Automated Gait Event And Walking Speed Detection System

Abstract:

Accurate human gait phase recognition system is the most important criteria to design an intelligent artificial prosthesis with optimal performance and control. In this paper, we proposed a method to detect various GAIT PHASE events using kinetic and kinematic data set with very less computational requirement. After labelling the kinetic data set with accurate GAIT phase events using the proposed Algorithm, we can easily calculate the exact walking speed of the subjects.

While the proposed algorithm could achieve the best performance in GAIT PHASE event detection, but it cannot be directly used for real-time application, because it requires pre-processed dataset. To overcome poor real-time performance issues of the proposed algorithm , we design a model by using the feature engineering concept of Machine–Learning, which can be used to detect GAIT PHASE events in real time.

Introduction:

The inflection and extreme point-based analysis on the calculated FORWARD DIFFERENCE OF FORCE SIGNAL and threshold-based approach have been used to automate the GAIT EVENT detection process. We have only used one component of Ground reaction forces to detect different GAIT EVENTS ,that allows it to be of very less computational complexity both in term of time and space. Although the proposed algorithm is enough to label the kinetic dataset with different GAIT PHASE, but it requires pre-processed data set and subject specific threshold value because of these factors, it cannot be used for real time performance. For real time performance we have created a machine learning Model to predict GAIT EVENTS. By using the combine analysis of kinematic and kinetic data set, we become able to calculate the walking speed of different 21 subject.

DIFFERENT GAIT EVENTS:

DATA_COLLECTIONS:

We have collected the data from FRIEDRICH-ALEXANDER-UNIVERSITÄT ERLANGEN-NÜRNBERG (FAU) university. The university had uploaded the full dataset on their website and published it in the following paper[1]:

Study Design:

Number of subjects-> 21 subjects (10 males, 11 females)

Subjects' specifications:

Age-> 23.8 years ± 3.3 years ,HEIGHT->: 172.8 cm ± 9.4 cm , Weight-> 66.6 kg ± 10.9 kg

Steps acquired=25306

Each subject performed walking exercise on split-belt treadmill at 12 different speeds ranging from 0.6m/s to 1.7 m/s. Speed increment rate was 0.1m/s f [0.6, 1.7] m/s with 0.1 m/s increments for one minute at each speed

Hardware Equipment and Sensor Setup

The motion data capture system has a QUALISYS, 8 OQUS cameras, collecting data at the rate of 200Hz. A BERTEC split-belt integrated force plate treadmill was used to capture Force signal with 1000 Hz sampling rate. Both motion and force system were synchronized.

SYSTEM SETUP:

The dataset contains the ground reaction force readings and the marker position in 3d space. The markers represented by the symbol FM1, FM2,FM5 and FCC are placed at the shoes above the first metatarsal, second metatarsal, fifth metatarsal and at the Achilles tendon.

FILE NAMING SYSTEM:

The file naming was done according to the following rules:
[Subject] /[Speed] /[force/marker/oversteps].csv
Reference frame coordinate system:
x: posterior-anterior direction
y: right-left direction
z: inferior superior (vertical) direction

Marker positions

The markers are named according to the foot side, anatomical position and the direction: [L/R] [Position] [x/y/z] and occur as columns in the following order:
L FCC x, L FM1 x, L FM2 x, L FM5 x, R FCC x, R FM1 x, R FM2 x, R FM5 x, L FCC y, L FM1 y, L FM2 y, L FM5 y, R FCC y, R FM1 y, R FM2 y, R FM5 y, L FCC z, L FM1 z, L FM2 z, L FM5 z, R FCC z, R FM1 z, R FM2 z, R FM5 z

Ground reaction forces representation

Force plate represented by the symbol FP1 is related to the left foot, force plate represented by symbol FP2 is related to the right foot. The columns name is according to the following:
FP1_x, FP2_x, FP1_y, FP2_y, FP1_z, FP2_z

METHOD:

We have observed regular periodic pattern in vertical force signal data as well as in forward difference of FORCE signal according to different GAIT EVENTS. In a GAIT CYCLE, there are total three types of rocker motions [2]. During these rocker motion, we have found a continuous regular pattern in FORCE SIGNAL value, as well as in FORCE SIGNAL FORWARD DIFFERENCE VALUES. This continuous pattern allows us to define various GAIT events with much more accuracy and clarity. We use this pattern-based analysis to automate the GAIT event detection process.

NOTE:

We are using a word 'DIFF' TO REPRESENT FORWARD DIFFERENCE OF FROCE SIGNAL or the DIFFERENCE BETWEEN CONSECUTIVE FORCE SIGNAL value

DATA ANALYSIS:

From below figures from fig.1 to fig.12, we have found a continuous predictable, regular and repetitive pattern in vertical force signal value as well as in it's diff values also

