ISSN 2278-3091
Volume 9, No.3, May - June 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcs224932020.pdf
https://doi.org/10.30534/ijatcse/2020/224932020

Experimental Approach in Gait Analysis and Classification Methods for Autism Spectrum Disorder: A Review

Nur Khalidah Zakaria[1], Nooritawati Md Tahir[1,2,*] and Rozita Jailani[1]
[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[2]Advanced Analytics Engineering Centre (AAEC), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[*]Corresponding Author: nooritawati@ieee.org

ABSTRACT

Recently, studies in autism have gained much attention. Hence, for this study, experimental methods for gait analysis in autism children done by previous researchers were reviewed prior to our proposed method. Although gait is not one of the diagnostic criteria for autism spectrum disorder (ASD), existences of motor deficits specifically abnormal gait patterns during walking could be investigated and explored further. Thus, the purpose of this study is to conduct a thorough review by previous researches related to walking gait for ASD children with specific scope defined. Here, the discussion focused on the sample sizes or subjects' database, gait analysis methods utilized, type of gait features extracted and the method used for assessment of the walking gait in ASD. At the end of this review, a new markerless based approach is proposed that will be more suitable to be used for detection of anomaly gait in children with autism specifically outside the laboratory environment. The proposed method will be based on the benchmark model of a 3D marker-based model and the proposed markerless model will be using a depth camera that will provide the three-dimensional (3D) skeleton image of the subject along with the motion sensor for data acquisition purpose.

Key words: Autism spectrum disorder, gait classifier, gait feature, gait technique, walking gait.

1. INTRODUCTION

1.1 Autism Spectrum Disorder

Standard diagnostic criteria for Autism spectrum disorder (ASD) is characterized by severe impairments in social communication and skills along with restricted and repetitive behaviors. There is no known cure for autism disorder; however, some of this group of children could recover through therapies. The aims are mainly to boost the children's ability by minimizing the symptoms in their skills development and learning via teaching new skills and improving their social skills as well. Tools such as Childhood Autism Rating Scale (CARS), Gilliam Autism Rating Scale (GARS) and to name a few as reported in [1, 2] were already used to diagnose ASD. In addition, common therapy that is currently being applied is the Applied Behavior Analysis (ABA), where rewards are given to the autistic child or subject if he or she displays the required behavior as a complimentary purpose and as encouragement for the child to continue doing the correct behavior [3].

Moreover, according to the Diagnostic and statistical manual of mental disorders (DSM-5), an existence of motor deficits which include abnormal gait, clumsiness, and irregular motor signs are categorized as some of the additional characteristics that support the diagnosis of ASD [4]. For instance, according to Teitelbaum et al., disturbance during walking in ASD children can be used to diagnose the presence of autism at an early age [5]. Note that an abnormal gait is defined as not being able to walk normally which result in deviation(s) as compared to normal walking gait. Previous studies have reported that autistic children have unstable movements during performing their daily activities such as walking [6] & [7] and may lead to pain, tiredness and joint strain and might affect the child's activity [6] & [8]. There were also findings that reported children diagnosed with autism demonstrated some form of different movement as compared to typical control group [9] and tend to be clumsy too [10]. Additionally, another study has found significant differences in kinematics and kinetics between autism and control group which increased in the range of motion [8]. For gait velocity, there was no statistical difference found [8], however, significant difference was found related to both stride velocity and normalized velocity for autism children as compared to the control group [6].

1.2 Gait Analysis

Gait analysis is a systematic study of human motion. It provides detailed objective in quantitative measurements about locomotion by measuring body motion, posture and muscles. In biometric field, gait that is based on complex spatio-temporal is considered unique for each individual [11]. Thus, study of gait is important as it relates people's walking stability, which can help to decrease the risk of falls as well as assisting medical practitioners in early detection, rehabilitation and recognize people's characteristic by their motion. In one study that compared healthy subjects from different age groups, a healthy gait is expected to be symmetric and regular with the standard deviation value close to zero [12]. Therefore, the deviations in motion can be used as the analysis in comparing pathological gait. Generally, walking gait refers to the pattern of walking or locomotion. Several methods have been proposed for gait monitoring systems, which include the applications for diagnosis, rehabilitation and treatment. These approaches have been widely used in gait monitoring approaches such as sensor-based, marker-based, markerless-based or any combination or fusion of these techniques. Another factor to consider is the gait parameters extracted and analyzed as well as the gait interpretation method or also known as classification or recognition stage.

1.3 Aim

Although the importance of variability in gait studies was recognized many years ago, studies that include measures related to ASD gait are still growing. Therefore, this study aims to conduct reviews and discusses in detail the experimental methods involved for gait analysis specifically for ASD children that will covers the scope of sample sizes, gait techniques, gait features and the methods used for assessment of walking gait in ASD children.

2. SELECTION CRITERIA

In this section, the experimental methods employed by previous researches related to gait analysis in children with ASD is reviewed and discussed. As for the review scope, inclusions and exclusions criteria were used from the following combination of words as tabulated in Table 1. Hence, this review will be based on scopes associated to walking gait, gait analysis method and ASD but will exclude non-functional activities. To be exact, in gait analysis terminology, this review will focus on gait features and gait parameters specifically on the analysis of spatiotemporal, kinematics, kinetics, pressure distribution and electromyography (EMG) analysis. Several gait analysis techniques have been developed by numerous gait studies. Based on reviews done in literatures related to this area, different methods were proposed for several gait monitoring systems. Most techniques worked well in research laboratory under control environment, however once outside laboratory scenario the developed systems were not fully suitable and underperformed including during usage in clinical practice.

3. RESULTS AND DISCUSSIONS

This section will discuss and elaborate each of the findings based on the reviews done. This includes the database used namely the sample sizes, the gait techniques that have been developed by previous researches, the type of gait features extracted as well as the assessment of walking gait in ASD based on the selection of the inclusions and exclusions criteria are as in Table 1. On the other hand, the reviews will be discussed in the flow below:

- Table 2 will detail the list of related work by previous researches in the field of gait, the detail on samples size and the participants' age range;
- Table 3 will discuss on the previous work that utilized either sensor-based while Table 4 will elaborate the marker-based and markerless-based technique used by other researches in their gait analysis studies;
- Table 5 will elaborate gait features extracted using combination of sensor-based and marker-based techniques, and
- Table 6 will summarize the overall reviews on gait techniques, gait features as well as gait classifiers versus the new proposed method.

