European Journal of Molecular & Clinical Medicine
ISSN 2515-8260 Volume 7, Issue 10, 2020

GAIT BASED PREDICTION AND DIAGNOSIS OF ABNORMAL WALK PATTERN AND RENDERING EFFECTIVE TREATMENT FOR PATIENTS WITH MUSCULOSKELETAL PROBLEMS

Dr. S. Sophia[1], K. Sowmiya[2], P.Vinesha[3], Dr.P.Thamaraiselvi[4]& Dr.S.R.Boselin Prabhu[5]

Professor & Head[1], PG Scholar[2,3], Associate Professor[4,5]

[1,2,3,4]Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu.

[5]Surya Engineering College, Mettukadai, Tamilnadu.

[1]sophia@skcet.ac.in, [2]sowmiyakaruppuchamy@gmail.com,
[3]jvinesha@gmail.com,[4]thamaraiselvi@skcet.ac.in[5]eben4uever@gmail.com

Abstract- Gait prediction plays a vital role in determining normal and abnormal walk patterns. Walking pattern is not given much importance by many persons but it is our basic transportation process. A person who faces the inability to walk can bring severe transformation to his/her life. They must always depend upon other people for their day to day activities and also have serious health issues. In some cases, a person with an abnormal gait pattern can walk normally without experiencing any of the symptoms and it can be identified only when the person meets with an injury or pain and it can lead to health issues such as cardiovascular problems, mental illness problem and musculoskeletal problems.Thus, gait prediction must be carried out to identify the abnormal walk pattern, providing proper treatment and lead a healthy life. The sportsperson should also carry out gait prediction methods to help them run effectively. This prediction helps in the diagnosis of the cause for ache, estimation, and classificationof observed abnormalities leading to further treatment. A method to determine and classify the normal and abnormal gait state based on the Convolution neural network classifier algorithm is proposed. Further usingCNN and SVM the gait abnormalities can be classified as Freezing of gait, Brady Kinesia, Tremor, Ataxic gait, myopathic gait, and muscle atrophy. A comparison for accuracy was performed

betweenalgorithms from results obtained from two algorithms. Since the prediction is highly accurate, accurate diagnosis andright treatment by therapists is ensured.

Keywords: Walk pattern; Cardiovascular problem; Mental illness; Musculoskeletal problem; Freezing of gait; Brady Kinesia; Tremor; Ataxic gait; Myopathic gait; Muscle atrophy; Convolution neural network; Support vector machine.

1. Introduction

Gait analysis or gait prediction is basically a systematic study of human motion and is carried out by instrumentation. It is done to measure the activity of the muscles, body movements and body mechanics.

At present, gait analysis and prediction widely find their place in the medical field and in treating the patients effectively who find difficulty to walk. Usually, the gait analysis is apt for analyzing walking patterns of animals and humans. More apparently, gait analysis hit upon appliance in sports biomechanics where athletes and sportspersons with injuries related to movement and posture-related problems are treated at the best. Deep within the medical field, gait analysis is found in Chiropractic and osteopathic utilizations, comparative biomechanics, and biometrics.

The most important tool in gait analysis is quantification and interpretation. In the past, gait and its balance were considered to be a hectic task as it was complex in terms of affective aspects. The two major factors where: 1) the apparatus that the patients use was really heavy that would burden joint movement and 2) the processing of the data and interpreting them was found difficult. But as of now various techniques for gait analysis and prediction are in existence and some of them serve to be: 1) Temporal/spatial analysis, 2) Kinematics, 3) Marker less gait capture, 4) Pressure measurement, 5) Kinetics, and 6) Dynamic Electromyography.

In recent days, gait analysis has become a popular and vital one in analyzing the human locomotion. It is because the inability to walk determines to be the concern towards the diagnosis of the Parkinson’s disease or stroke. With the help of developed technologies and above listed methodologies, from the obtained and observed abnormalities in gait patterns, we can predict issues like subtle neuronal dysfunction, dementia and also diabetes before years than they could be diagnosed with present clinical arrangements. The general phases of gait cycle are shown in Figure 1.1.

