Deep learning in Human Gait Recognition: An Overview

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Abstract: **One of the rudimentary forms of human locomotion is Gait that roves the center of mass (COM) of the body in different directions. The human gait is comprised of details of the personals that consist of movements related to patterns and intentions. The detection of human gait is through either wearable sensors or an electromyography signal that shows the most promising potential as a therapeutic method. While analyzing Gait, a large number of gait parameters are required which are interdependent, and this makes it difficult to interpret as a large number of parameters have a large amount of data. These data are mostly collected from various clinical laboratories. The current paper discusses human gait and the recognition of these events based on various deep learning models. Adding to this, issues and challenges that are related to Gait are also elaborated with prominent techniques used in gait recognition.**

Keywords: Gait analysis, Gait events detection, Deep learning (DL), Neural networks (NN), Computational intelligence (CI)

I. INTRODUCTION:

Today, Health is seen as a critical need to fulfill our life. Lack of regular health examinations can lead to various critical diseases. As can be seen in the U.S. where 90% of people including children and adults having a disease called cerebral palsy. An introduction of more advanced analytical methods such as computational intelligence (CI) would greatly support the traditional gait analysis. The CI is a combination of learning processes and computation uniquely tailored to make efficient decision-making systems that can interpret and processes a huge amount of data.

Gait refers to the way one person walks. Usually, gait data are converted to a gait cycle for some analysis. It requires knowing the exact timing of foot touch and foot off events. Some of the authors [1], [2] explain the foot strike and foot off gait events of child and detects these events through Recurrent neural networks (RNN), Deep neural networks (DNN), DL approaches. The researchers [3] describes the gait in one leg standing and sitting mode of an adult with having age between 29-40 years. Using the DL approach they extract the features from professional athletes. There are different robust available methods in the stance and swing phase for detecting the gait events. Therefore, several methods for identifying the gait events based on either kinematic or Spatio-temporal have been elaborated by various authors [4],[5],[6] respectively. Most of the authors[7],[8] detecting the gait data either through electromyography signals or wearable sensors.

The gait patterns of autism and normal children were classified through the NN model [9]. During the classification, the Spatio-temporal and kinematic data of children are collected from the UITM (Universiti teknologi MARA)

research ethics board. The stance and swing phase of human gait events [10]is classified through the DL approach in surface electromyography during walking conditions[11].

The gait data were collected through force and Electromyography based wearable sensors. Sometimes these sensors based data requires a small amount of noisy data and this creates a big problem in the feature extraction phase [12]. To overcome this problem, some of the authors proposed [13] images based gait event recognition of humans through convolutional neural networks (CNN). The authors [14]recognize the young and old age human gait events through neural networks based on kinematic and normal data. Most of the authors used the neural network approach to analyze[15], [16]the paralyzed human gait through daily activities on the ground flat during walking. These walking signals [17]were collected as on the inertial movement unit (IMU). The researchers [18]reviewed an the early and modern approaches of human gait recognition through biometric video[19]. Also the heel of person through is adjusted automatically [20]. The foremost unbiased goal of this current research is to review the status of CI event-related technology based on gait events. Section methodology reviews the research method and extracts some studies based on research questions. Results and discussions section provides the answers to research questions that are extracted from the selected studies. The conclusion of this paper is described in the last section.

II. METHODOLOGY:

In the field study, the bibliographic analysis includes two steps: a) collection of related work b) Detailed review of this work. In the first step, we will find the papers with the help of the search string. The search string is used to find the papers from Science Direct, IEEE Xplore, and google scholar. With the help of keywords and related work, the following search string has been created:

("Gait") AND ("Analysis" OR "Recognition") AND ("Deep Learning" OR "Neural network" OR "Neural Networks")

Using this search string, the papers that refer to only deep learning models and are based on GAIT have been referred. In the second step, we are considering the following research questions:

RQ1: What are the various types of gait events?
RQ2: What are the different types of DL models have been used for the gait recognition?
RQRQ3: What data sources have been used?
RQ4: Have the authors been checking the performance of their models?

RQ5: What are the most dominant journals for this paper that analyze the DL approach?

The main findings and description about these research questions are presented in the next section.