Table 1: Inclusion and Exclusion Criteria Utilized for Topic Reviewed

Inclusions Criteria	**Exclusions Criteria**
• Walking gait; • Gait analysis; • Autism spectrum disorder (ASD).	• Toe walking; • Treadmill walking; • Measurement scales or indices; • No appropriate groups and variables; • Performed dual task during walking.

3.1 Sample Sizes

Table 2 detailed the sample size used by previous studies. It was found that one study [36] recruited ASD participants as early as the age of 3 years. In addition, findings by researches conducted by O. Manicolo et al. and C. Z. C. Hasan et al. have employed more than 30 ASD participants as compared to other researches with average of 10 to 12 participants. Another main observation was the gender size populations of the ASD participants with male higher than female [13-16]. In addition there are several studies that conducted researches based on age-matched, gender-matched or combination of both for these two ASD and control group [17-20]. Also, as reported by J. S. Dufek et al., their study has employed a pair of Monozygotic twins as subjects and both were clinically diagnosed with ASD [21]. On the other hand, all subjects in the listed studies comprised of two groups namely the ASD and control group except for studies conducted by J. Pauk et al. [25] that specifically employed ASD (HFA) and ASD (LFA) whilst A. Nayate et al. [13] employed both ASD and Asperger's Disorder. Note that most studies are clinically diagnosed, five studies used DSM for diagnosing purpose DSM [15], [17], [18], [34] & [35] three studies used CARS for diagnosing [8], [9] & [25] and one study diagnosed based on CD-10. Conversely, research done by A. Nayate et al. [13] used Wechsler Intelligence Scales for diagnosing purpose while work conducted by M. Nobile et al. [33] was diagnosed using combination of DSM, ADOS and Wechsler Intelligence Scales.

Table 2: Summary of Sample Sizes and Age in Related Study

Previous Research	Groups	Sample Size	Age (year) Mean (SD)
O. Manicolo et al. (2019) [22]	ASD Control	32 36	9.2 (3.8) 9.0 (3.8)
J. D. Eggleston et al. (2018) [20]	ASD Control	9 9	9.0 (2.3) 8.9 (2.1)
S. Morrison et al. (2018) [23]	ASD Control	20 20	21.2 (4.4) 24.3 (2.8)
J. S. Dufek et al. (2018) [21]	ASD	2	9
C. Z. C. Hasan et al. (2018) [24] [25]	ASD Control	30 30	8.63 (2.16) 9.52 (1.96)
J. Pauk et al. (2017) [26]	ASD–HFA ASD–LFA Control	18 10 30	7.9 (1.9) 7.3 (2.2) 8.3 (2.1)
J. D. Eggleston et al. (2017) [16]	ASD	10	5 to 12
C. Z. C. Hasan et al. (2017) [27]	ASD Control	15 25	9.67 (2.06) 9.50 (2.04)
C. Z. C. Hasan et al. (2017) [28]	ASD Control	24 24	8.95 (2.13) 9.67 (1.88)
J. S. Dufek et al. (2017) [17]	ASD Control	10 10	9.00 (2.1) 9.00 (2.2)
C. Z. C. Hasan et al. (2017) [29]	ASD Control	30 30	4 to 12
M. M. Nor et al. (2016) [30] [31]	ASD Control	8 10	8.75 11.30
S. Ilias et al. (2016) [32] [33]	ASD Control	12 32	9.85 9.46
B.-O. Lim et al. (2016) [19]	ASD Control	15 15	11.2 (2.8) 11.1 (2.9)
C.-S. Yang et al. (2014) [15]	ASD Control	15 15	11.2 (2.8) 11.1 (2.9)
M. J. Weiss et al. (2013) [9]	ASD Control	9 10	16 to 20
V. L. Chester et al. (2012) [13]	ASD Control	14 22	5 to 9
A. Nayate et al. (2012) [14]	ASD Asperger's Disorder Control	10 10 10	7 to 18
M. Calhoun et al. (2011) [8]	ASD Control	10 10	18 to 29
M. Nobile et al. (2011) [34]	ASD Control	16 16	6 to 14
N. J. Rinehart et al. (2006) [18]	ASD Control	11 11	5.10 (0.9) 5.9 (1.1)
S. Vernazza-Martin et al. (2005) [35]	ASD Control	9 6	4 to 6
M. B. Denckla et al. (1993) [36]	ASD Control	5 5	25 to 38
J. A. Vilensky et al. (1981) [37]	ASD Control	21 15	3.3 to 10 3.9 to 11.3

Meanwhile, diagnosing method in study conducted by C.S. Yang et al. [14] was not specified. As for database, most studies utilized normal walking speed during gait data acquisition with seven studies also included ground reaction force caused by the foot that hit the force plates during walking [12], [20], [24], [26], [27], [30] & [32].

3.2 Gait Technique

In this review, gait techniques are grouped into three main categories namely the sensor-based, marker-based, markerless-based or combination among these three categories. For the sensor-based techniques, the gait monitoring process are normally in the form of portable or/and wireless thus made it suitable to be used outside the laboratory environment. However, the output data of the sensor-based is limited. On the other hand, the marker-based techniques produced 3D data from markers trajectories. The marker-based technique is like an optoelectronic system that is based on synchronization between electronic devices and the systems. Normally, this type of system is costly. Moreover, marker positions must be placed correctly on the subjects clothing or body for accurate data acquisition. This technique offers a wide range of output gait data; however, the limitation in the system makes it suitable to be used mostly in the laboratory. Conversely, the markerless-based techniques normally were based on video analysis and offered low-cost system as compared to the marker-based system. However, the challenge with this technique is usually due to imperfect object segmentation that resulted in reducing the performance during gait analysis and lesser recognition accuracy too.