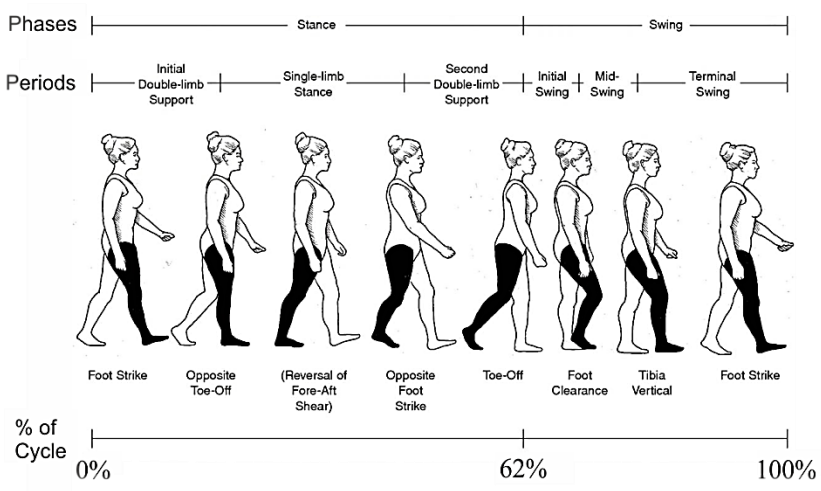

Fig.1.1 Phases of gait cycle

Gait analysis and prediction has gained enormous support from researchers, therapists and clinicians for its ability to prevent diagnose and rehabilitate the gait impairments.To be obvious, the Gait analysis isn't a new method but ultimately an older one with history over 100 years but has not been given any importance. But for the past 10 years, it is considered useful and very research is being carried out. One such topic is the classification of abnormalities from the data gathered from the gait pattern. This sort of classification is more vital in providing correct treatment to the patients. To facilitate this classification process, we make use of machine learning technique as it acts as black box and also provides insights over biological, chemical, and physical systems. Particularly, Convolution Neural Network (CNN) classifier and Support Vector Machine (SVM) Algorithm is set as a platform here. With no doubt, they both are best considerations in the aspect of machine learning strategies.

Using the above spectators, we have proposed a method by which based on the abnormalities observed in the gait pattern, they are classified among Brady Kinesia, Ataxic gait, freezing of gait, muscle atrophy and myopathic gait. The listed disorders are closely related to the slowness in the movement, irregularity in muscular action, lack of mobility. These abnormalities indicate weakness, tremor and rigidity that constitute a part in Parkinson's disease.

2. Literature Survey

The gait analysis methods can be carried out in various aspects. According to the survey, the existing methods are enhancing to the higher level and necessary steps are also taken. The gait

analysis methods now thrive as a crucial factor and an easy method of analysis. Everyone has proposed different ideas in their perspective and is being used. Gait analysis was carried out with the help of microphones [1]. A person fitted with a microphone is allowed to walk ordinarily for a particular distance for extracting the gait features. Acoustic waveforms are obtained from the footsteps. The microphone used in this method is cost effective. The obtained gait features are provided to the severalstudy methods. TKOE method was effective than other two estimates and showed slightest dissimilarities among different zones. Whenever the foot touches the ground, the acoustic waveform shows increase in amplitude.

In one of the methods, gait recognition is performed from incomplete gait cycle. This method [2] was introduced to tackle a problem of reduced gait cycle that occurs due to occlusion. From incomplete gait cycle information, gait recognition is achieved by creating an incomplete energy image and reconstruction of complete energy image from an incomplete energy image by using a deep auto-encoder.A real-time method of gait analysis based on ground reaction forces (GRF) [3] involves measurement using a pair of insoles. The inputs are measured only by the pair of insoles based on ground reaction forces, hence abnormal gait that bring causes to pattern and time period of foot events can be easily detected. The states of the gait were identified from the contact of foot to the ground. The attained duration and state sequence, are demonstrated into a semi-Markov process. To characterize individual gait patterns,gait structures that is attained fromsemi-Markov process is used. Both the normal and abnormal gaits are analyzed in this method.Gait recognition using Gait Gaussian image [4] is based on the spatio-temporal method. Features are extracted using Gait Gaussian image and are classified through nearest neighbor method. This method is a period-based technique and the characteristics of gait are obtained from one image, from everypixels GGI was calculated. The nearest neighbor method adopted in this method is highly effective. The classification for different categories was performed based on the shortest distance between the samples.Finally, the outputs are presented in terms of correct classification rate.