1. **VERTICAL FORCE SIGNAL FOR GROUP-1 SUBJECT WALKING AT 0.6 m/s**

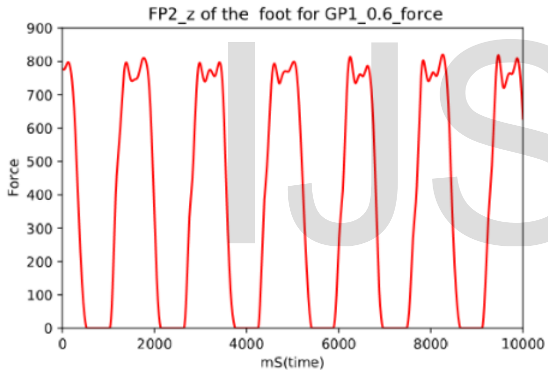


fig 1

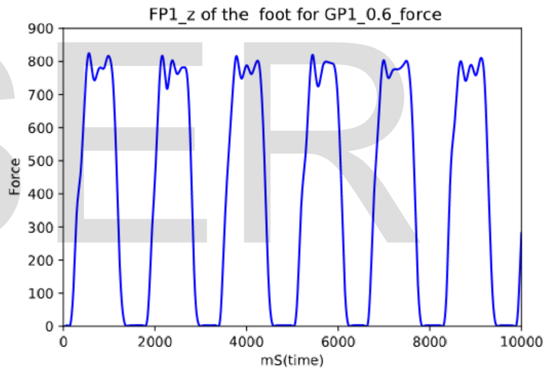


fig 2

2. VERTICAL FORCE SIGNAL FOR GROUP-2 SUBJECT WALKING AT 1.6 m/s

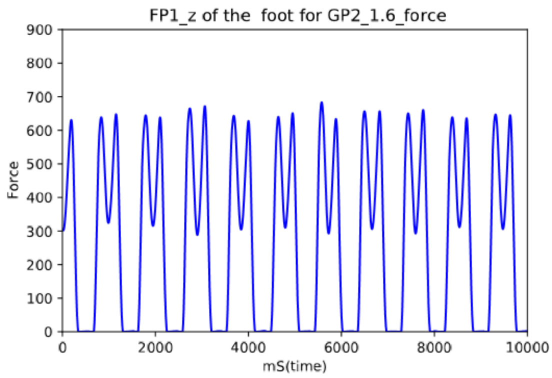


fig 3

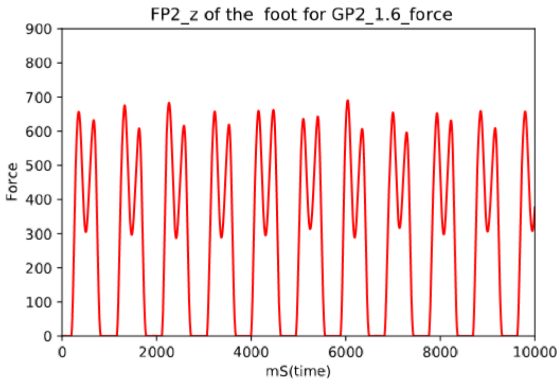


fig 4

3. VERTICAL FORCE SIGNAL FOR GROUP-3 SUBJECT WALKING AT 0.9 m/s

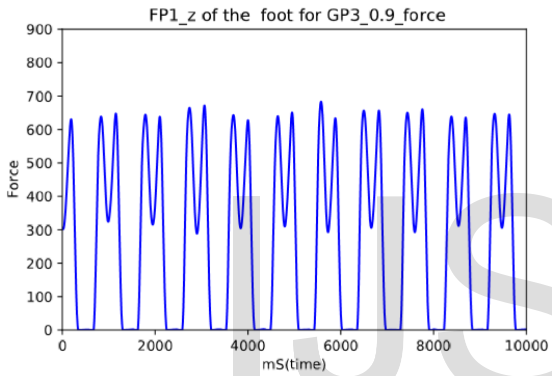


fig 5

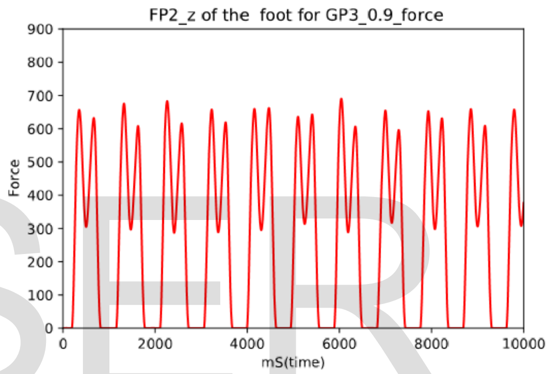


fig 6

4. VERTICAL FORCE SIGNAL FOR GROUP-7 SUBJECT WALKING AT 0.9 m/s

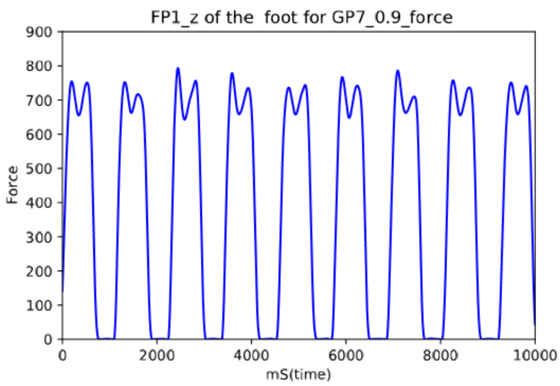


fig 7

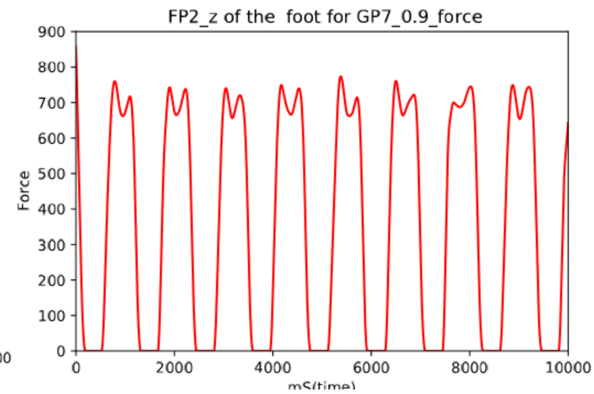


fig 8

REPITATIVE PATTERN IN DIFF OF FORCE SIGNAL:

1.DIFF SIGNAL FOR GROUP-1 SUBJECT WALKING AT 0.6 m/s

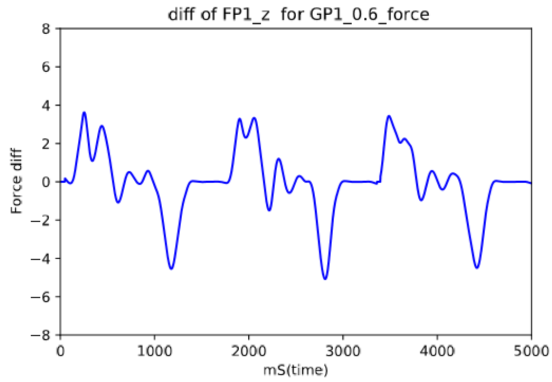
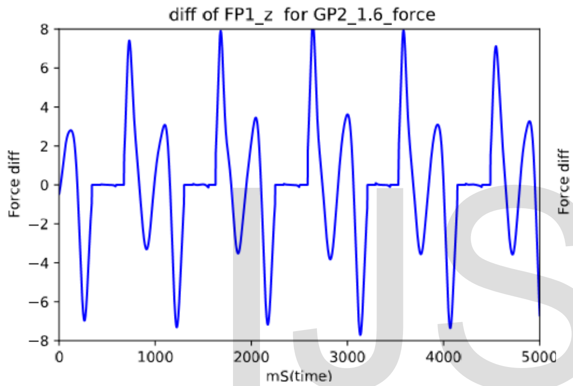


fig 9 **fig 10**

2. DIFF SIGNAL FOR GROUP-2 SUBJECT WALKING AT 1.6 m/s



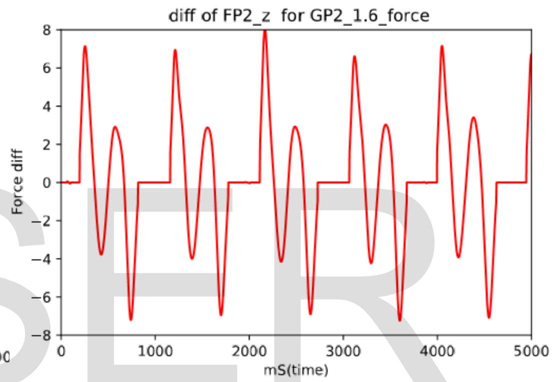
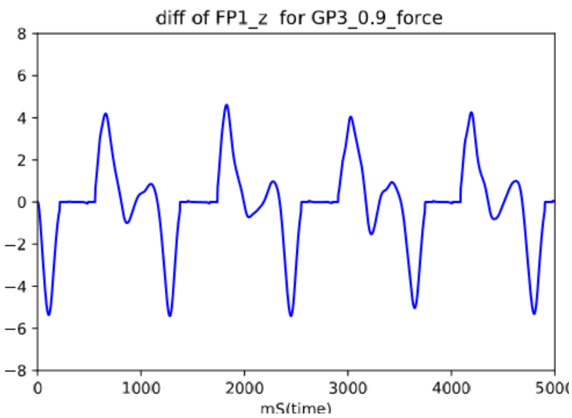


fig 11 **fig 12**

3. DIFF SIGNAL FOR GROUP-3 SUBJECT WALKING AT 0.9 m/s



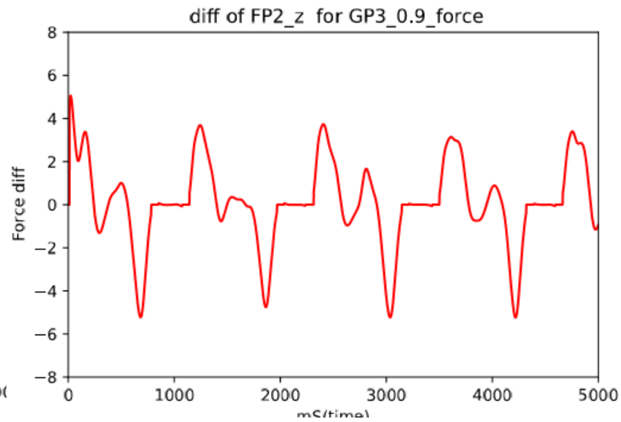


Fig 13 **fig 14**

4. DIFF SIGNAL FOR GROUP-7 SUBJECT WALKING AT 0.9 m/s

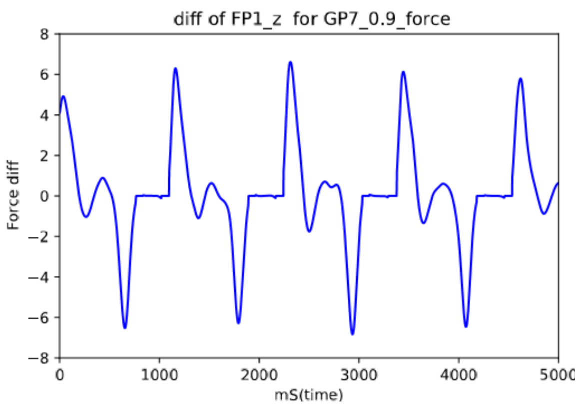


fig 15

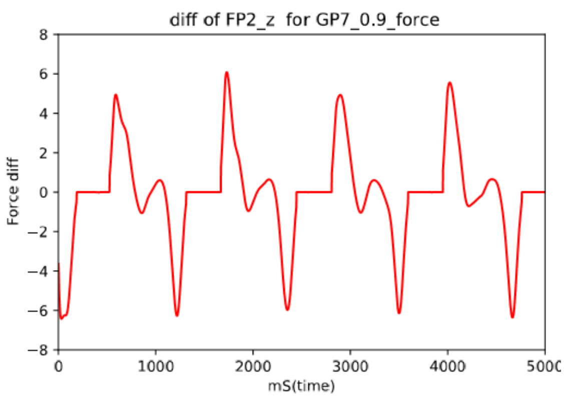


fig 16

From the above graph, it is clear that vertical force reading and its diff values have repetitive pattern. These patterns repeat itself after every complete gait cycle. However, from analysis point of view the repetition in diff values of force signal is in line with respect to changing EVENTS OF GAIT. So, we have decided to go with repetitive pattern of diff values to analyse kinetic data for GAIT event detection.