Next, some examples of these three techniques will be elaborated. One popular example of the sensor-based technique is pressure mat. Pressure mat is an electronic walkway with pressure sensors embedded in the horizontal grid. A sensor mat is normally used to extract information via monitoring of gait problems due to lack of stability, balance, and coordination. For instance, GAITRite is a pressure mat available in the market used by researches in their studies as reported in [9, 15, 18]. Other notable sensor based that is widely used is force plate [16]. Meanwhile, Jolanta et al. used shoe insoles with capacitive sensors to measure plantar pressure distribution for ASD children. In their experiment, subjects were required to walk approximately 50 m distance at their self-speed in gait laboratory scenario while wearing the shoe with specified insole inside their shoes [26]. Furthermore, another study used a sensor that captured the electrical activity generated due to instances of contraction in body muscle. This is done using a surface electromyography (SEMG) known as a non-invasive sensor by placing the electrodes on rectus femoris (RF) and biceps femoris (BF) muscles to capture the EMG signal of ASD children during walking [30]. On the hand, the marker-based techniques involved tracking the subject movement through optical sensors namely by identifying the marker positions that were attached to the subject's body [38]. Normally, there are two types of markers in the case of marker-based system. Firstly, an active marker is triggered and will lit since these markers are made from light-emitting diodes (LEDs). Hence, this signal is used to locate the markers position as each individual marker functioned at predefined frequencies. On the other hand, passive markers are spheres in shape and covered with reflective tape. These sphere markers are specially designed to directly reflect light along its line of occurrence [39]. VICON, SMART and ELITE are some examples of marker-based systems that are used in gait researches. Such studies as discussed in [17, 26, 40] employed marker-based technique to capture the gait data and further examining these data across the gait cycle. Further, as reported in [15], gait symmetry is analyzed in ASD children and data in discrete time points were used to describe potentially meaningful asymmetries throughout the gait cycle [16]. Often, marker-based technique is also used together with force plate nonetheless with different set-up. For example, eight optical cameras with two force plates [16, 17], two optical cameras with two force plates [26] and eight optical cameras with four force plates [13].

Conversely, the markerless-based technique used camera as motion sensor detector in capturing the gait features and parameters. This markerless-based technique is considered as economical as compared to the marker-based technique. However, as mentioned earlier, the systems often require extra precautions to maintain its accuracy as it will affect the imperfect object segmentation and reduce the performance of the gait itself [41]. As reported by previous study, adding a template matching procedure may enhance the system downside [42]. Conversely, J. A. Vilensky et al. utilized two cameras to record walking trial videos. While walking barefoot, hallux as joint marker were used that allowed movements of the metatarsophalangeal joint to be attained in determining the measurements of the ankle joint [37].

3.3 Gait Feature

This section will discuss the related gait features involved. For this review, the gait features or gait parameters are divided into three (3) main group specifically spatiotemporal, kinematic and kinetic parameters. Firstly, in spatiotemporal parameter, the gait features are usually based on the time and length parameter. Meanwhile, kinematic parameters are related to position of angles, body segments and joints during walking. Spatiotemporal and kinematic analysis contributed to kinetic analysis. Next, by adding force plate(s) into the 3D motion system, the centers of gravity, ground reaction forces(GRF) as well as other joint forces and moments can be computed as reported in [8, 17, 27]. In addition, some researchers have utilized the used of pressure distribution and EMG signal in their gait analysis studies [19, 26, 30]. Next, Table 3 tabulated each type of gait features extracted using sensor-based, marker-based and markerless-based techniques followed by Table 4 that detailed the combination of both sensor-based and marker-based techniques.

From Table 3, nine researches have used sensor-based gait techniques for gait parameters extraction from both ASD and control group. Results reported found that ASD participants showed reduction in cadence, velocity and stride length as compared to normal healthy children [9, 15, 18], nevertheless study done by A. Nayate et al. found that speed and stride length was higher for ASD participants [14]. Meanwhile, Lim et al. identified additional gait features related to pressure distribution in their gait analysis study [19]. Conversely, differ from other sensor-based techniques, SEMG was used for measuring muscles activation during walking as reported in [30, 31]. Furthermore, recent studies by O. Manicolo et al. has included gait variability in stride velocity, stride time and stride length using percentage coefficient of variation (CV) [22] and S. Morrison et al. has computed average (mean) and intra-individual variability (IIV) for all gait features as reported in [23].

Next, gait features extracted using marker-based approaches are tabulated in Table 4. Research by V. L. Chester discussed the spatiotemporal features extracted from left and right gait cycle that computed and further analyzed as six different symmetry indices namely symmetry ratio, symmetry index average, symmetry index left, symmetry index right, symmetry angle and gait symmetry [13]. On the other hand, M. Nobile et al. performed normalization of two spatiotemporal features with body height and further examined and analyzed the hip, knee and ankle angles during initial contact (IC), toe-off (TO) and the range of motion (ROM) with all these represented the gait kinematic feature [34]. Also, some other kinematic features approaches were performed by examining and analyzing the vertical translation, angular dispersion and sacrum trajectory as mentioned in [35]. Further, markerless-based approach developed by J. A. Vilensky et al. [36] elaborated the gait features extracted by analyzing the lateral films in microreader followed by manually chanting these data on paper in estimating and calculating the location of hip, knee and ankle joint centers followed by measuring process using protractor [37].

In addition, combinations of both sensor-based and marker-based gait techniques are further discussed as in Table 5. Here, fusion of both techniques was done that allowed better in-depth gait interpretations to be explored. This is done by adding the force plates to the marker-based techniques as third party system to measure the three-dimensional (3D) forces and moments that are part of kinetic features. As tabulated in Table 5, most studies explored all features including spatiotemporal, kinematics and kinetics in more depth. However, studies by C. Z. C. Hasan et al. focused solely on kinetics features analysis using fusion of sensor-based and marker-based as discussed in [24, 25, 27, 29]. Meanwhile study by J. D. Eggleston et al. examined the lower extremity during walking followed by joint stiffness ailment was calculated as the difference in the joint moment divided by the change in joint angular displacement at loading response, mid-stance, terminal stance and pre-swing [20].