FOG episodes classification [5] was performed by using asensor that is placed on the leg. Pearson’s correlation is used and each stride was described by various features such as duration, velocity and certain mechanisms.Pearson’s Correlation was mainly used to describeno pathological and abnormal gait. It provides detailed classification of strides and warning for

severe freezing of gait episodes.Sum-of-harmonics and Radar [6] provides greater advantage in classifying gait as it is reliable and provides privacy preserving sensing. In this process both the parametric and non-parametric methods are used in classifying all forms of gait. The time and frequency behavior is extracted using harmonic sum and from obtained behavior classification of gait was performed.

In another method, a sensor that is worn by the human [7] is used to analyze the gait in a limitlessly and unnoticeable environment that is carried out during normal activities of the human. The main process that is to be noted is dispensation and examination of the data. Also, it boons a process that is based on the symbol which was mainly used in detection of different periods of gait. It finds as a useful, and easy in understanding and progression. A method of diagnosing the gait abnormality based on the symptom [8] involves non-invasive devices and deep learning analysis. This method provides greater advantage by eliminating the need for health care professionals to diagnose gait accurately.

Gait analysis can also be studied by using reliable foot switch [9]. The foot switch used here collects various gait signals from a person over a long period. The recorded foot signal is applied with anti-causal anti bounce filter in order to eliminate the spikes produced due to bounces created by the foot switch. The signals recorded from the foot switch are different for each of the case such as normal person, person affected with Parkinson's disease and so on. The collected gait signal is then segmented into separate signals and proceeded for classifying normal and abnormal gait.Web cameras can be used to obtain gait data from a person, by placing two web cameras on the sides of treadmill. At different velocity, the gait angles are recorded. The features such as weight, height, speed and age of the person are used as the mechanisms for classifying normal and abnormal gait.

A software [10] is also created in this method by using artificial neural network and the recorded data is applied to this software and classification of normal and abnormal gait is carried out.

3. Existing System

There are various methodologies available for Gait pattern analysis such as database, and audio analysis. One such audio analysis-based strategy is Acoustic GA that uses acoustic sounds. In this method, from the sound of the footsteps during the walking motion of a person, human gait

characteristics of a human are derived. The sound of the footsteps is first collected by the microphones and the temporal signal analysis is done. Some of the gait parameters are then extracted by the aid of acoustic gait profile. In this Acoustic GA, three profiles such as:

- Squared energy estimate,
- Teager-Kaiser energy operator and
- Hilbert transform

are used and those estimated parameters are found to be consistent and reliable for any of the clinical assessments. The framework and related parameters are discussed in detail in below sections.

Acoustic GA method of gait analysis involves the processing of AGP. Acoustic Gait Profile (AGP) is a waveform representation that can be obtained as a result of successive footstep sound busts. It can be either linear or nonlinear and from the waveform, details like timings, shape, energy and duration can be gathered. AGP approach is quite similar to that of tools like electrocardiogram that are used as diagnostic plot by clinician to mine information.

The guideline that suits to be framework of AGA can be compressed and outlined in three phases as follows:

1. *Evenness of succeeding footstep:* It is found that the gait pattern obtained from a normal walking object consists of certain consistency, and fluctuations that take place naturally. To analyze this type of walking patterns, an effective analysis method is mandatory.
2. *Occurrence of manifold pulse in a pace burst:* When sound burst is subjected to footstep, it results in one or more subbursts and it is due to the fact that different parts of a foot come into get in touch with the walking facade. When those subbursts are analyzed, the results are called as pulses.
3. *Irregularity between left and right foot:* It can be found that the acoustic characteristics results obtained for left and right foot are different due to the various reasons like floor plane, footwear and pathological circumstances.