III. RESULTS AND DISCUSSIONS:

RQ1: What are the various types of gait events?

a)   Gait cycle outlining: The limb movements are denoted as human gait. Various types of gait patterns are analyzed by various selected studies. There are different categories of gait patterns that are characterized through some limb-movement, velocity, force, and changes in the contact with the ground level. Stride is denoted as a single gait cycle. The human gait is classified in different ways. Each gait event can be generally categorized into two ways either stride or swing as shown in figure 1.

b)   Stance phase: It is known as foot strike and it undergoes five movements of the foot. In this phase, the foot is contact with ground level and it is analyzed in gait cycle. It constitutes 60% of the gait period. Therefore, four-foot movements are analyzed in this phase. Figure 1 shows the overview of stance phase [21].

a)   *Initial contact.* In this, the foot born is in touch with the ground. The movement of hip and knee is observed in this phase so it also known as heel strike.

b)   *Loading response.* When the first foot is in touch with the ground, the weight is transferred into another leg. Therefore, it called as foot flat phase.

c)   *Midstance.* It describes the alignment of the foot which is directly touched with the ground.

d)   *Terminal stance.* In this, when the heel of one foot keeps on rising and the other foot hits the ground and at the last, limb passes the forefoot rocker. Therefore, the heel does not contact with ground so it is also known as heel off phase.
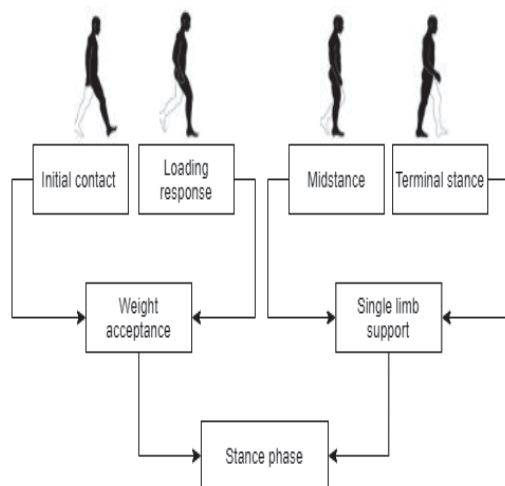

Figure 1: Overview of Stance phase

c)   Swing phase: In this phase, the foot does not contact the ground level and the swings are in the air so it is called as foot off phase. It constitutes 40% of the gait period. When this phase begins, the heel is changing from positive to negative. Figure 2 shows the brief overview of swing phase [22]. Foot off have four types which are described as:

- *Toe-off.* This means that when the foot is moving in the walking direction then this phase is known as toe-off. In this step, the reference toe is rising and moving in the air and it often known as pre-swing phase.

- *Initial-swing.* It starts when the foot is lifted from the floor and it ends when the foot that is lifted is just opposite to the standing foot. The total swing of the foot is nearly one-third to the standing foot.

- *Mid-swing.* This stage commences when one of the limbs that are swinging is just opposite to the standing limb and this stage ends when the limb that is swinging came to the front.

- *Terminal-swing.* During this phase, the limb is achieved with the extension of knees.
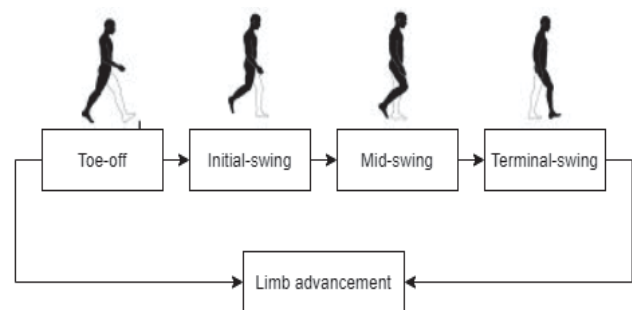

Figure 2: Overview of Swing phase

d)   Spatial gait parameters: For, identification of disorders, normal gait parameters ranges is pre-requisite. The special gait parameters are shown in figure 3. The parameters that are measured during normal gait activities are described as:

- *Step length.* The distance is measured in opposite feet between corresponding successive heel points.

- *Stride length.* In this, the distance is measured between two corresponding feet.

- *Step width.* It determines the distance between progress lines of left and right foot.