Table 3: Summary of Gait Features Extracted using Sensor-Based Technique

Previous Research	**Gait Features Extracted**	
	Spatio-temporal	**Others**
[19]	- step and cycle time; - single and double support time; - swing, stance & ambulation time; - distance, cadence, velocity, normalized velocity, step length, stride length, step width, toe out angle, step length/extremity ratio.	Pressure distribution at lateral and medial footprint
[15]	Similar Spatio-temporal gait features as in [18] above.	Not Applicable (N/A)
[22]	- Velocity, stride time, stride length, base of support; - CV stride velocity, CV stride time, CV stride length.	N/A
[23]	- Step/stride length & time; - velocity, cadence	N/A
[18]	- Velocity, cadence, stride length, stride time; - double support and heel-to-heel base of support.	N/A
[9]	- Step & stride length; - support base, toe in/out angle, cadence; - velocity, cycle, step, stance and swing time; - heel on/off time, double support time.	N/A
[14]	- Speed, cadence, stride length, base of support and its coefficient of variability and Y-axis range	N/A
[30]	N/A	Amplitude of EMG signals at BF muscle and RF muscle during gait;
[31]	N/A	Amplitude of EMG signals at GAS muscle and Tibialis Anterior (TA) muscle during gait.

3.4 Gait Classifiers

In this section, several classification approaches involved in this review scope is discussed. As stated earlier, the purpose of gait classifiers was to distinguish between normal and pathological gait patterns. To be exact, the types of classifiers chosen were to fulfill one main purpose specifically that can classify both groups with the utmost accuracy or recognition rate. Note that in classifying the ASD and normal walking gait, some studies implemented statistical analysis [43, 44] and machine learning (ML) [27-29, 32] too.

Table 4: Summary of Gait Features Extracted using Marker-Based (3 references) and Markerless-Based (1 reference)

Previous Research / Technique	**Gait Features Extracted**	
	Spatio-temporal	**Kinematic**
Marker-Based [13]	- Cadence, stride length; - Swing, stance & double stance time.	N/A
[34]	- Stance & double support period; - velocity/body height; - stride time, cadence	- Hip flexion-extension (fle-ext) at IC and TO; - hip ROM, knee fle-ext at IC and TO; - knee ROM, ankle fle-ext at IC and TO; - ankle ROM, foot progression, pelvic obliquity, pelvic rotation, pelvic tilt; - shoulder obliquity, shoulder rotation & walk orientation.
[35]	- Stride duration, step length, velocity, cadence; - swing and stance period.	- vertical translation during locomotion of head, shoulder, hip and foot; - angular dispersion of the head, shoulder, pelvic at frontal and horizontal plane; - head and trunk at sagittal.
Markerless-Based [37]	Cycle duration, stride length, percentage stance phase.	Hip, knee and ankle angles at IC and TO.

Table 5: Summary of Gait Features Extracted based on Fusion of Both Sensor-Based and Marker-Based Technique

Previous Researches	**Gait Features**		
	Spatio-temporal	**Kinematic**	**Kinetic & Others (if any)**
[26]	- Velocity, stride and step length; - stance phase duration, cadence, double support duration.	- pelvic tilt, hip flexion, hip extension, sagittal hip ROM; - knee flexion and extension; - sagittal knee & ankle ROM; - ankle dorsiflexion, plantar flexion	- hip extension & flexion moment; - knee extension & flexion moment; - dorsiflexion & plantar-flexion moment; - ground reaction forces (GRFs); - Plantar pressure at toes, metatarsal heads, lateral arch, medial arch and heels.
[32] & [33]	Stride time, cadence, walking speed.	- Hip angle at heel strike (HS) and TO; - Hip flexion & extension; - knee angle at HS and TO; - knee flexion &extension; - ankle angle at HS and TO; - ankle plantarflexion & dorsiflexion.	- Vertical loading response & vertical mid stance force; - Vertical terminal stance force; - horizontal mid stance force; - horizontal terminal stance force.
[8]	- Cadence, walking speed, stride length, double stance, toe-off, cycle time	- Pelvic tilt, obliquity & rotation; - hip flexion & extension; - sagittal hip ROM, hip abduction; - knee flexion & extension; - sagittal knee & ankle ROM; - ankle dorsiflexion & plantarflexion; - foot rotation.	- Hip extension & flexion moment and hip power; - knee extension & flexion moment and knee power; - knee dorsiflexion & plantarflexion moment; - concentric & eccentric ankle power.
[36]	- Velocity, cadence; - step length & width; - step length & width symmetry; - stance time.	- Knee joint angle; - ankle joint angle.	- Knee joint moments; - ankle joint moments.
[20] & [21]	N/A	- Joint angular positions of the hip, knee and ankle.	- Vertical GRF; - anterior-posterior GRF; - Joint stiffness.
[16]	N/A	- Hip, knee and ankle joint positions at loading response; - mid & terminal stance; - pre swing, initial swing, mid swing and terminal swing.	- Vertical GRF; - anterior-posterior GRF.
[28]	N/A	- Pelvic tilt & pelvic obliquity; - hip flexion & extension; - knee flexion & abduction; - ankle dorsiflexion & plantarflexion.	- Knee abduction & rotation moment; - ankle plantar flexor moment; - ankle moments; - hip & knee power, - eccentric ankle power, GRF (Fy, Fz); - push-off rate, peak ratio.
[17]	N/A	- Hip, knee and ankle joint positions at stance sub-phases, swing sub-phases and complete gait cycle.	- Vertical GRF; - Anterior-posterior GRF.
[24, 25, 27, 29]	N/A	N/A	- Max supination & foot flat force; - Max pronation & max braking force; - Max zero force & max propulsion force; - first vertical peak force & vertical minimum force; - second vertical peak force & relative time occurrence; - loading rate, push-off rate, peak ration.

For instance, studies done by [15, 45] utilized statistical analysis method specifically t-test, while Pearson correlation was used as reported in [2], Ancova [46], stepwise method of discriminant analysis (SWDA) [25] as well as ML methods such as Linear Discriminant Analysis (LDA) [28], Neural Network (NN), Support Vector Machine (SVM) [25, 32] and k-nearest neighbor (kNN) [29]. Table 6 tabulated the summary of gait classifiers used by previous researches related to ASD gait. To date, the use of ML for automated system has grown enormously in the last decades.