In AG framework, the first step is that the footstep sounds over an epoch of few minutes is gathered. It is then analyzed and certain parameters are generated. They are known as AG

parameters and are given in Figure 3.1. The below mentioned parameters are spatio-temporal gait parameters that are widely used in clinical settings.

Parameter	Definition
C	The number of pulses in one footstep sound.
D_1	$(n_i^{E_2} - n_i^{E_1})/F_s$, needs $C \geq 2$.
D_2	$(n_i^{E_3} - n_i^{E_2})/F_s$, needs $C \geq 3$.
T_1	$(n_i^{t_1} - n_i^{E_1})/F_s$.
T_2	$(n_i^{t_2} - n_i^{E_2})/F_s$.
E_L and E_R	E_1^i and E_1^{i+1}, respectively, when i is the index of a left footstep.
S_1	$(n_{i+1}^{E_1} - n_i^{E_1})/F_s$.
S_{2L} and S_{2R}	$(n_{i+2}^{E_1} - n_i^{E_1})/F_s$, i is the index of a left footstep for S_{2L}.

Fig. 3.1. AG parameters

An important note about all the parameters is that they are time or distant relate parameters but rather are time-varying sound pressure measurements. More importantly, the value of E_L/E_R and C can be necessary to find out any pathological issues.

If the value of E_L/E_R is other than 1, then it indicates asymmetry gait level. Similarly, in case of elderly people with forward lean with disease like osteoporosis and kyphosis, or in cases with the forward lean condition, the cardinality level would be C> 1 indicating that the subject might have pathological issues.

The main advantage of AGP is that it provides magnitude of locomotion and the information regarding each stage of the gait cycle. In AGP method, all these parameters or information can be collected easily by means of off-the-shelf microphone sensors that are fitted on pressure mats or force plats. It is easier and cheaper and hence can be found out in many gait laboratories.

For AGP measurements, we follow certain formulas to deal with. The magnitude of first pulse, E_1^i is given by formula (1). The term magnitude here represents the energy of the footstep.

$$E_1^i = \max_{n\epsilon}\left[n_i,\ n_i + \partial_1\right]\left\{AGP_{\{.\}}\left[n\right]\right\} \qquad (1)$$

Where,

i= time duration

N is total (foot steps)

Δ is maximum duration

$n_i$is calculated from the annotations.

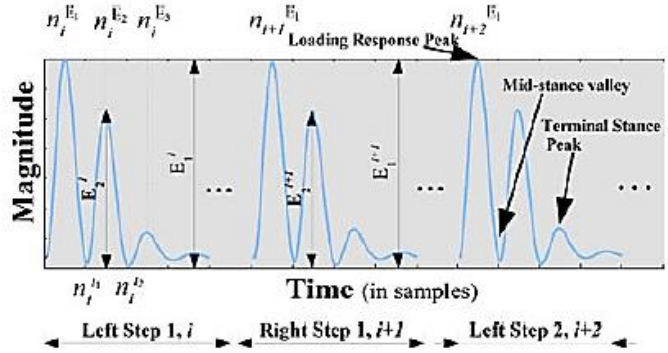

Fig. 3.2. Plot demonstrating measurements taken from AGP

The above Figure 3.2 depicts the overall representation when the data extracted from AGP are plotted in terms of time and magnitude. The plot is obtained when the values are applied to SEE and TKEO (both are nonlinear differential transformation methods that calculate energy from the amplitude and frequency of the sound signals).

When this kind of multiple realizations is carried out, it paves way naturally towards statistical description. Based on the results, statistical analysis is carried out in three ways:

- ✓ It verifies the internal constancy of the obtained parameters: Verification is done on the basis of intrasession and intersession consistency.
- ✓ Helps in easy understanding of the variations in parameters especially in the healthy subject
- ✓ Provides a comparative result obtained from three signal strategies and helps in obtaining a relative power of parameters from other methodologies.

With the help of statistics results and comparative analysis, it can be found that the AG method is consistent and is highly reliable. We have examined and tested the AG method by picking some of the characteristics of gait database of a person. TKEO profile is used for the execution and proved better as it provides better consistency and less error.

