.,* 2014	Trunk control measurement scale and Plug-in-Gait model	Yes	Yes
Scheys *et al.,* 2011	Rescaled generic based kinematic model and magnetic resonance based kinematic model	No	Yes
Swinnen *et al.,* 2018	Gross motor classification system and thorax, spine and pelvis range of motion.	No	Yes
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Condliffe *et al.,* 2016	Inhibitory post-synaptic potential is used to measure CP by sensors and sensory stimulation produce by peri-stimulus frequency grams.	No	Yes
Eek *et al.,* 2011	Kinetic pattern and muscle strength with bilateral spastic cerebral palsy and correlation with planter flexing gait movement and muscle strength	Yes	No
Piccinini *et al.,* 2011	Comparative in kinetic, kinematics and EMG on hereditary spastic paraparesis	Yes	No
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Enriquez *et al.,* 2012	Design the fuzzy system to provide a linguistic interpretation of kinematic analysis for thigh and knee.	Yes	No
Wallard *et al.,* 2017	Robotic-assisted gait training therapy (RAGT)	Yes	No
Wallard *et al.,* 2017	Measure thorax-pelvis & lower limb using IMMS (Inertial and Magnetic measurement system)	No	Yes
Kamruzzaman *et al.,* 2006	Automated classification and detection using a support vector machine in respect of temporal-spatial two gait parameters (stride length and cadence)	No	Yes
Nguyen *et al.,* 2014	Extracting 3D information (silhouette-based) of each walking from stereo cameras and sensors	Yes	Yes
Gestel *et al.,* 2011	Bayesian network approach is used for classifying 3D gait analysis of ankle and knee	Yes	No

TABLE VI NEUROPATHIC GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE (VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Hohne *et al.,* 2012	Examine how to reduce plantar-afferent feedback and can be reduced by intra-dermal infection of an anaesthetic solution without affecting proprioception.	Yes	Yes
Gomes *et al.,* 2011	Change in electromyography and kinematics in diabetic neuropathic, delayed peak in plantar flexor activity	No	Yes
Sawacha *et al.,* 2009	Four segment foot and ankle model for accessing kinematics of neuropathic foot	No	Yes
Terrier *et al.,* 2011	Random sequence of treadmill and over ground walks. Fractal dynamics was assessed by detrended fluctuation analysis of stride interval	No	Yes
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Diliberto *et al.,* 2018	Single-segment foot modelling approach for diabetic mellitus and peripheral neuropathy. Evaluate mid foot and rear foot with DMPN. Electro-magnetic and force plate used to record multi-segment foot kinematics and GRF during walking.	No	Yes
Diliberto *et al.,* 2018	Examine the ankle and mid foot power of healthy people. Multi-segment foot motion and GRF are used.	No	Yes
Kim *et al.,* 2018	Using inverse dynamics-based optimization for foot joint contact forces	Yes	Yes
Long *et al.,* 2007	Examine multi-segmental foot motion in between double rocker sole shoe and unmodified sole shoe at mid-stance (hip, knee and ankle)	Yes	Yes
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Arai *et al.,* 2013	Mode-based tracking may yield a collection of static or dynamic skeletal parameters such as limb, leg, arm, and thigh. The model-free method focuses on the flow of silhouettes. The 3D skeleton model is a component of SVM-based model-based feature extraction.	Yes	Yes
Chan *et al.,* 2013	Internal accelerometer with micro electro-mechanical system sensors are used to collecting data using iPhone. Various ML algorithm such as KNN, SVM, MLP, Decision tree are implemented to determine low back pain patients.	No	Yes
Wafai *et al.,* 2014	Using smartphone camera to classify gait pathologies with a hierarchical classifier using SVM combining gait energy images and angles.	Yes	No
Wafai *et al.,* 2014	Evaluate the feasibility by Appling ANN to identify and classify the plantar pressure symmetry during control and pathological gait.	No	Yes

D. Myopathic Gait

During walking, the pelvis level is dependent on the hip girdle muscle, but waddling is caused by proximal pelvic girdle muscular weakness. When walking, if one side of the pelvis is weak, the contralateral side of the pelvis drops (Trendelenburg sign). Waddling causes the pelvis to sink on both sides, resulting in bilateral paralysis. Patients with muscular dystrophy, such as myopathies, are seen walking in this manner. Table VII displays gait analysis approaches.

E. Choreiform Gait

In this gait, the patient exhibits uneven, jerky, and involuntary movement in all limbs. Certain basal ganglia illnesses, Sydenham's chorea, Huntington's disease, neurological disorders. Table VIII depicts Gait Analysis Approaches of Kinematics, Kinetics, and Computational Intelligence in Choreiform Gait.

F. Ataxic Gait

The cerebellar cortex is the cerebellum's outermost layer, consisting of a continuous layer of nerve cells. The cortex is very regular geometrically organized and is substantially associated with the three sheets of neurons. The information is obtained from numerous areas of the brain and the cerebellar cortex of the majority of the body parts. Because of the cerebellar malfunction, this gait is defined as a stumbling movement with a wide-based stride and clumsiness. During titubation, the patient's body may strut back and forth and from side to side since he or she is unable to walk from heel to toe or in a straight path. Table IX depicts gait analysis methodologies for kinematics, kinetics, and computational intelligence in ataxic gait.