As reported in [32], classification of ASD gait pattern using NN and SVM showed that SVM achieved higher accuracy. In addition, deep neural network (DNN) application has recently gained attention in computer vision and ML research community. Deep convolutional neural network (CNN) was used as gait parameter extraction as discussed in [47]. In this study, method to interpret data information provided by wearable sensors to context-related expert features based on deep CNN was used to enable integration-free and data-driven extraction [47]. Furthermore, FM Castro et al. developed CNN for gait recognition using each subject gait signatures [48]. Another study proposed an automated system for analyzing and classifying Parkinson gait using deep learning system too [49].

4. PROPOSED APPROACH

As shown in Table 6, gait techniques, gait features and gait classifiers employed by previous studies as well as the new method to be proposed are tabulated. Some previous findings have reported contradictory results, which might be associated with the difficulty of collecting data from autism participants. The inconsistency results may due to participants' behavior especially when the children were required to perform in an unfamiliar testing environment such as in the laboratory while wearing tight clothes that could lead to participants' maladjustment and anxiety [19]. To the extent of our knowledge and based on the reviews conducted, only one study by J. A. Vilensky [37] has used markerless-based approach for ASD gait analysis and classification. However, this team researchers have deliberated the features were manually acquired in estimating the locations of hip, knee along with ankle joint centers followed by measuring using protractor and this process was labor-intensive.

Therefore, our study proposed a potential new markerless-based gait approach by extracting the gait features from the video image sequences using image processing technique. The proposed markerless-based technique will conduct in parallel simultaneously two stage of gait data acquisition; one using a well-known 3D motion VICON system and the other will use a depth camera that will generate the 3D skeleton image of each subject upon detection of movements by the motion sensor. Suitable feature extraction technique will be identified and finally ML for classification. The new proposed markerless-based method will be benchmark with the marker-based performance. This new proposed markerless method will provide less experimental protocol. The new markerless-based gait technique will be used in distinguishing the gait pattern in children with autism and further to be used outside the laboratory environment that is considered as 'familiar environment' by the participants. In detail, as depicted in Figure 1 our proposed study comprised of three stages namely the initialization phase, main processing phase and finalization phase.

Table 6: Summary of Gait Techniques, Gait Features, Gait Classifiers versus our Proposed Method

Research/ Attributes	Gait Techniques			Gait Features				Gait Classifiers	
	Sensor-based	Marker-based	Markerless based	Spatio-temporal	Kinematic	Kinetic	Others	Statistical method	ML method
[22]	/			/				/	
[20]	/	/			/	/		/	
[23]	/			/				/	
[21]	/	/			/	/		/	
[24]	/	/				/		/	
[25]	/	/				/		/	/
[26]	/	/		/	/	/	/	/	
[16]	/	/			/	/		/	
[27]	/	/				/		/	
[28]	/	/			/	/		/	/
[17]	/	/			/	/		/	
[29]	/	/				/		/	/
[30]	/						/	/	
[32]	/	/		/	/	/		/	/
[33]	/	/		/	/	/			/
[31]	/						/	/	
[19]	/			/			/	/	
[15]	/			/				/	
[9]	/			/				/	
[13]		/		/				/	
[14]	/			/				/	
[8]	/	/		/	/	/		/	
[34]		/		/	/			/	
[18]	/			/				/	
[35]		/		/	/			/	
[36]	/	/		/	/	/		/	
[37]			/	/	/			/	
Proposed Method			/	/	/			/	/

Firstly, for initialization phase, the skeleton joints of participants will be extracted for both groups. Here, two types of test set-up in specifically marker-based and markerless based approach will be conducted. For markerless based approach, the joint skeleton features will be extracted.

Meanwhile, for marker-based approach, VICON motion system will be used. Next, 30 participants will be involved in both groups namely children with autism (ASD group) and typical healthy children (TD group) with an aged range between 5 to 12 years old. As mentioned earlier, gait data acquisition will be done simultaneously using VICON motion capture system as the marker-based method and depth camera and motion sensor as the markerless-based approach since both data are indeed vital in determining and developing the proposed markerless based approach.

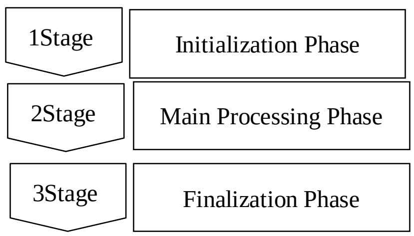

Figure 1: Proposed Method based on Markerless-Based Approach

A depth camera and motion sensor is chosen as part of our proposed markerless method since previous studies have reported the suitability of this device as a non-intrusive gait monitoring [50] & [51] with the built-in infrared camera adaptable to ambient light [52]. Without using markers, this depth sensor can track body movement using its depth, red, green, and blue (RGB) and infrared sensor to extracts a 3D virtual skeleton of the body [53]. From the depth image and with customable function, this device can provide in detail the value of the 20 body joints [54]. A recent study by Mohsen et al. also utilized the 3D depth sensors to capture skeleton data. The study managed to differentiate between two walking gait, which is normal and tip-toeing walking that could further be suggested to be used in screening the ASD children based on their walking gait pattern [55]. Hence, our proposed study will explore further the potential features of this depth camera and motion sensor in developing the proposed markerless model to detect the anomaly gait patterns for both ASD and TD groups based on the extracted gait features.

Next is the second stage specifically the processing phase. Upon completion of gait data acquisition, the extracted gait features will be preprocessed and normalized accordingly within one full gait cycle. Gait data extracted using depth camera and motion sensor comprised of skeleton joint points specifically each output values of the twenty joint coordinates in the x, y and z coordinates. Each of these joint values representing vector values and it can be used as inputs to compute the gait features via development of feature extraction algorithms. Further, this skeleton joints data will be used to calculate the kinematic gait data. The algorithms to be developed for computing the joint angles will be based on the definition of the dot product between two vectors. In addition, the center of mass (COM) will also be computed. COM is defined as the physical point to be used as an indicator that the volumetric mass distribution is balanced. While body segments are in motion, the COM of the whole body will continuously change over time [56]. From the 20 body joints, 19 body segments can be further defined. All 19 body segments will be used to calculate the whole-body COM namely, foot, legs, thighs, upper arms, forearms, hands, abdomen, thorax and head.