The two main factors that make the AG strategy the more complicated one is that the footwear and objects. When there is a variation in the footwear such as presence and absence of a heel and

addition of any material to the footwear, the gait characteristics may vary. In addition, if a person carries or hold a heavy object, it may result in the variation of the gait pattern. Thus, normalization of footwear is vital for the succession of the Acoustic GA method because one cannot find out the region or the origin where the footwear shows variation.

The recording setup is simplified in such a way that the pathway system is in a straight line, so that the person can walk easily and such that all areas are equally covered and so that sound is recorded and localized precisely. This method of gait isn't compared to the any of the gait assessments.

4. Proposed System

Our proposed method classifies normal and abnormal gaits using gait data classification based on convolutional neural network. The convolutional neural network has three layers such as convolution, pooling and fully connected layersthat are used for different purposes. The data is given as the input and a gait signal is extracted from it.

From the gait signal the features such as velocity, angular speed is obtained for classifying normal and abnormal gait.

The abnormal walk pattern includes many movement disorders such as Freezing of gait, Brady Kinesia, Tremor, Ataxic gait, myopathic gait, muscle atrophy, Huntington's disease, Wilson's disease, Rett syndrome, and Tourette syndrome. Freezing of gait produces inability in forward progression and can even lead to damage.

Brady kinesia is a condition in which there occurs a deliberate movement and it is also symptom for many health issues. In tremor there occurs a shake in body parts and often affects the hand. Ataxic gait leads to absence of balance in the walking condition and sometimes it is due to the gene related problem.

When muscle weakens, it leads to myopathic gait and when muscles gets wasted it leads to muscle atrophy. Brain cells gets dead when Huntington's disease occurs and when the disease gets worsen it leads to shaking of various parts. Wilson's disease, Rett syndrome and Tourette syndrome are brain and neuro related movement disorders. Thus, all of the movement disorders vary slightly from one another and requires different treatments. For this purpose, the movement disorders should be classified, and proper treatment should be carried out.

Classifying normal and abnormal gait is alone not effective to provide a proper treatment, different movement disorders of gait should be classified. For classification of abnormal gait, two algorithms are used and compared with each other in terms of accuracy. The two algorithms used are CNN and SVM.

The accuracy is identified with the help of confusion matrix. It consists of tp, tn, fpand fnvalues.By the figure given below Fig. 4.1, we can easily understand the concept of confusion matrix,

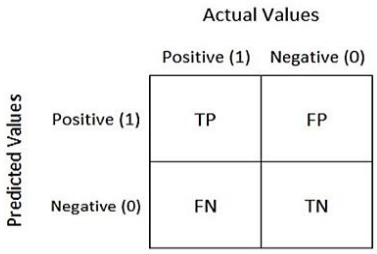

Fig. 4.1 Confusion Matrix

SVM and CNN acts as a simple and efficient classifier. Comparing with the convolution neural network algorithmand support vector machine algorithm, support vector machine algorithm provides higher accuracy and precision, thus providing accurate classification. By classifying the abnormal walk pattern, we can provide appropriate treatment and thus resulting in improvement of the quality of life.The proposed method is also used for classifying various movement disorders such as Freezing of gait, Brady Kinesia, Tremor, Ataxic gait, myopathic gait and muscle atrophy. Not Pathological gait is nothing but a normal walk pattern and is also identified in this work.Classification of remaining different movement disorders such as Huntington's disease, Wilson's disease, Rett syndrome, and Tourette syndrome will be carried out in the future work. Also, efficiency will also be improved in the future development.