TABLE VII MYOPATHIC GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE (VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Grabiner *et al.,* 2018	To examine the extent of fractal scaling of thrice step width variability and get affected the performance by attention-demanding task.	Yes	No
Dingwell *et al.,* 2017	Causes of variability can be separated by GEM (Goal Equivalent Manifold) computational framework. By applying this framework, it examines the stepping of one stride to next in both young and high-functioning healthy older adult. Increasing then variability on the age likely precede impaired stepping control.	Yes	No
Stout *et al.,* 2016	To examine the gait functionality author used detrended fluctuation analysis alpha metric by non-weight-supporting harness over a treadmill.	No	Yes
Dingwell *et al.,* 2018	While adopting a different gait, speed would be different invariability aspects in walk-to-run transition.	Yes	No
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Harris-love *et al.,* 2018	Investigate between upper and lower extremity strength and physical performance.	No	No
Huang *et al.,* 2019	After total hip replacement the gait abnormality remains, due to this author examine the step length symmetry and other aspects that are related to it and examine the mechanical energy exchange in it.	Yes	No
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Armand *et al.,* 2007	Artificial intelligence technique is used to facilitate interpretation and decreases subjective interpretation. Limbs evaluated of ankle kinematic and toe-walking pattern.	Yes	No
Wong *et al.,* 2012	Method for extracting a robust set of depth feature and demonstrate using depth vision sensors combined with wearable sensor using 3-layer ANN.	Yes	Yes
Pereira *et al.,* 2015	Low-cost kinematic parameter measuring system for walker devices. Six force detecting resistors and one 3D accelerometer connected to a signal circuit.	No	Yes

G. Parkinsonian Gait

Individuals with this gait style display Bradykinesia and stiffness. Patients with Parkinson's disease frequently have a distinctive posture in which their head and neck are angled forward, and their legs are bent in a flexed stance. The upper extremities are also flexed, with fingers commonly extended. The patient's steps are noticeably sluggish and short, reflecting a gait known as "marche a petit pas," or "little step walk."

For some patients, taking the first step might be difficult. Furthermore, some people may unintentionally begin moving quickly, a condition called festination. This characteristic gait pattern is frequently seen in disease and other illnesses that produce parkinsonism, such as drug-related side effects. Table X summarizes the many gait analysis methodologies used to analyse Parkinsonian movement, including Kinematic, Kinetic, and computational intelligence methods.

TABLE VIII CHOREIFORM GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE (VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Singh-bains *et al.,* 2019	Examine the brain-tissue whether the purkinje cell degenerate the neocerebellum that present in the Huntington's disease using unbiased stereological counting method.	No	No
Despard *et al.,* 2015	Upper limb motor profile can characterize on various difficulty level with and without visual target in Huntington disease with nine HD symptomatic, nine premanifest HD and nine matched controls to fitts law.	Yes	No
Rao *et al.,* 2014	Examine whether there is timing variability in an explicit interval timing test and whether this is affected prior to clinical diagnosis of HD.	Yes	No
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Termsarasab *et al.,* 2018	Gait disorder in HD that are often mixed with PD and dystonia. In addition to chorea and PD causes sudden lapse of muscle tone in leg or trunk.	No	No
Mirek *et al.,* 2017	In HD gait pattern can be conducted or examine by the mean angular movement changes in kinematics parameters (lower limb joints and trunk) performed using passive markers with vicon camera and based on golem biomechanical model.	Yes	No
Farina *et al.,* 2019	In dementia wearing activity monitors examine the feasibility with assistive technology (QUEST) for asses compliance.	No	Yes
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Montanini *et al.,* 2017	Automatically Detection of fall through wearable and non-wearable technological solution. Through sensor the stigma is perceived that associated with primary function of fall detection. It also recognized the abnormal configuration, fall and foot orientation through smart shoe.	No	Yes
Gibson *et al.,* 2017	On accelerometer-based intelligent technique for fall detection system, consist wearable shimmer to generate data and detect using principle component analysis-based classifier and detect fall analysis.	No	Yes
Concepcion *et al.,* 2014	Monitoring of the user's physical activities (such as an accurate, comfortable and efficient system). This is done using an accelerometer sensor in a discrete format and tested in a non-controlled environmental.	No	Yes

TABLE IX ATAXIC GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE (VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Conte *et al.,* 2014	kinematic of the upper body in an ataxic patient. The range of motion of the head and trunk segments is measured using optoelectronic motion analysis. Reduce trunk and upper body oscillations using elastic orthosis and increase dynamic stability.	No	Yes
Mari *et al.,* 2014	Examine the co-activation pattern in the ankle and knee joints of an ataxia patient while walking. Neurological illnesses have an impact. walking cycle and sub-phases of walking can be used to quantify knee, ankle, and antagonist muscle.	No	Yes
Chini *et al.,* 2017	Examine the stability of trunk cerebellar ataxia patients with spatio-temporal parameters using inertial sensors that measure the trunk kinematics and spatio-temporal parameter during walking. Results, higher corresponds more serve disease, while lower value corresponds less serve diseases.	No	Yes
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Martino *et al.,* 2014	Cerecellaratacia effect on gait can be demonstrated by an idiosyncratic feature where spatiotemporal structure leg activity and biomechanics of CA gait impairment can be examined through this. Results, optimizing the foot load and muscle activity during locomotion	No	Yes
Chini *et al.,* 2017	Examine the stability of trunk in degenerative cerebellar ataxia patients with spatio-temporal parameters using inertial sensors that measure the trunk kinematics and spatio-temporal parameter during walking. Results, higher corresponds more serve disease, while lower value corresponds less serve diseases.	No	Yes
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Kim *et al.,* 2019	A novel variable is examined using multiple inertial sensors in tandem walking test which distinguish the abnormal and gait control patient more easily and precisely with vestibular hypofunction. Results degree of balance and gait irregularity.	No	Yes
Schniepp *et al.,* 2019	The neurological disorders assessment done through clinical and automated systems and mainly focuses on the cerebrallar, vestibular and functional gait disorders.	Yes	No
Kim *et al.,* 2018	To determine the knee injury using IMU based system and optical motion capture system to get the region of limb stability value.	No	Yes