Lastly, in the finalization phase, classifier algorithms will be applied for recognition of anomalous gait pattern between these two groups. In this proposed method, the DNN model will be trained for detection of normal and anomaly walking gait pattern of both groups. The network architecture specifically the number of hidden layers, neurons in each layer, transfer function, learning rate and activation function for the proposed model will be attained based on the numerical analysis and simulation in determining the optimum accuracy. The grid search method will be performed in order to select the optimum accuracy and the final parameters based on its performance measure. Finally, the output of the proposed classifier will be either as 'Normal gait' or 'Anomaly gait'. Further, the results from this proposed markerless-based model will be validated with the results from the marker-based system. This is to confirm that features and algorithms developed for the proposed gait markerless model will perform within the acceptable satisfactory range of accuracy when compared with the benchmark marker-based model, which in this study using the VICON motion system.

5. CONCLUSION

As a conclusion, reviews and discussion regarding several gait techniques, gait parameters as well as classification methods from previous studies related to ASD are conducted. Based on the reviews done, three methods namely sensor-based, marker-based, markerless based or combination of these methods are discussed and highlighted with regard to analysis of walking gait in ASD. In addition, the walking gait data extracted include spatiotemporal, kinematics and kinetics. Spatiotemporal gait parameters include velocity, walking speed, cadence, stride length and time and stance length and time. In addition, kinematic features namely hip, knee and ankle joint angles extracted in one full gait cycle along with hip, knee and ankle joint moments were extracted as well. Kinetic features were utilized too namely vertical and horizontal GRF. Some studies also included pressure distribution of foot as gait features in their ASD walking gait researches. It was found based on the reviews that marker-based gait techniques and statistical analysis gait classifiers are the most chosen in capturing and analyzing data in ASD. Finally, we conclude that for anomaly gait detection in children with autism, we proposed to develop a new markerless based method that will lead to effective of its usage outside the laboratory environment.

ACKNOWLEDGEMENT

This research is funded by Research Management Centre (RMC), Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia Grant No: 600-IRMI/MyRA5/3/BESTARI (041/2017) and 600-IRMI-5/3/GIP (084/2018). The authors would like to thank UiTM for the facilities provided for this research namely the Human Motion and Gait Analysis Premier Laboratory.

REFERENCES

1. S. J. Spence, P. Sharifi, and M. Wiznitzer, "**Autism spectrum disorder: screening, diagnosis, and medical evaluation**," in *Seminars in Pediatric Neurology*, 2004, pp. 186-195. https://doi.org/10.1016/j.spen.2004.07.002
2. M. Shigeta, A. Sawatome, H. Ichikawa, and H. Takemura, "**Correlation between Autistic Traits and Gait Characteristics while Two Persons Walk Toward Each Other**," *Advanced Biomedical Engineering,* vol. 7, pp. 55-62, 2018.
3. J. L. Matson, N. C. Turygin, J. Beighley, R. Rieske, K. Tureck, and M. L. Matson, "**Applied behavior analysis in Autism Spectrum Disorders: Recent developments, strengths, and pitfalls**," *Research in Autism Spectrum Disorders,* vol. 6, pp. 144-150, 2012.
4. P. Association, ***Diagnostic and statistical manual of mental disorders (DSM-5®)***: American Psychiatric Pub, 2013.
5. P. Teitelbaum, O. Teitelbaum, J. Nye, J. Fryman, and R. G. Maurer, "**Movement analysis in infancy may be useful for early diagnosis of autism**," *Proceedings of the National Academy of Sciences,* vol. 95, pp. 13982-13987, 1998. https://doi.org/10.1073/pnas.95.23.13982
6. C.-S. Yang, G.-S. Lee, B.-K. Choi, D. O'Sullivan, Y.-H. Kwon, and B.-O. Lim, "**Gait Analysis in Children with Autism using Temporal-Spatial and Foot Pressure Variables**," in *ISBS-Conference Proceedings Archive*, 2012, pp. 307-310.
7. G. Esposito, P. Venuti, F. Apicella, and F. Muratori, "**Analysis of unsupported gait in toddlers with autism**," *Brain and Development,* vol. 33, pp. 367-373, 2011.
8. M. Calhoun, M. Longworth, and V. L. Chester, "**Gait patterns in children with autism**," *Clinical Biomechanics,* vol. 26, pp. 200-206, 2011.
9. M. J. Weiss, M. F. Moran, M. E. Parker, and J. T. Foley, "**Gait analysis of teenagers and young adults diagnosed with autism and severe verbal communication disorders**," *Frontiers in Integrative Neuroscience,* vol. 7, 2013. https://doi.org/10.3389/fnint.2013.00033
10. V. Jones and M. Prior, "**Motor imitation abilities and neurological signs in autistic children**," *Journal of Autism and Developmental Disorders,* vol. 15, pp. 37-46, 1985.
11. O. R. Devi, Dr.L.S.S.Reddy, and Dr.E.V.Prasad, "**Face Recognition Using Fused Spatial Patterns**," *International Journal of Advanced Trends in Computer Science and Engineering,* vol. 4(2), pp. 15-21, 2015.
12. R. Senden, B. Grimm, I. Heyligers, H. Savelberg, and K. Meijer, "**Acceleration-based gait test for healthy subjects: reliability and reference data**," *Gait & posture,* vol. 30, pp. 192-196, 2009.
13. V. L. Chester and M. Calhoun, "**Gait Symmetry in Children with Autism**," *Autism Research and Treatment,* vol. 2012, pp. 1-5, 2012.
14. Nayate, B. J. Tonge, J. L. Bradshaw, J. L. McGinley, R. Iansek, and N. J. Rinehart, "**Differentiation of high-functioning autism and Asperger's disorder based on neuromotor behaviour**," *Journal of Autism and Developmental Disorders,* vol. 42, pp. 707-717, 2012.
15. C.-S. Yang, G.-S. Lee, Y.-T. Lim, and B.-O. Lim, "**Comparative Gait Analysis Between Children with Autism and Age Matched Controls**," in *ISBS-Conference Proceedings Archive*, 2014.
16. J. D. Eggleston, J. R. Harry, R. A. Hickman, and J. S. Dufek, "**Analysis of gait symmetry during over-ground walking in children with autism spectrum disorder**," *Gait & posture,* vol. 55, pp. 162-166, 2017. https://doi.org/10.1016/j.gaitpost.2017.04.026
17. J. S. Dufek, J. D. Eggleston, J. R. Harry, and R. A. Hickman, "**A Comparative Evaluation of Gait between Children with Autism and Typically Developing Matched Controls**," *Medical Sciences,* vol. 5, p. 1, 2017.
18. N. J. Rinehart, B. J. Tonge, R. Iansek, J. McGinley, A. V. Brereton, P. G. Enticott, and J. L. Bradshaw, "**Gait function in newly diagnosed children with autism: cerebellar and basal ganglia related motor disorder**," *Developmental medicine and child neurology,* vol. 48, pp. 819-824, 2006.
19. B.-O. Lim, D. O'Sullivan, B.-G. Choi, and M.-Y. Kim, "**Comparative gait analysis between children with autism and age-matched controls: analysis with temporal-spatial and foot pressure variables**," *Journal of Physical Therapy Science,* vol. 28, pp. 286-292, 2016.
20. J. D. Eggleston, J. R. Harry, and J. S. Dufek, "**Lower extremity joint stiffness during walking distinguishes children with and without autism**," *Human Movement Science,* vol. 62, pp. 25-33, 2018.
21. J. S. Dufek, J. R. Harry, J. D. Eggleston, and R. A. Hickman, "**Walking Mechanics and Movement Pattern Variability in Monozygotic Twins with Autism Spectrum Disorder**," *Journal of Developmental and Physical Disabilities,* vol. 30, pp. 793-805, 2018. https://doi.org/10.1007/s10882-018-9620-2
22. O. Manicolo, M. Brotzmann, P. Hagmann-von Arx, A. Grob, and P. Weber, "**Gait in children with infantile/atypical autism: Age-dependent decrease in gait variability and associations with motor skills**," *European Journal of Paediatric Neurology,* vol. 23, pp. 117-125, 2019.
23. S. Morrison, C. N. Armitano, C. T. Raffaele, S. I. Deutsch, S. A. Neumann, H. Caracci, and M. R. Urbano,