5. Results and Discussion

Gait analysis involves the identification of normal, abnormal walk patterns and classification of abnormal movement disorders. Gait signal extraction is the first process involved in it. Only when the gait signal is obtained, the gait features can be obtained by using various formulae.By providing the dataset, gait signal for different positions of the leg are obtained and it is shown in Fig. 5.1

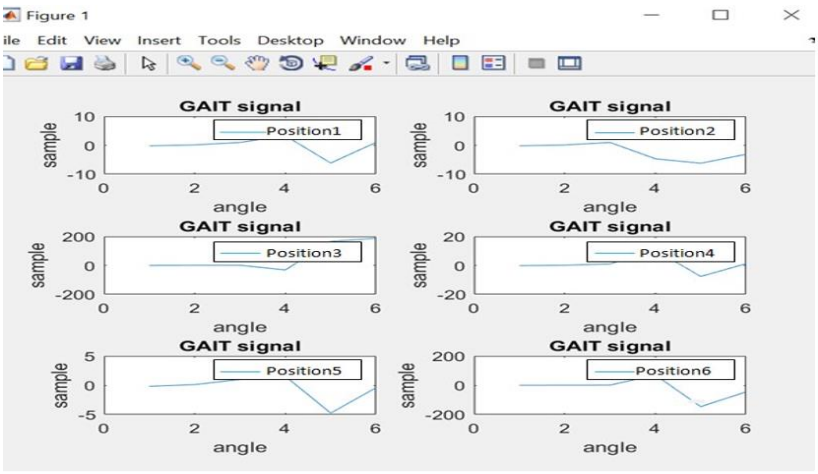

Fig.5.1 GAIT signal

The gait signal is obtained in terms of angle, hence to obtain velocity signal, the angles in degree is converted into radians and is obtained as one degree equals to 0.01745329252 radians ($1^{\cdot} = \prod/180$). Angle α in radians equals to angle in degrees times pi constant divided by 180 degree (α(radians) = α(degree). ∏ / 180. The velocity signal obtained is shown in Fig. 5.2

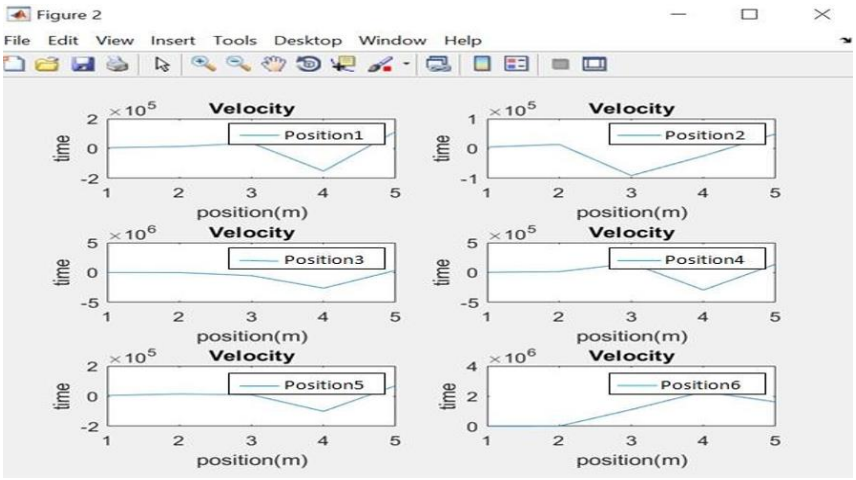

Fig. 5.2 Velocity signal

From the velocity signal it is possible to obtain the angular speed by using the formulae, angular speed (rotations per sec) = velocity / 360 and the obtained angular speed signal is shown in Fig. 5.3