<u>SWING PHASE DETECTION:</u> Ideally during swing phase, the sensor force reading should be zero. NOTE that in fig 17 the swing phase vertical force value seems like zero, but from fig 18 after close inspection on small scale of force value, we can clearly observe the actual variation in vertical force signal reading. The abnormal variation in vertical force signal value is due to presence of many factors like noise in force signal, remarkably close distance between foot and ground walking plate. We have found a unique pattern in all the dataset of 21 subjects, that just after toe-off and just before heal-strike gait event in both the cases there is regular slight deviation of force signal from zero value, to overcome this issue, we have used threshold-based approach to mark SWING PHASE gait events, but this threshold-based approach is only used on the non-zero zones (Fig.18.1, Fig.18.2, Fig.18.3). This threshold value is subject independent because the weight of the person will not determine the threshold value for non-zero zone.

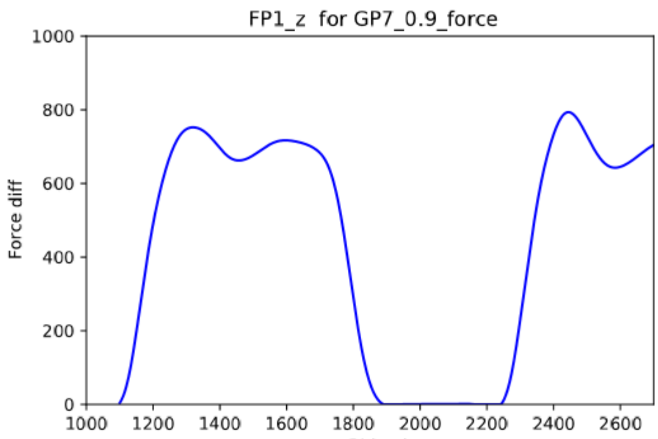


Fig 17

AFTER Magnifying the frame from 1850 to 2300

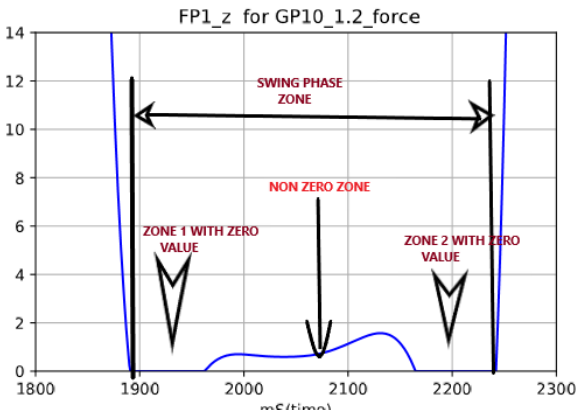


Fig 18.1

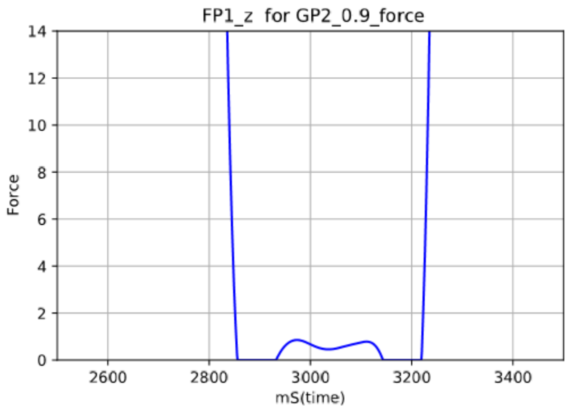


Fig 18.2

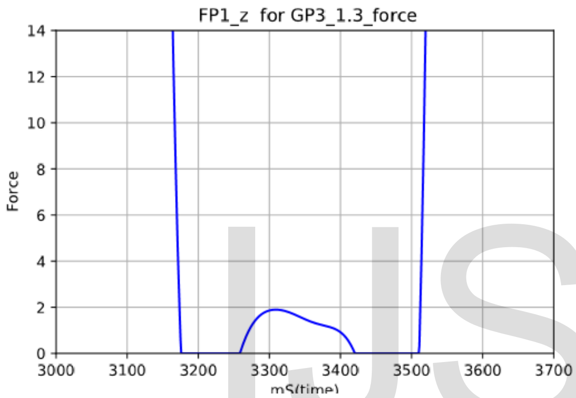


Fig 18.3

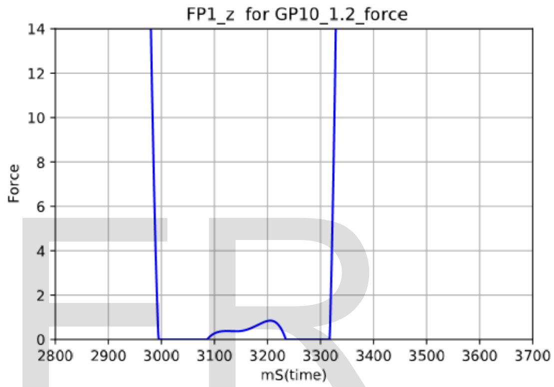


Fig 18.4

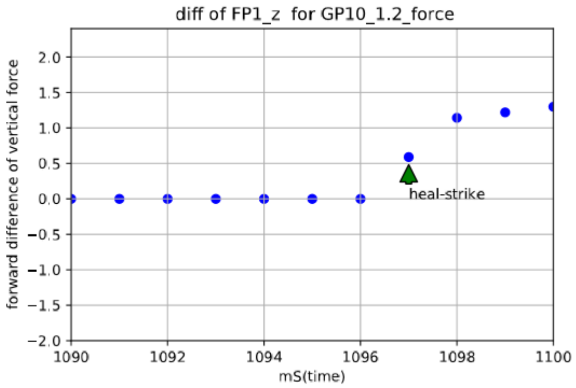
HEAL STRIKE GAIT EVENT DETECTION:

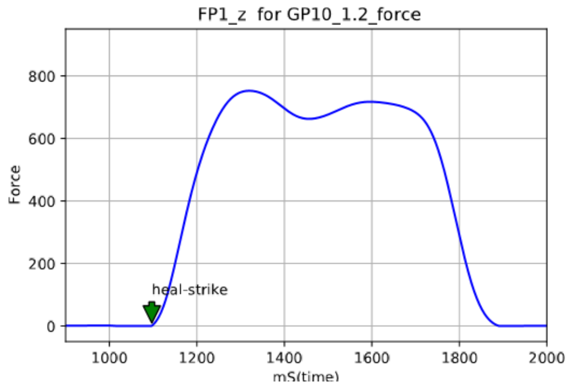
In normal walking, the heel strikes the ground to start the rotation over the heel till foot flat. Heel strike gait event leads to the first rocker type rotation motion in GAIT CYCLE. HEAL STRIKE to FOOT FLATE , is actually a transition phase from double legged support to single legged support.The body weight will keep on shifting from two legged support to one.This body weight shifting phenomenon will