"**Neuromotor and cognitive responses of adults with autism spectrum disorder compared to neurotypical adults**," *Experimental brain research,* vol. 236, pp. 2321-2332, 2018.

24. Hasan, R. Jailani, N. M. Tahir, and H. Desa, "**Vertical ground reaction force gait patterns during walking in children with autism spectrum disorders**," *Int. J. Eng. Trans. B Appl.,* vol. 31, pp. 705-711, 2018.
25. Z. C. Hasan, R. Jailani, and N. M. Tahir, "**ANN and SVM Classifiers in Identifying Autism Spectrum Disorder Gait Based on Three-Dimensional Ground Reaction Forces**," in *TENCON 2018-2018 IEEE Region 10 Conference*, 2018, pp. 2436-2440.
26. J. Pauk, N. Zawadzka, A. Wasilewska, and P. Godlewski, "**Gait Deviations in Children With Classic High-Functioning Autism and Low-Functioning Autism**," *Journal of Mechanics in Medicine and Biology,* vol. 17, p. 1750042, 2017. https://doi.org/10.1142/S0219519417500427
27. Z. C. Hasan, R. Jailani, N. M. Tahir, and S. Ilias, "**The analysis of three-dimensional ground reaction forces during gait in children with autism spectrum disorders**," *Research in Developmental Disabilities,* 2017.
28. C. Z. C. Hasan, R. Jailani, N. M. Tahir, I. M. Yassin, and Z. I. Rizman, "**Automated Classification of Autism Spectrum Disorders Gait Patterns Using Discriminant Analysis Based on Kinematic and Kinetic Gait Features**," *J. Appl. Environ. Biol. Sci,* vol. 7, pp. 150-156, 2017.
29. C. Z. C. Hasan, R. Jailani, N. M. Tahir, and R. Sahak, "**Autism Spectrum Disorders Gait Identification Using Ground Reaction Forces**," *TELKOMNIKA (Telecommunication Computing Electronics and Control),* vol. 15, 2017.
30. M. M. Nor, R. Jailani, N. Tahir, I. M. Yassin, Z. I. Rizman, and R. Hidayat, "**EMG signals analysis of BF and RF muscles in autism spectrum disorder (ASD) during walking**," *International Journal on Advanced Science, Engineering and Information Technology,* vol. 6, pp. 793-798, 2016.
31. M. M. Nor, R. Jailani, and N. Tahir, "**Analysis of EMG signals of TA and GAS muscles during walking of Autism Spectrum Disorder (ASD) children**," in *Computer Applications & Industrial Electronics (ISCAIE), 2016 IEEE Symposium on*, 2016, pp. 226-230.
32. S. Ilias, N. M. Tahir, R. Jailani, and C. Z. C. Hasan, "**Classification of autism children gait patterns using Neural Network and Support Vector Machine**," in *Computer Applications & Industrial Electronics (ISCAIE), 2016 IEEE Symposium on*, 2016, pp. 52-56.
33. S. Ilias, N. M. Tahir, and R. Jailani, "**Feature extraction of autism gait data using principal component analysis and linear discriminant analysis**," in *Industrial Electronics and Applications Conference (IEACon), 2016 IEEE,* 2016, pp. 275-279.
34. M. Nobile, P. Perego, L. Piccinini, E. Mani, A. Rossi, M. Bellina, and M. Molteni, "**Further evidence of complex motor dysfunction in drug naïve children with autism using automatic motion analysis of gait**," *Autism,* vol. 15, pp. 263-283, 2011.
35. S. Vernazza-Martin, N. Martin, A. Vernazza, A. Lepellec-Muller, M. Rufo, J. Massion, and C. Assaiante, "**Goal directed locomotion and balance control in autistic children**," *Journal of Autism and Developmental Disorders,* vol. 35, pp. 91-102, 2005.
36. M. B. Denckla and J. Rumsey, "**Locomotion of autistic adults**," *Archives of Neurology,* vol. 50, p. 13041308, 1993.
37. J. A. Vilensky, A. R. Damasio, and R. G. Maurer, "**Gait disturbances in patients with autistic behavior: a preliminary study**," *Archives of Neurology,* vol. 38, pp. 646-649, 1981.
38. M. Leo, G. Medioni, M. Trivedi, T. Kanade, and G. Farinella, "**Computer vision for assistive technologies**," *Computer Vision and Image Understanding,* vol. 154, pp. 1-15, 2017. https://doi.org/10.1016/j.cviu.2016.09.001
39. C. Prakash, K. Gupta, A. Mittal, R. Kumar, and V. Laxmi, "**Passive marker based optical system for gait kinematics for lower extremity**," *Procedia Computer Science,* vol. 45, pp. 176-185, 2015.