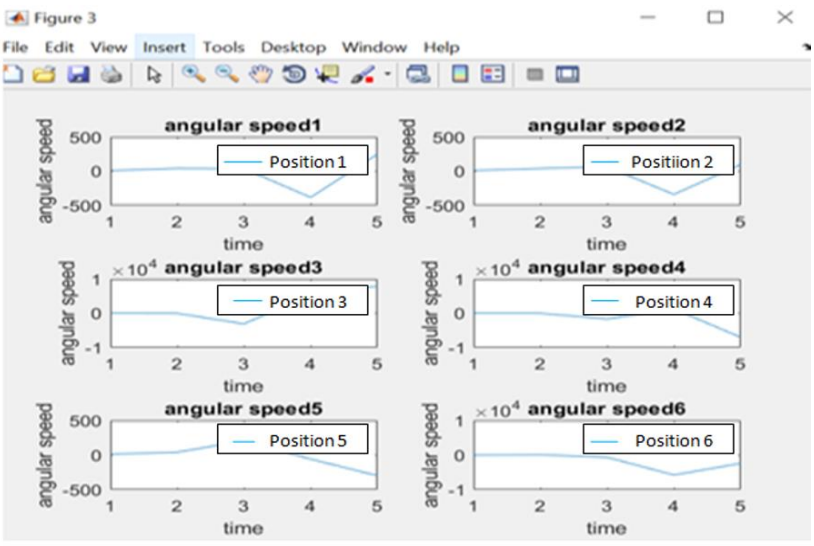

Fig. 5.3 Angular speed

Now by applying the convolutional neural network algorithm , the abnormal walk pattern is identified. In convolutional neural network the three layers convoluted layer, pooling layer and fully connected layers perform different functions. The convolutional layer extracts various informations and also acts as a filter. Pooling layer compresses the all types of data involved. Fully connected layer is the final layer and it connects all the resultant informations. The identification of abnormal gait is shown in Fig. 5.4

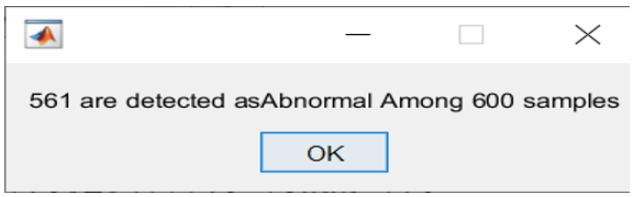

Fig. 5.4 Identification of abnormal gait

The classifications of abnormal walk pattern such as Freezing of gait, bradykinesia, tremor, ataxic gait, myopathic gait and muscle atrophy are also done by using Convolutional neural network and it is shown in Fig. 5.5. The not pathological gait denotes the normal walk pattern, and it is also identified in this method.

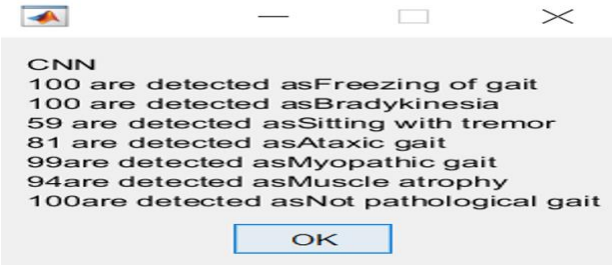

Fig. 5.5 Classification of movement disorders using CNN

SVM algorithm uses a hyperplane that is used to classify the data. It is very simple method and empirical classification error is very low in this method. It also classifies various movement disorders as shown in Fig. 5.6 and provides accuracy higher than CNN algorithm.

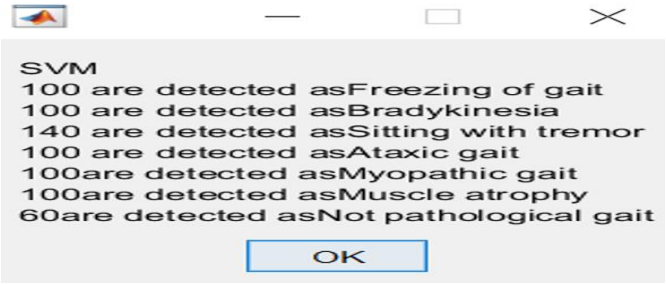

Fig. 5.6 Classification of movement disorders using SVM

By using the confusion matrix, accuracy, precision, F-measure and recall can be obtained. From the comparison we can come to conclusion that Support vector machine algorithm provides higher accuracy, precision values and it is shown in the Table 5.1

Table 5.1: Performance metrics

Method	Accuracy	Precision	F-measure	Recall
CNN	0.90	0.69	0.74	100
SVM	0.94	100	0.83	100

The overall comparison of both SVM and CNN algorithm can be understood by a graph shown in Fig. 5.7