ends at FOOT FLATE GAIT EVENT as FOOT FLATE of one leg leads to TOE-OFF GAIT EVENT of another leg. From natural understanding we can say that from HEAL STRIKE to FOOT FLAT ,the vertical force reading will keep on increasing till foot flat gate event . Hence the vertical force signal diff value will also remain positive from the begining to end of HEAL STRIKE phase and from our graph it can also be verified.

It is almost difficult to determine any threshold value for heal strike phase detection, as the weight of the walking subject will determine the FORCE SIGNAL VALUE during heal strike gait event. Using the threshold value is a kind of assumption which may vary from subject to subject. But from our analysis we can clearly identify a regular pattern in diff(Fz) value. We have assumed

to mark the first non-zero positive diff value of vertical force signal, just after swing phase, as the HEAL STIKE GAIT EVENT.

Whenever the diff-value of force signal reaches to the first non-zero positive value in one cycle particularly after swing phase, we have marked this point as HEAL STRIKE GAIT EVENT.

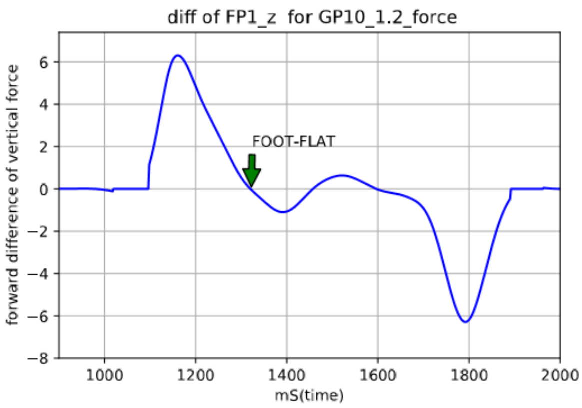


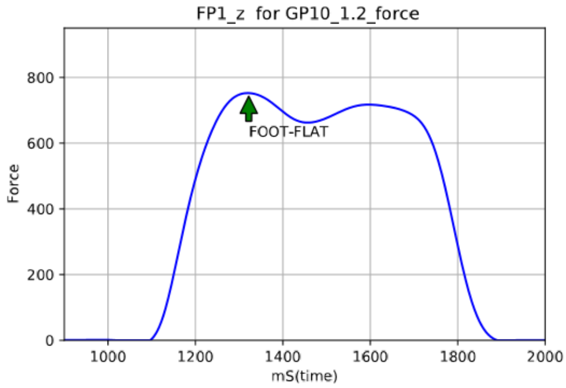


FOOT FLAT GAIT EVENT DETECTION:

During FOOT FLATE gait event the knee flexes slightly for shock absorption to stabilize the single foot support. Because of this shock absorption phenomenon there will be continuous decrease in the vertical force reading, so naturally the force signal diff value will become negative. We use this technique to mark our FOOT FLATE GAIT EVENT.

Whenever the force signal diff value reaches to the zero value and then shift towards negative zone BECAUSE OF THE SHOCK ABSORPTION in foot flat phase, we will mark this point as FOOT FLAT gait event. Our algorithm will start the search for Foot flat phase just after the Heal strike phase detection.