TABLE X PARKINSONIAN GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE
(VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Agosti *et al.,* 2016	Global postural re-education is a type of physical treatment that involves lengthening the antigravity muscle chain across the knee, ankle, and thigh.	Yes	No
Sorrentino *et al.,* 2016	PD can be diagnosis based on the clinical recognition on the main factor's rigidity, bradykinesia and tremor test that effect the moments of gait and posture using 3D motion analysis.	Yes	No
Rucco *et al.,* 2017	To examine the spatio-temporal and joint excretion using motion analysis for the gait pattern of bvFTD (behavioral variant of frontotemporal dementia) and AD (Alzheimer disease) patients in single and dual task. It indicates the velocity and stability of the impairment.	Yes	No
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Manap *et al.,* 2011	Examine Parkinson diseases patient to identify and classify the abnormal gait pattern during normal walking, based on the kinetics and kinematics evaluation and tries to attain the accuracy using artificial neural network.	No	No
Manap *et al.,* 2013	Examine the gait pattern using principal component analysis as a feature selection between healthy adults and parkinsonian patients. Various classifier has been chosen such as SVM, ANN, NBC.	No	No
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Cho *et al.,* 2009	A vision-based diagnosis system has been used to identify gait pattern of Parkinson's diseases patient, it utilizes combined algorithm of PCA and LDA. The feasible system for identifying PD gait was tested using videos of PD and normal subjects.	Yes	No
Pasluosta *et al.,* 2015	PD patient data can be monitored real-time using wearable device connected to IoT using mobile or tablet, not only medical visit but also at home. Where the patient disorder information automatically saved in database for assessment. main aim is to lie this approach in efficient and maximized the resources and drastic improvement patient experience.	No	Yes
Zhu *et al.,* 2019	Smarter way to gather the data using hybrid mechanism in cotton sock to monitor various sensing related to kinematics and kinetics in daily life. Developed self-functional and self-powered sock using piezoelectric chip. Through this also examine the humidity, temperature, walking pattern recognition and weight variation.	No	Yes

TABLE XI SENSORY GAIT RELATED TO KINEMATIC, KINETICS AND COMPUTATIONAL INTELLIGENCE
(VB-VISION-BASED AND SB- SENSOR-BASED)

Kinematics			
Author	**Methodologies**	**VB**	**SB**
Hohne *et al.,* 2009	Examine how to reduce plantar-afferent feedback and can be reduced by intradermal infection of an anaesthetic solution without affecting proprioception	Yes	Yes
Slajpah *et al.,* 2014	Sensory fusion algorithm is been used for assessing the orientation and segment of human body for long-term human walking by wearing sensory systems. This can be measured via known kinematics consist angular velocity and linear acceleration between segments	No	Yes
Rao *et al.,* 2010	Examine affiliation between ankle dorsiflexion and range of motion. Subjects with diabetics mellites and to measure the DF ROM and stiffness using Iowa ankle ROM device.	No	Yes
Kinetics			
Author	**Methodologies**	**VB**	**SB**
Requejo *et al.,* 2005	Person walking with Forearm crutches, can be determined by the upper extremity of kinetics, with 3D biomechanical model.	Yes	No
Blaya *et al.,* 2004	Active ankle-foot orthoses can vary the impedance of the orthotic joint during the walking cycle to treat drop-foot gait. We observed that slap foot's lower resistance allows for greater plantar flexion and a smaller kinematic difference between swing and normal.	No	Yes
Sacco *et al.,* 2009	Plantar pressure distribution and ankle range of motion during neuropathic gait are investigated. Ankle range of motion and plantar pressure were measured using general linear model, results reduce in ankle mobility in plantar pressure distribution. Midfoot and forefoot receive higher loads on push-off due to small stance phase and ankle flexion.	No	Yes
Computational Intelligence			
Author	**Methodologies**	**VB**	**SB**
Howell *et al.,* 2013	Kinetic measurement of gait by low-cost force resistors with help of insole and it evaluates six control and four hemiplegic subjects. Linear regression model was used in this article to examine GRF and movements such as ankle dorsiflexion, knee flexion and knee abduction.	No	Yes
Fu *et al.,* 2008	Walking pattern synthesis for humanoid while climbing stair. It formulated as nonlinear optimization problem with a kinematic and stability constraints. This based on reinforcement-based learning, it experimented on 32-degree-of-freedom.	Yes	Yes
Shahrokhshahi *et al.,* 2019	Optimal walking pattern generation model for humanoid robot, for pelvis and feet a trajectory is design and for joints angles inverse kinematics. Two different types used maximum joint torque and energy consumption using genetic algorithm for optimization.	Yes	Yes

H. Sensory Gait

This gait defines proprioceptive information received at that location when a foot touches the ground. The loss of proprioceptive inputs leads to a sensory ataxic gait. To sense it, the patient will slam the foot on the ground and know their foot's land and location. In this gait, it involves exacerbation when a patient is not able to see their feet (in the dark). This gait also is known as stomping gait, where the patient lifts their leg very high and hits the ground hard to sense it. The disease affecting the peripheral nerve or dorsal columns is seen as a disorder. Gait analysis approaches of Kinematic, Kinetics and computational intelligence in Sensory gait are shown in Table XI.