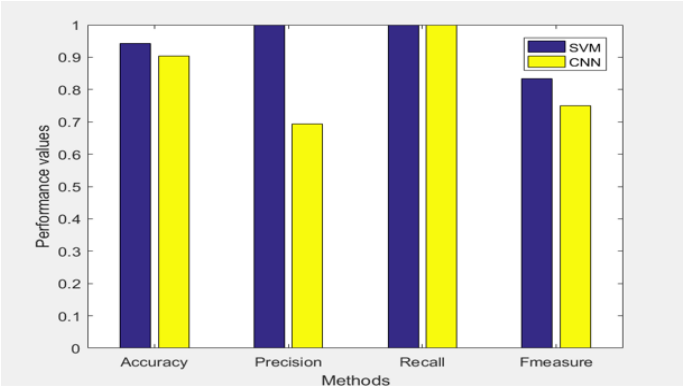

Fig.5.7 Overall performance graph

6. Conclusion and Future Work

Gait pattern and its analysis, a significant division in clinical field is given an introduction in this research paper. Additionally, concepts relating to gait diagnosis and certain methodologies that are used to obtain the gait pattern of human are also discussed. Acoustic GA, a method that deals with sounds to infer the gait pattern of a person is explained in detail. As the main concept, a system by which classification of normal and abnormal gait pattern is proposed along with prediction of bradykinesia, freezing of gait, and Tremor is performed with the help of Convolution neural network and SVM classifier. Based on the confusion matrix, accuracy and Precision is calculated and as a result SVM algorithm has showed greater accuracy.

As a future work, further classification of abnormal gait patterns relating to Huntington's disease, Wilson's disease, Rett syndrome, and Tourette syndrome is to be performed.

Acknowledgement

The authors extend their heartfelt thanks to *The Department of Science and Technology (DST), New Delhi* for extending their valuable support for carrying out this research work.

References

[1] M. Umair Bin Altaf, TarasButko, and Biing-Hwang (Fred) Juang, "Acoustic Gaits: Gait Analysis with Footstep Sounds", IEEE Transactions on Biomedical Engineering, Vol. 62, No.8, August 2015

[2] Maryam Babaee,Linwei Li and Gerhard Rigoll, "Gait recognition from incomplete gait cycle", IEEE, 978-1-4799-7061-2/18, 2108

[3] Hao Ma and Wei-Hsin Liao, "Human Gait Modeling and analysis using a semi-markov process with ground reaction forces", IEEE Transactions on Neural systems and Rehabilitation Engineering, Vol. 25, No. 6, June 2017

[4] Parul Arora and Smriti Srivastava, "Gait Recognition Using Gait Gaussian Image", 2nd International Conference on Signal Processing and Integrated Networks(SPIN),2015

[5] Milica D. Djurić-Jovičić, Nenad S. Jovičić, Saša M. Radovanović, Iva D. Stanković, Mirjana B. Popović, and Vladimir S. Kostić, "Automatic Identification and Classification ofFreezingofGaitEpisodesinParkinson'sDiseasePatients",IEEEtransactionsonneural systems and rehabilitation engineering, Vol.22, No.3,May2014

[6] Ann-Kathrin Seifert, Abdelhak M. Zoubir and Moeness G. Amin, "Radar Classification of Human gait abnormality based on sum-of-harmonics analysis", IEEE, 978-1-5386-4167-5/18, 2018

[7] Anita Sant'Anna and Nicholas Wickstrom, "A symbol – based approach to gait analysis from acceleration signals: Identification and detection of gait events and a new measure of gait symmetry", IEEE transactions on Information Technology in Biomedicine, Vol.14, No. 5, September 2010

[8]Alexander Turner and Stephen Hayes, "The classification of minor gait alterations using wearable sensors and deep learning", IEEE Transactions on Biomedical Engineering, DOI 10.1109, 2019

[9]Valentina Agostini, Gabriella Balestra and Marco Knaflitz, "Segmentation and classification of Gait cycles", IEEE Transactions on Neural systems and Rehabilitation Engineering, Vol. 22, No. 5, September 2014

[10] Vieira, Alexandra; Sobral, Heloísa; Ferreira, João P; Ferreira, Paulo; Cruz, Stephane; Crisóstomo, Manuel; Coimbra, A. Paulo, "Software for Human gait analysis and classification", IEEE 4th Portuguese Bio Engineering Meeting porto, February 2015