40. M. Barkocy, J. Dexter, and C. Petranovich, "**Kinematic Gait Changes Following Serial Casting and Bracing to Treat Toe Walking in a Child With Autism**," *Pediatric Physical Therapy,* vol. 29, pp. 270-274, 2017.
41. H. Ng, H.-L. Ton, W.-H. Tan, T. T.-V. Yap, P.-F. Chong, and J. Abdullah, "**Human identification based on extracted gait features**," *International Journal of New Computer Architectures and their Applications (IJNCAA),* vol. 1, pp. 358-370, 2011.
42. M. A. Ali, K. Sundaraj, R. B. Ahmad, N. U. Ahamed, and M. A. Islam, "**Vision-based motion tracking rehabilitation system for gait disorder**," in *Control System, Computing and Engineering (ICCSCE), 2012 IEEE International Conference on,* 2012, pp. 371-375.
43. J. K. Kern, D. A. Geier, J. B. Adams, M. R. Troutman, G. Davis, P. G. King, J. L. Young, and M. R. Geier, "**Autism severity and muscle strength: A correlation analysis**," *Research in Autism Spectrum Disorders,* vol. 5, pp. 1011-1015, 2011.
44. M. Shetreat-Klein, S. Shinnar, and I. Rapin, "**Abnormalities of joint mobility and gait in children with autism spectrum disorders**," *Brain and Development,* vol. 36, pp. 91-96, 2014.
45. H. N. de Souza, A. K. P. Lisboa, M. D. F. T. Maia, M. R. D. Dos Santos, E. M. da Silva Filho, L. G. Cezarino, R. de Oliveira Cacho, and Ê. W. A. Cacho, "**Effects of dual task training on gait temporal-spatial parameters of children with autism**," *Manual Theapy, Posturology & Rehabilitation Journal,* vol. 15, pp. 1-5, 2017.
46. N. J. Rinehart, B. J. Tonge, J. L. Bradshaw, R. Iansek, P. G. Enticott, and J. McGinley, "**Gait function in high-functioning autism and Asperger's disorder**," *European child & adolescent psychiatry,* vol. 15, pp. 256-264, 2006.
47. J. Hannink, T. Kautz, C. F. Pasluosta, K.-G. Gaßmann, J. Klucken, and B. M. Eskofier, "**Sensor-based gait parameter extraction with deep convolutional neural**

networks," *IEEE journal of biomedical and health informatics,* vol. 21, pp. 85-93, 2017.

48. M. Castro, M. J. Marín-Jiménez, N. Guil, and N. P. de la Blanca, "**Automatic learning of gait signatures for people identification**," in *International Work-Conference on Artificial Neural Networks,* 2017, pp. 257-270.
49. J. Ajay, C. Song, A. Wang, J. Langan, Z. Li, and W. Xu, "**A Pervasive and Sensor-Free Deep Learning System for Parkinsonian Gait Analysis**."
50. E. E. Stone and M. Skubic, "**Unobtrusive, continuous, in-home gait measurement using the Microsoft Kinect**," *IEEE Transactions on Biomedical Engineering,* vol. 60, pp. 2925-2932, 2013. https://doi.org/10.1109/TBME.2013.2266341
51. M. Gabel, R. Gilad-Bachrach, E. Renshaw, and A. Schuster, "**Full body gait analysis with Kinect**," in *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2012, pp. 1964-1967.
52. E. I. C. Jr., C. L. M. Flores, and G. S. N. III, " **Kinect-based Teleoperated Pseudo-Anthropomorphic Robotic Arm**," *International Journal of Advanced Trends in Computer Science and Engineering,* vol. 8, pp. 2240-2245, 2019. https://doi.org/10.30534/ijatcse/2019/59852019
53. W. Z. W. Z. Abiddin, R. Jailani, A. R. Omar, and I. M. Yassin, "**Development of MATLAB Kinect Skeletal Tracking System (MKSTS) for gait analysis**," in *Computer Applications & Industrial Electronics (ISCAIE), 2016 IEEE Symposium on*, 2016, pp. 216-220.
54. J. Sutopo, M. K. A. Ghani, M. A. Burhanuddin, and Zulhawati, "**Gesture Recognition of Dance using Chain Code and Hidden Markov Model**," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8(6), pp. 3194-3199, 2019. https://doi.org/10.30534/ijatcse/2019/85862019
55. M. Ebrahimi, M. Feghi, H. Moradi, M. Mirian, and H. Pouretemad, "**Distinguishing tip-toe walking from normal walking using skeleton data gathered by 3D sensors**," in *Robotics and Mechatronics (ICROM), 2015 3rd RSI International Conference on*, 2015, pp. 450-455.
56. D. A. Winter, ***Biomechanics and motor control of human movement***: John Wiley & Sons, 2009. https://doi.org/10.1002/9780470549148