IV. METHODOLOGIES

Walking principles have been described by famous people such as Leonardo da Vinci, Galileo, and Newton. Borelli, a student of Galileo, proposed the notion of the centre of gravity, which may be used to produce balanced walking. To appropriately define and categorize gait data, statistical and machine learning methodologies are applied. Statistical techniques are used to investigate the effects of several independent factors in the gait model, particularly gait kinematics [John *et al.,* 2006, Phinyomark *et al.,* 2014, Gaba *et al.,* 2014, Tao *et al.,* 2012]. Machine learning approaches are further classified as supervised, unsupervised, probabilistic, reinforcement, evolutionary, hybrid, and rule-based, all of which contribute to gait analysis implementation. There are numerous subcategories within these machine learning categories, such as supervised learning techniques (e.g., Neural Networks, Ensembles, etc.), fuzzy logic, clustering-based approaches (e.g., Self-Organizing Map, hierarchical, k-means, fuzzy c-means), and evolutionary and reinforcement learning techniques, which are specifically designed for gait analysis.

A. Sensor Based (SB)

Data for gait analysis can be together using sensors on the subject's body [Ngo *et al.,* 2012, Sutherland *et al.,* 2001]. Sensors such as inertial systems (EMG) are put on the subject's body to capture movement data. A force platform can be used to analyse the dynamics of the subject's movement. EMG can reveal information on gait phase detection and muscle electrical activity during walking. (MUAPs) can be captured using surface EMG electrodes or needle electrodes [Mannini *et al.,* 2010]. Accelerometers and gyroscopes are used in inertial systems to measure inertia and segment orientation.

These sensors are resistant to motion changes and have sampling speeds comparable to accelerometers. Some studies recommend using gyroscopes in conjunction with accelerometers to record the kinematics of the subject's movement [Zhang *et al.,* 2014, Frenkel *et al.,* 2005]. This combination allows for stride length, segment location, and step detection. Ground response force, pressure distribution, force detection, and step and gait phase detection may also be measured using equipment such as floor platforms [Moeslund *et al.,* 2001]. As shown in Table XII sensor-based gait analysis has been the subject of several research investigations.

TABLE XII GAIT ANALYSIS SENSOR-BASED

Author	Description
Qui *et al.,*2019	Patient monitoring and ambulatory is done by decision -making and multi-sensor fusion method using body sensor network. Improvement in diagnosis and assessment of the lower limb rehabilitations.
Kluge *et al.,* 2017	Extraction of spatio-temporal is done using camera-based motion capturing system to check test retest reliability of subjects.
Cha *et al.,* 2018	Piezoelectric flexible sensors in loose cloth to evaluate the gait recognition system and flexible sensors are used to detect the hip and knee (lower part of body joints).
Ngo *et al.,* 2014	Largest gait database on the inertial sensor-based that provides statistically reliable performance and gait-based authentication. Maximum database was constructed on accelerometer and gyroscope with reliable dependencies.
Qui *et al.,* 2018	Lightweight and low-cost wearable device to evaluate fluctuation of joint angles and symmetry of foot during walking through body sensor network, that help to rehabilitate assessment of patient with gait impairment.
Hsu *et al.,* 2018	A comprehensive analysis was done to identify the patients with neurological disorders using wearable sensors (placement of multiple sensors). Sensors are placed on different seven location (such as lower back (L5), both thighs, shank, and foot) to fetch value and classify on feature-based classification method with MLP algorithm on the basis of time domain and temporal features.
Avvenuti *et al.,* 2018	In foot contact time and temporal gait parameters has to be examined using single wearable accelerometer. Through single sensor, it examines the both trunk and pocket position sensor results gait parameters with mean absolute error.

B. Vision-Based (VB)

Gait analysis can be used by digital or analogue cameras. Vision-based techniques such as gait phase detection and segment location identification have been employed in several research [Whittle *et al.,* 2014, Aggaewal *et al.,* 1999, Poppe *et al.,* 2007, Moeslund *et al.,* 2006, Prakesh *et al.,* 2015, Wang *et al.,* 2010]. The marker-based method, often known as the direct method, includes measuring human kinematics using active or passive markers [Lu *et al.,* 2014, Kluge *et al.,* 2017]. Active markers provide light signals that an optoelectronic system converts into electrical impulses, enabling accurate tracking. This technique can provide real-time gait analysis. The sagittal and frontal planes are generally regarded as the best perspectives for evaluating gait problems. There are several 2D and 3D motion-based cameras on the market for marker-based gait analysis. The indirect-based gait analysis, on the other hand, does not employ markers and instead depends on video cameras to collect data. This method uses models and appearance to analyse the characteristics of participants [Cha *et al.,* 2018, Ngo *et al.,* 2014]. Several research surveys on sensor-based gait analysis, encompassing both vision-based and sensor-based approaches, are listed in Table XIII.

TABLE XIII VISION-BASED GAIT ANALYSIS

Author	Description
Martinez *et al.,*2018	On clinical test of mild PD patient comparison of properties related to free-walking at natural pace. Kinetics and kinematics parameters an inferential statist analyses have performed to compare group performance, where feature selection.
Teufl *et al.,*2019	An inertial measurement unit can assess validity and test-retest reliability. A kinematic approach used in real-time for inertial and terminal contact event.
Dang *et al.,*2019	To estimate stooped posture, wearable sensors (accelerometer) are mounted on neck and upper back to measure the clinical assessment.
Ortells *et al.,*2018	Single video camera to compute number of semantics and normalization of gait features with low-cost sensors. Features are aimed to quantify gait impairment from conventional spatio-temporal such as gait symmetry and falling risk.
Verlekar *et al.,*2019	Using a single 2D video camera to evaluate biomechanics of gait features and acquisition is based automatic classification and detection of gait impairment.
Roy *et al.,*2020	3D human gait analysis has been done through the cameras and optical markers attached on the subject for fetching values. A 3D model is initialized with every gait parameter.
Tang *et al.,*2019	Single 2Dvision camera is used to detect accurate toe-off event and consecutive silhouettes difference map can represent gait pattern.
Cai *et al.,*2019	Gait symmetry can be evaluated using single camera while the subject is in unconstraint walking direction. For monocular monitoring, sequence of human silhouette into multiple steps after human motion detecting.
Verlrkar *et al.,*2019	The silhouettes of walking can be computed using 2D video, after then biomedical gait indicators are estimated such as temporal features, toe-off instance and initial foot contact.