MID STANCE GAIT EVENT DETECTION:

2nd rocker motion of gait cycle starts at FOOT FLATE and ends with heal off, during this whole period both heel and toe are on the ground. It can be divided into following part

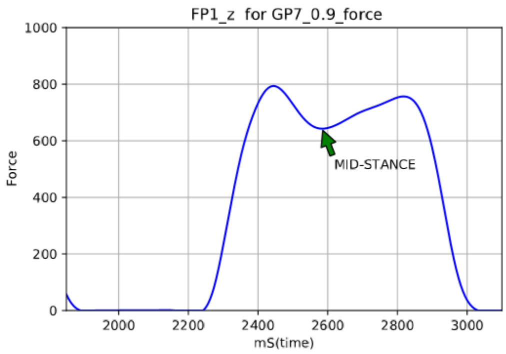
1. PRE-MID STANCE

2. POST-MID STANCE

Whenever the centre of mass and hip joint centre is in straight line with the ankle joint centre, is known as MID-STANCE gait event. The FOOT-FLATE gait event of the supporting foot on the ground, leads to the TOE-OFF gait event of another leg. The upward pushing effect to the body during TOE-OFF gate event of another leg, result in upward acceleration of body centre of mass[3]. The upward acceleration of body in pre-midstance phase causes a continuous decrease in Vertical force signal value so naturally vertical force signal diff value will remain negative throughout the pre-midstance phase. But in POST-MIDSTANCE phase, the body centre of mass will have a downward acceleration [3] to achieve contact with ground. The downward acceleration results in continuous increase in vertical force signal value so the diff value will also remain positive throughout the POST-MIDSTANCE value.

From the above discussion we can say that the DIFF OF VERTICAL FORCE SIGNAL should have a unique pattern of changing the sign from negative to postive repectively in PRE and POST-MIDSTANCE. We use this unique pattern of DIFF(Fz) to mark MID STANCE GAIT PHASE.

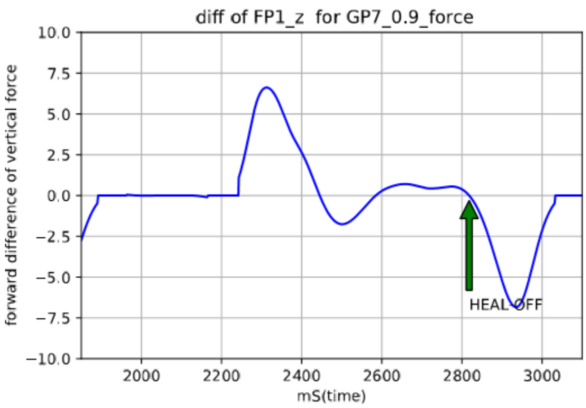
The moment of MID STANCE is detected whenever the value of diff(Fz) changes sign from negative to positive for the first time, after the FOOT FLAT phase detection. Our Algorithm will start the search for MID_STANCE only after FOOT-FLAT phase detection.

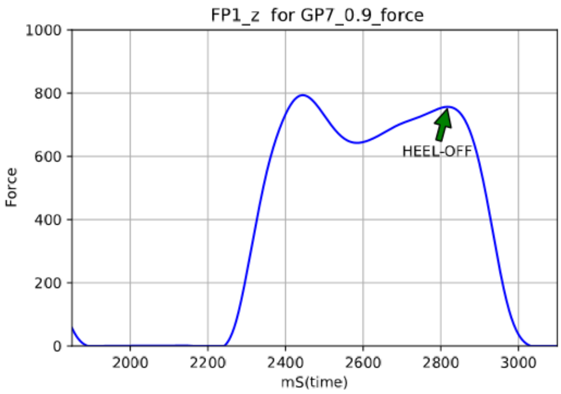


HEAL OFF GAIT EVENT DETECTION:

3rd rocker motion of gait cycle starts at heal off and ends at TOE OFF.Heal-Off GAIT EVENT leads to double legged support from single legged support.The distribution of weight from single to double legged support system,results in continuous fall of vertical force reading in the previously single legged sensor's.The downward trend in vertical force will remain till TOE-OFF GAIT EVENT.Hence the diff value of force signal should be continuously negative after HEAL-OFF GAIT PHASE EVENT. We use this property of diff to identify HEAL-OFF gait event.

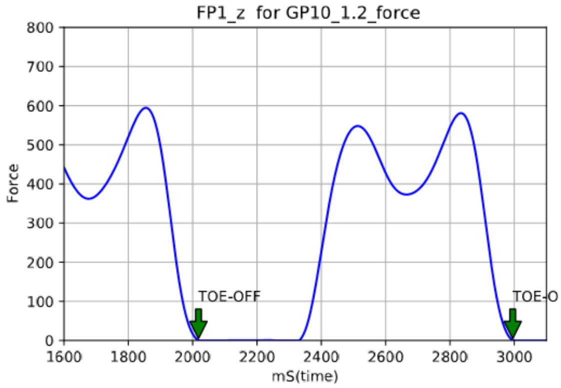
The moment Force signal differentiation value reaches to ZERO at a certain point particullary after MID STANCE ,such that it is continuously negative after this point ,we marked this as HEAL OFF GAIT EVENT. Here we have used backward approach to search for the HEAL-OFF phase. We start our search from SWING PHASE till we reach to the first non-negative vertical force diff value.