- *Cadience.* When the person is walking and the foot is touch with ground-level then no of steps are counts. These step counts are known as foot angle.
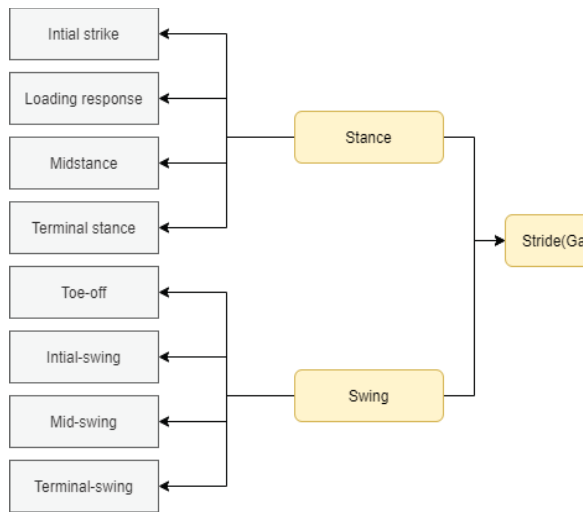
Figure 3: Gait cycle

RQ2: What are the different types of DL models have been used for the gait recognition?

After the selection of studies, we have analyzed the DL models used in the detection of human gait events. Mostly the deep learning models can extract the features and classify the gait events automatically. Based on selected studies, we will define the various types of DL models which have been used mostly and their usage is also mentioned in table 1.

a) *Artificial neural network (ANN).* ANN is pattern-based networks. ANN is also known as feed forward neural network. ANN is composed of three layers- input, secret and output layer. The input layer accepts the input, secret layer processes the input and result is generated through output layer. The ANN can solve the image related and tabular related problems. Basically, during input layer ANN changes the pixels arrangement of an image.

b) *Convolutional neural network (CNN).* The CNN can be used in both image and video recognition. A CNN uses a device much like a multilayer perceptron and built to meet the reduce criteria for processing. A CNN consists of input layer, an output layer and hidden layer that contain several convolution layers, pooling layers and completely linked layers. The main building blocks of CNN are kernels which can extract the related features from an input image automatically.

Table 1 Technique Usage for recognition of gait in literature

Technique	Usage Percentage (%)
ANN	52.58
CNN	26.31

The above table has mentioned that ANN technique has been used more frequently than the other identified techniques.

RQ3: What data sources have been used?

The gait data is recorded from human analysis through various phases which we are described in the above sections. From the selected studies, various types of data analysis recording in the form of gait data are described as:

a) *Spatio-temporal data*: Basic gait analysis analyses the Spatio-temporal activities such as walking speed, stride length, location and swing time.

b) *Kinematic data*: Kinematic measures include the movement of body parts and other important parts of body landmarks. These measurements yield angles of joint/part and values of different velocities along different axes.

The dataset is either publically or privately available. The publically dataset is available can easily accessible for all users but the private dataset is only used by some researchers. Some of the authors used the various types of data which is shown in table 2.

Table2 Selected studies dataset values

Selected Studies	Data Size	Form of data
S1	226	Child
S2	9092	Child
S3	27	Spatio-temporal
S4	20	Males and females
S5	245673	Adults
S6	87	Kinematic
S7	630	Spatio-temporal
S9	44	Child
S10	23	Adults
S11	24	Adults
S12	12	Kinematic
S14	24	Kinematic
S15	166	Spatio-temporal
S17	21	5(spatio-temporal), 12(kinematic)
S18	2313	Walking cycles
S19	25	CMU database

Some of the selected studies used their dataset values for experimentation. For example, S13 used the McGill and Osaka University datasets. But some of the selected studies S16 and S19 the review of given studies.

RQ4: Have the authors been checking the performance of their models?

Some of the selected studies evaluate the DL model along with their dataset values through performance metrics. These selected studies used the performance parameters such as accuracy, recall and precision used to evaluate the model. The definition of each parameter is defined as:

- *Accuracy:* Accuracy is most intuitive measure of performance and it is simply a ratio of properly expected observation to the total observations.

- *Precision:* Precision is the ratio of correctly expected positive observations to the actual total forecasted observations.

- *Recall:* Recall is the ratio of correctly expected positives to all real class observations.

- *Root means square error (RMSE).* RMSE is most common evaluation metric used in regression problems.

Most of the selected studies used the accuracy metrics used to evaluate the DL models and it is shown in figure 4.