V. MACHINE LEARNING METHODS

Machine learning techniques are used to design algorithms from labelled data or data points of patterns. Gait data representation and classification are used by the statistical and machine learning approaches (Qiu *et al.,* 2018). The gait model uses statistical techniques for various effects of independent variables on dependent variables. The various machine learning techniques are used in gait analysis such as (Supervised Learning, Unsupervised Learning, Reinforcement Learning, Rule-based Learning, Evolutionary Learning, Probabilistic Learning, Hybrid Learning, etc.) shown in Table XIV. Supervised learning input is known but the intended consequence is uncertain. An input with desired output is performed by developing a mathematical model that allocates unknown data to a class as precisely as the model allows. The basic purpose of supervised learning is to minimise risk or error.

Data in gait analysis can be labelled by healthcare professionals. Examples of supervised learning include the (SVM), (k-NN), radial basis function (RBF), decision tree, and a group of (bagging, random forest, boosting) (Verma *et al.,* 2023). In unsupervised learning there are similar data points given where each point has a set of attributes and similarity measures. This learning is based on similarity measures, each data points gather into a cluster where clusters are predefined. Manhattan, cosine distance, Minkowski and many more are taken to as a similarity measure. The main objective of unsupervised learning is to minimize intra-cluster distance and maximized inter-cluster distance. Here are some examples of clustering techniques such as K-mean, self-organizing map, Fuzzy k-mean clustering. Reinforcement learning that occurs without the assistance of a teacher. It is inspired by human psychology, where behaviours are led by prior experiences, with the goal of maximizing rewards while continually assessing and refining the algorithm's performance. Its principal application is the optimization of humanoid step sizes via actor-critic encounters, as discussed in Verma *et al.'s* study in 2023.

Rule-Based Learning or Fuzzy logic methodology is reflected as a rule-based approach. Extraction of information from inherently indefinite data can be represented by Fuzzy Logic with insufficient knowledge, imprecision and vagueness. The development of an intelligent system can be done through fuzzy logic scenarios where judgement-making capability is given to a machine by a reasoning algorithm to simulate human reasoning. This procedure will help the various researcher in the field of artificial intelligence systems because data representation is not in binary form. Evolutionary Learning, as implemented by various algorithms such as particle swarm optimization (PSO), genetic algorithm (GA), and others, is crucial in optimization-based challenges (Khan *et al.,* 2023). Probabilistic Learning leads to rapid noise and uncertainty; a probabilistic model is used consisting of some mathematical probability. Probabilistic models (gaussian process regression and Bayesian, hidden Markov model (HMM)) are used in gait analysis for human physical activity of recognition, artificial gait and kinematics prediction model respectively. Hybrid Learning is a combination of two or more machine learning techniques to provide better feature recognition. The proposal for creating artificial gait is done by a combination of neural networks with a rule-based paradigm (Arya *et al.,* 2023) in table XIV.