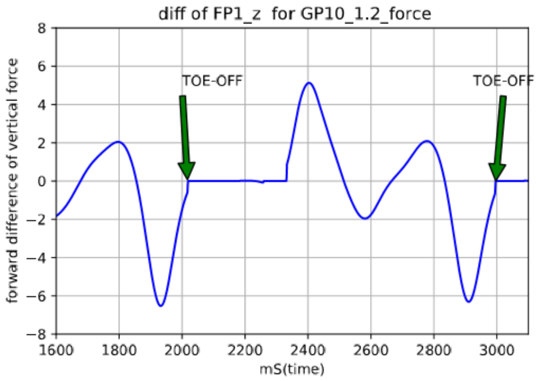




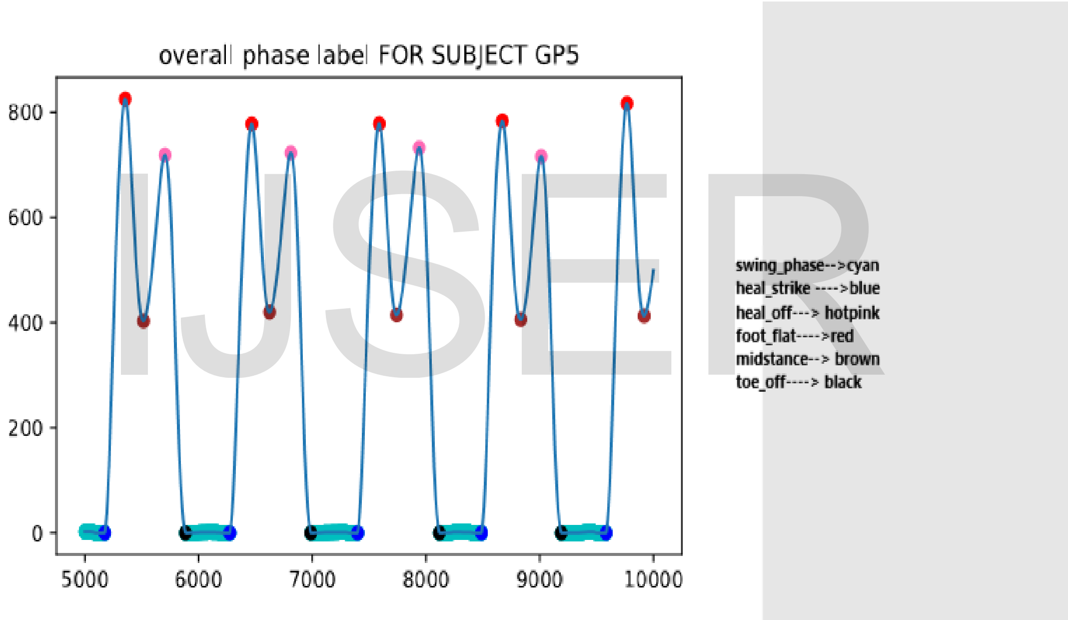
TOE OFF GAIT-EVENT DETECTION:

Toe-off is the last event of contact in complete gait cycle. Whenever the vertical force signal value reaches to the zero value, after heal-off phase detection, we labelled this point as TOE-OFF GAIT event.





PHASE DETECTION COMBINE RESULTS:



WALKING SPEED PREDICTION:

By using the kinematic data and labelled kinetic dataset with accurate GAIT event using the proposed algorithm, we develop an insight which can further be used to detect the walking speed using only kinetic and kinematic data set.

We have calculated the rate of change of X,Y and Z component of each marker position given in kinematic data with respect to time (time gap between two consecutive frames), using the given formulae.

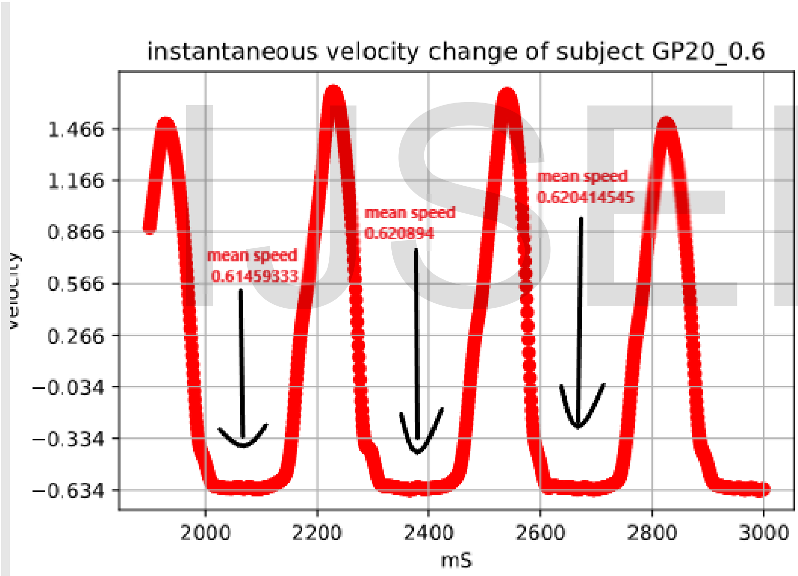
Rate of change in X direction= FORWARD DIFFERENCE ON marker position X VALUES*FREQUENCY OF CAMERA

Rate of change in y direction= FORWARD DIFFERENCE ON marker position Y VALUES*FREQUENCY OF CAMERA