From fig. 2, we can analyze that most of the selected studies used accuracy parameter used to evaluate their model.
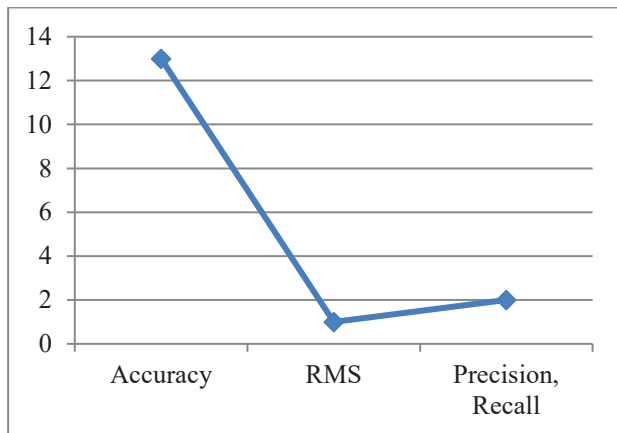

Figure 4 Model evaluations through Performance parameters

RQ5: What are the most dominant journals for this paper that analyze the DL approaches?

Table 3 has been used to mention the dominant journals of Gait recognition.

Table 3: Details of selected studies

Sr. No	Name of the Journal/ conference	Percentage (%)
1	Journal of Biomechanics	5.26
2	PloS One	5.26
3	Scientific Reports	5.26
4	Gait & Posture	10.52
5.	Biomedical signal processing and control	5.26
6.	International conference on image processing(IEEE)	5.26
7.	First Workshops on Image Processing Theory, Tools and Applications, IEEE	5.26
8.	Sensors	15.78
9.	IEEE Symposium on Computer Applications & Industrial Electronics	5.26
10.	Electronics	10.52
11.	Video processing	5.26
12.	Symposium on Neural Network Applications in Electrical Engineering, IEEE	5.26
13.	IEEE Transactions on Information Technology in Biomedicine	5.26
14.	Conference on Convergent Technologies for Asia-Pacific Region, IEEE	5.26
15.	International Conference on Automatic Face and Gesture Recognition, IEEE	5.26
16.	In International Conference on Audio- and Video-Based Biometric Person Authentication, Springer	5.26

a) *Publication Year:* Figure 5 presents the count of selected studies having their publication year respectively. From the below figure the most of the selected articles are published in 2018 and 2019 respectively.
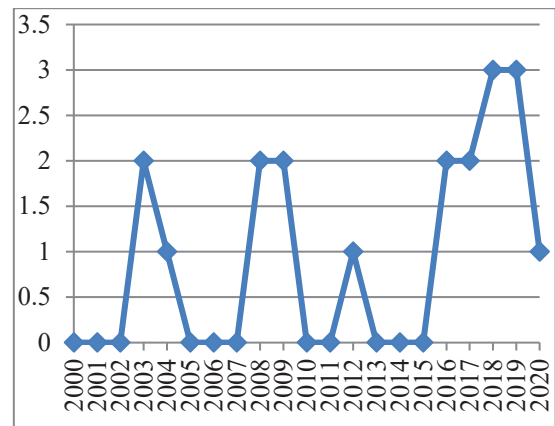

Figure 5: Year wise article published

b) *Scores:* Based on the research questions strategy we are easily filtering the studies from various research portals. Each selected study defines the gait events and their prediction/classification through various DL approaches. Even some of the studies used the gait event data either publically or private data for detection. Figure 6 mentions the scores of each selected study with respect to the research questions information gathered.
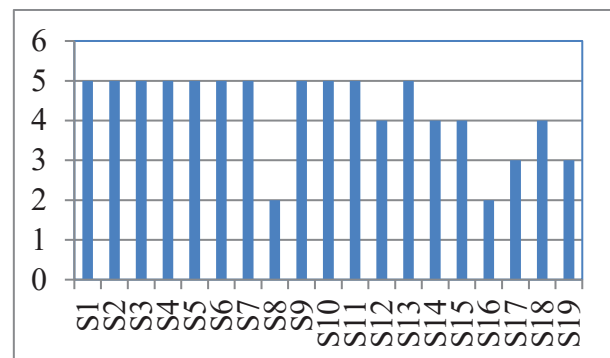

Figure 6: Scores of each selected studies

IV. CONCLUSION:

The current paper defines the systematic review of human gait event analysis humans through CI. After the introduction of humans, the search string and research questions can easily select some relevant studies. In the third part, several gait events were described and DL approaches are used for decision making for prediction were identified. Studies on gait analysis methods based on data sources which are categorized into Spatio-temporal and kinematics based data. After the data description, each selected studies have evaluated their model through some performance parameters. Once the development of a decision making based system through computational intelligence will be widely performed in daily environments. The convergence of these technologies

in the positioned becomes an omnipresent healthcare technology that promises enormous benefits for the continuous improvement of the global quality of human life.

V. REFERENCES:

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