TABLE XIV MACHINE LEARNING METHODS

Supervised Learning	
Author	**Description**
Hu *et al.,*2019	Author proposes CNN architecture for Freezing of gait for better characteristic and time-efficient assessment.
Zhang *et al.,*2019	Classification of sagittal gait pattern with spatic diplegic in cerebral palsy children
Yoshida *et al.,*2019	Using smartphone-based deep learning the author proposes an accurate approximation technique of walking speed in Pedestrian Dead reckoning. PDR requires an accelerometer and gyroscope to more correctly anticipate pedestrian speed and direction (stride or step estimation).
Unsupervised Learning	
Author	**Description**
He *et al.,*2019	Examine through smartphone that auditory cues can prompt subjects to reduce knee adduction moment and modify gait pattern.
Matic *et al.,*2019	Data of PD patient with more fluctuation. Unsupervised learning applied to check whether the sensor data can indicate alone with patient motor state. Using clustering the clusters matched against physician estimated relatively.
Guimaraes *et al.,*2019	Prediction of right knee angle of patient while walking in common video, cost-effective and complete affordable system in motion capturing. With multilayer perceptron model.
Reinforcement learning	
Author	**Description**
Gil *et al.,*2019	A multi-level system is proposed where in first level same RL method is used to configure robot joints to sit and stand stability, in second level sequence of pose that react in shortest time with furthest distance and avoiding fall down. Author focusses on the time that travel by robot for a certain distance.
Yuan *et al.,*2019	RL method of Trajectory-learning scheme combined with dynamic movement primitive to present lower limb exoskeleton that helps in assistive human walking. It bifurcated into two-level planning, inverted pendulum that consider locomotion parameter to utilized zero-moment points and second level, joint trajectory with DMPs.
Huang *et al.,*2019	It is applied that aim motion trajectory modeling online and through pilot and exoskeleton interaction, it can combine using impedance model and propose a reinforcement learning method to policy path integrals and improvement online. Results single degree-of-freedom platform.
Rule -Based Learning	
Author	**Description**
Gupta *et al.,*2019	Data driven feature along with autocorrelation and cross correlate the time series gait data for creating different set of features. Moreover, rule-based learning is applied using decision tree to classify neuro generative diseases from healthy controls.
Zhao *et al.,*2019	Gait detection with an adaptive method, which models a human gait with HMM and employs NN to feed the HMM classification and raw measurement. Gathering the enough gait data from six gait event for detailed analysis such as heel strike, foot flat and toe-off for training a gait model and rule-based model is applied for labeling the gait data.
Zhao *et al.,*2019	Offer an optimal sensor configuration, effect of type, number and location of inertial sensors. The hybrid adaptive method is used with the combination of HHM and NN. Multi-subjective Gait data on foot through inertial sensors that has been evaluated which results angular rate is more reliable information for gait recognition
Evolutionary Learning	
Author	**Description**
Kormushev *et al.,*2019	Passive compliance for the walking robot with efficient energy. Compromising two parts: optimization of vertical CoM trajectory and generate the dynamically-balanced gait using this trajectory. For optimization, uses reinforcement learning and walking part, variable-CoM-height ZMP based bipedal walking.
Stone *et al.,*2019	In split-belt treadmill walking, it examines the frontal plane mirror feedback effect on gait adaptation and retention.
Probabilistic Learning	
Author	**Description**
Kovac *et al.,*2019	Skchange in walking spee of skeleton model-based gait recognition, focuses to improve the algorithm robustness and performance of high walking speed.
Maratinez *et al.,*2019	Activity of siting and standing cam be examined by Bayesian formulation with sequence analysis method. This method deals with noise and uncertainty in sensors, while it performs autonomous iterative accumulation of decision-making and measurement of sensors.
Wang *et al.,*2019	On ensemble learning a cross-view gait recognition method is proposed which enhance the effectiveness and under various angles condition, reduction in the sensitivity of gait recognition. It results to resolve the multi view angles problem for gait recognition.
Hybrid Learning	
Author	**Description**
Tanaka *et al.,*2019	Examine the effect of robotic gait training on gait parameters and gait speed. Through measurement of spatiotemporal characteristic related to gait speed and improvement with hybrid assistive limb (HAL) in chronic patient.
Yao *et al.,*2019	Methods are bifurcated into two: model-free feature and model-based feature. Model-free are sensitive due to variance and cloths whereas model-based feature extracts the underlying models. Through multi-stage CNN network author proposes SGEI (skeleton gait energy image) with hybrid representation of gait energy image for instance.
Molazadeh *et al.,*2019	Designing of iterative learning switching controller for the measurement of joint torques through functional electric motor and electrical simulation with a hybrid walking exoskeleton.

VI. GAIT BASED APPLICATIONS

Gait analysis is discussed within the state of the art. Gait analysis applications can be bifurcated into four categories: Clinical-based analysis, Artificial gait, control application, and other applications.

A. Clinical Based Analysis Application

Healthcare workers use the notion of gait phase recognition to diagnose or detect abnormalities (Lai *et al.,* 2019, Wang *et al.,* 2019). There is a wide-ranging gait behaviour even a single individual, it is difficult to determine the normal gait parameter range and diagnosis of pathological gait (Molloy *et al.,* 2019). This technique is used to identify the unknown impairments which affect gait patterns. Pathological gait diagnosis is one of the most trustworthy implementations of gait analysis.

There are various pathologies (such as knee osteoarthritis, cerebral palsy, dementia stroke, tendon rupture, Parkinson's disease and patellofemoral pain syndrome, etc.) that can be cured by gait analysis (Wang *et al.,* 2019). Kinesiology can be used as usage for movement disorders and to analyze healthy subjects. The possible potential sports injuries can be aided by gait analysis and provide the best available treatment options.

B. Artificial Gait

In several countries, new research and development activities are derived to develop the life and consistency of rehabilitation. Nowadays researchers are estimating the consequences and causes of various deformities regarding the postural and waking gait conditions. Kinetics and kinematics can give useful information on human walking through gait analysis, to develop or manufacture humanoid robots. Other than clinical practises, new technology for instrumental gait analysis can help doctors analyze the patient's state, recuperation, and healing for musculoskeletal complex models and neurological illnesses.

In many hospitals, a treadmill-based rehabilitation system is utilized to check the 6-minute or 12-minute test by walking on a level surface. Robotic rehabilitation system (such as Gait Master 5, Haptic Walker (Schmidt *et al.,* 2019), and Stair Master), helps to set their walking speed and support automatically as per the harshness of the disease disorders. Gait has introduced and inspired the artificial locomotor controllers and artificial limbs (orthosis and prostheses) for amputees that are used in robotics and exoskeletons. Artificial limbs help to evaluate the alignments of lower limbs in orthosis and prosthesis (Tanaka *et al.,* 2019). The fuzzy neural network has been used to propose a robotic gait synthesis on kinematics but for joint angles, a hybrid genetic algorithm is explored that is based on the prediction of accelerator data.

C. Control Based Application

Gait parameters and computational approaches are used in the entertainment sector to regulate human-computer interaction and improve the user experience. In the animation business, gait analysis ideas are used to produce accurate position estimates, resulting in more lifelike animations. Several ways have been proposed in the entertainment sector to construct a 3D system for mixed reality, including the development of 3D human avatars, virtual reality apps, and video games [Tanaka *et al.,* 2019]. Gait analysis has applications in a variety of sectors, including collision biomechanics and ergonomic approaches.

D. Biometric Trait

Face recognition, fingerprint recognition, voice recognition, iris and palm recognition, and other technologies are used in biometric systems to identify and categorise persons [Tanaka *et al.,* 2019]. However, because to elements such as glass, eyelashes, corneal reflections, varied facial expressions, haircuts, eyelids, and unreadable fingerprints, these systems may have limits when scanning the iris. Recent advances in human contact have concentrated on non-invasive technologies that do not require the subject's consent.

Gait recognition, a biometric attribute based on walking style, may be used in criminal investigations to identify perpetrators, even when dealing with people attempting to stay anonymous. It allows for large-scale monitoring of people based on their gait patterns. Model-based techniques to gait recognition are the two primary categories [Tanaka *et al.,* 2019; Yao *et al.,* 2019; Wang *et al.,* 2019]. Furthermore, computer tools for analyzing crowd behaviour, individual behaviours, and activities have been proposed. Vision-based gait analysis, for example, can track unusual actions and warn authorities to suspected illegal movements.

VII. LIMITATIONS

Gait analysis, like any other technique, has advantages and limitations. Among the limitations are limited space for conducting experiments, the discomfort experienced by subjects wearing sensors, the potential impact on results from muscle relaxants that affect the CNS, the high cost of equipment, the complexity of measuring gait parameters, and the possibility of erroneous interpretations due to slow responses. Table XV contains more constraints.

TABLE XV LIMITATIONS OF GAIT ANALYSIS

Technologies	Limitation
Magnetic system	Distortion in signals. High complexity in data processing. Not High reliability analysis due to limited responses system. Uncomfortable due to marker applied to body. Not commonly used. Difficult to handle with modern technologies.
Electromyography (EMG)	Difficult to use Iemg. Other system responses should be combined in gait analysis. For flittering and amplification external circuit is required. Impedance variation in electrode -skin interface. Result affected due to muscle relaxants in nervous system.
Electroencephalography (EEG)	Evident to combined with mechanical systems. Required signal identification is difficult. Complex signal processing strategies should be applied. Poor SNR. For flittering and amplification in EEG external circuit is required.
Electro Goniometer (EGM)	Single plane angular movement. Lower limbs result quality is not good. Gait parameters are limited. External power is needed. Provide relative angular information.
Medical imaging technique	In model skeletal system, kinetics and kinematics data are required. Gait analysis system should be combined with other system. Expensive for creating good dataset. Error should be minimized in medical imaging technique.
Motion capture camera	Active line-of-site experiment need special setup. Faster Locomotion needs faster sampling rate. Low intensity of light cannot be adjusted due high shutter speed. Capture volume and size is limited to view angle and distance. Inaccuracy analysis of marker-less at interest point selector. Uncomfortable due to marker attached to the body.
Inertial systems	Difficult of exact length of rotational axis and segment. Data may interrupt the movement of skin. Battery duration is restricted. Attachment of sensor at different position shows variation in acceleration sensing. Gait parameters needed complex strategy for analyzing.
Optoelectronic system	Decrease in accuracy for quick movement due to of sampling rate (50Hz to 1kHz) Drawback with reflective and transparent surface. High-priced labs setup is required.
Force plates mechanism	Fixed with ground. Appropriate for labs only. Misplaced foot contact. Limb kinematics need to be combined for gait analysis.
Gait mat or pressure mat	Variation in resolution provide by determinant size of sensors. Decrease in system scan rate, increase in resolution. Limb kinematics need to be combined for gait analysis. Appropriate for labs only.
Force shoes	Data of limb kinematics need to be combined. Uncomfortable to wear. For non-distribution arrangement it is difficult placed in proper position. Wrong interpretation if there are slow responses. On stepping up-down on stairs, bumpy or rough surface leads to less effective.

VIII. AVAILABLE DATASETS

This part includes a complete gait dataset that is freely available to the public, to facilitate consistent assessment and performance comparison for gait analysis [Yao *et al.,* 2019]. The dataset is separated into parameters such as numerical data such as kinetics and kinematics and visual data such as imaging and video capture. Table XVI includes links to gait datasets for future study and performance evaluation.

TABLE XVI PUBLICLY AVAILABLE DATASETS FOR GAIT ANALYSIS

Dataset	Description
BMClab	Different types of dataset available in various forms such as walking, running and human balance and inertial sensors signals.
Biomechanics- Laboratory University of Essen	Dataset is based on barefoot pressures, barefoot walking and pressure running shoes.
International society of biomechanics	Movement data: Consist of 2D walking (kinetics and kinematics) and 3D motion capturing (videos).
	Pressure data: Consist of pressure foot distribution during walking and running.
	Musculoskeletal Models: Consist of 3D lower limb and pelvis model.
Gait Recognition	CMU graphics lab releases: Original and normalized data in the form of motion capturing with extension of ASF/AMC extension format.
Halmstad University	Analysis of movement while walking and running by using flat and slope treadmill as an accelerometer in real world environment.
Physio Net	Physiological Complexity and healthy aging: It consist two-arm randomized clinical trial.
	Gait in Aging and Disease: A collection of young and old volunteers with Parkinson’s disease.
	Gait in Parkinson’s disease: Collection of multi-channel foot pressure recording through force sensors.
	Long Term Movement Monitoring: It includes 3-day 3D accelerometer video recording of elders, to study of fall risk, gait and stability.
Clinical Gait Analysis Database	CGA Normative gait database: It consists of collective set of databases with 3D kinematics and kinetics mac system, regression, temporal-spatial parameters, Nomograms, EMG data, orthopedics.
	Body Building Model repository: It consists of various vicon body building modeling packages taken from vicon motion system
	Biomechanics related dataset, societies, videos, software, journals, search engine for gait analysis, companies related to it and various GAIT laboratories situated in countries are given.
Machine learning and data analytics	It is a collection of gait phases with daily activities, basic step activities, expenditure on energy, sensor-based validation, smart annotation of cyclic activities, etc.

IX. TOOLS FOR GAIT ANALYSIS

Various technologies are used to analyze human movement and capture bodily motion. Table XVII shows how these technologies use biomechanical modelling and simulation methodologies.

TABLE XVII VARIOUS GAIT ANALYSIS TOOLS

Tool	Description
Statistical Shape Modelling Research Toolkit (SSMRT)	This toolkit creates a 3D biological structure of a body part and through various shape of body helps to predict the analysis of it and create your own modelling.
Gait Analyzer system (Tekscan)	Gait analyzer software gather the actionable gait information and displayed in various ways such as pressure profiles, charts, etc. that consent to identify the abnormalities. Segmentation of foot can be analyzed using teckscan 3-Box approach and shows the region involve with foot such as (center of force movement and progression).
GRAIL (Motek)	GRAIL is a gait analysis and training solution. During the same session, it improves abnormal gait patterns and provides real-time feedback. It was utilised to provide better and faster rehabilitation outcomes, and it was also paired with treatments.

X. DISCUSSION

A top-level analysis of Gait must focus on the Gait abnormalities. In early tries at Gait, a clinical test was maintained for the future pattern testing. A literature surveys shows that the Gait analysis applications and development has diversified, in line with various author’s background, expertise and are of interest. Some authors associated with various methodologies rather than in one methodology, or application. In this paper, author has discussed gait in various discipline areas, including computer science engineering, medical rehabilitations, physiotherapist, orthopedics and other medical fields. A comprehensive review articles collected from various digital repositories associated with SCI/(E) indexing journals of repute.

Gait analysis can be done by Gait parameters which are bifurcated into two fundamental parameters used for the specific measurements and other basic parameters used for common measurement of human walking. There are eight types of gait abnormalities such as There is some major abnormality that are mainly found in children’s that is cerebral palsy. There are various aspects such as automated technologies, neurogenerative disorders/neurological surgery, rehabilitation medicine/ techniques, Physical therapies, orthopedics, sports monitoring and defenses recruitment, etc. that impact on the gait analysis.

Article defines the methodologies that has been used for the gait analysis such as Sensor-based and Vision-based approaches and Machine Learning techniques. Sensor-based approach are applied to gather the data using sensors, inertial systems, etc. from the subject body (such as EMG, force platform, inertial systems (GRF, foot pressure pattern distribution, accelerometer, gyroscope)). Vision-based or image processing approach are used to gather the data in the form of images/frames or videos using human 3D motion capturing cameras and can be accomplished by with two methods: marker-based (direct) and without marker-based (indirect). Equipment used to capture the gait analysis in vision-based are analog or digital cameras. Machine learning techniques and statistical technique are used to classify and represent the gait data. Machine learning technique such as such supervised, unsupervised, rule-based, reinforcement, etc. this helps to improve the performance, accuracy, optimizations in an efficient way. In statistical technique are LDA, PCA, etc. are used to form a linear relationship in gait data. Computational intelligence is a combination of kinematics and kinetics approaches, as well as other machine learning methodologies.

In every technology there are some pros and cons that effect the results such as limited space to set up experiments, subject uncomfortable wear of sensors, resulted effected due to some muscles relaxants due to CNS, etc. There is huge publicly available gait dataset for consistent evaluation and performance comparison for the gait analysis (Molazadsh *et al.,* 2019). The available datasets, in term of walking environment has a large diversity but still insufficient for reliable gait analysis. Data of gait is highly heterogenous, temporal de-pendent, highly dimensional and variable in nature. Gait pattern cannot be generalized for a person, be-cause till now there is insufficient data to mark a standard generalized gait pattern for a given age-groups and genders. Biometric dataset is very limited in com-parison with biometric individuals such as finger print and face recognition. There are limited datasets related to gender and age, and eight specific gait abnormalities. Currently, various datasets have been open for the re-searchers publicly related to genders and age, gait abnormalities, and many more to identify and classify the gait pattern, and various gait behavior activities. The dataset consists of various musculoskeletal values related kinetics and kinematics to identify various features in gait, body movements, pressure pattern distribution, clinical analysis, etc. A precise description of various gait analysis or musculoskeletal analyzer/simulator tools that has been used to gather the input and give the output with better performance and accuracy such as OpenSim, Anybody Tech and many more. Industrial application on gait analysis have increased in the recent decade.

XI. CONCLUSION

Concludes a study on human gait and the parameters for the study considered are gait types, methodologies, approaches, dataset availability, tools and applications. Various methodologies to measure gait analysis, including machine learning techniques (supervised, unsupervised, reinforcement learning, etc.), sensor-based methods, vision-based techniques, and computational intelligence are studied. It is identified that sensor-based and vision-based approaches are commonly used to measure human motion. The sensor-based approach for gait analysis faces several limitations, such as space constraints for experiment set-up, discomfort caused by subjects wearing sensors, high costs associated with equipment, complex strategies for measuring gait parameters, and the potential for wrong interpretation due to slow responses. In contrast, the vision-based approach overcomes these limitations by utilizing bio-chemical modelling and simulation tools. However, a hybrid approach called computational intelligence combines both sensor-based and vision-based approaches to enhance performance. Within this hybrid approach, machine learning techniques such as unsupervised and supervised, reinforcement learning play a significant role. This hybrid learning contributes to improving the efficiency of human gait analysis. On the basis of the study conducted, it can be concluded that there is a clear need to develop efficient procedures for real-time monitoring in vision-based gait analysis. Ultimately, this approach will offer new insights and significant advantages in measuring gait analysis and im-prove the fundamental applications of gait analysis.

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