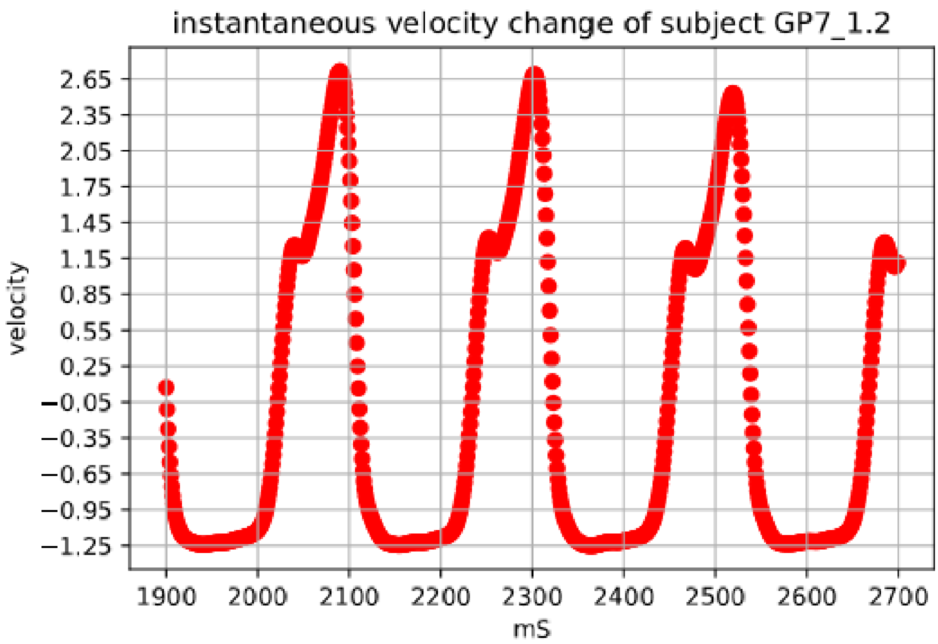
Rate of change in z direction= FORWARD DIFFERENCE ON marker position z VALUES*FREQUENCY OF CAMERA

The above calculated values have been marked by their respective GAIT PHASE using the proposed algorithm. From observation we have found that the WALKING SPEED of EVERY SUBJECT is actually the MEAN of calculated instantaneous SPEED in X direction (direction of walking) during the SWING PHASE. From our analysis on 21 subjects walking at 12 different speeds we have found that the walking speed of every subject is the mean of calculated swing phase speed.

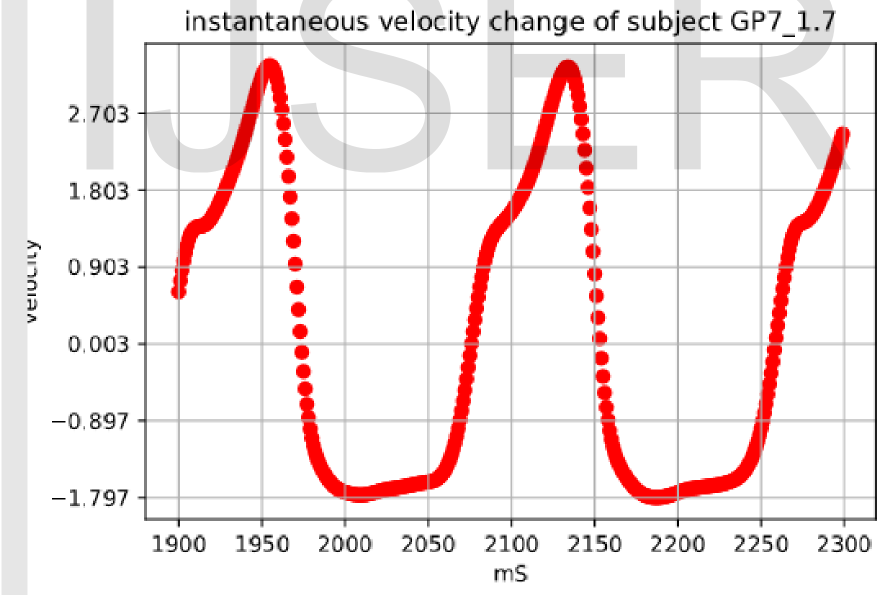
<u>SUBJECT WALKING AT 0.6M/S:</u>



<u>SUBJECT 7 WALKING AT 1.2 m/s:</u>



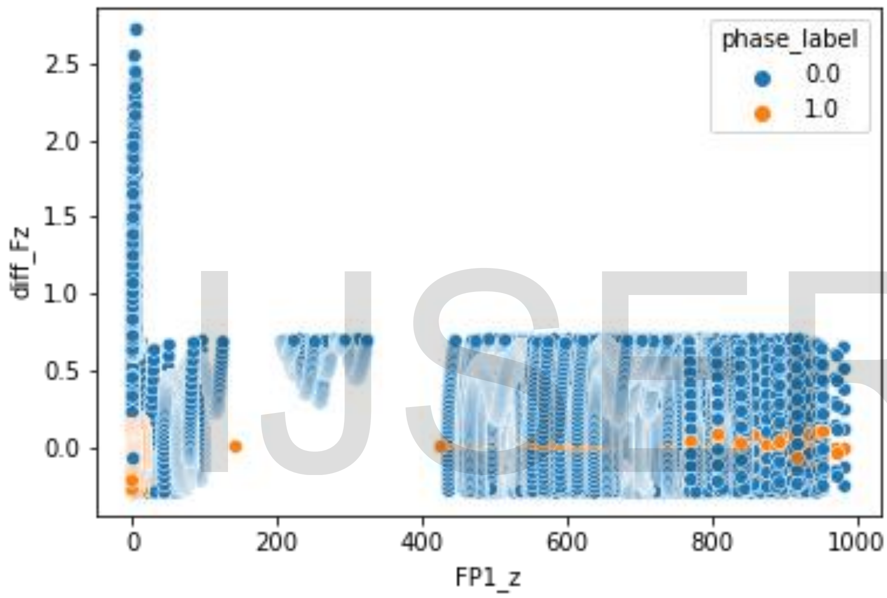
SUBJECT WALKING AT 1.7 M/S:



From the above three figures we can easily analyse that the walking speed of the subject,is actually the mean of swing phase speed.

MACHINE LEARNING MODEL TO DETECT DIFFERENT PEAKS IN DATA-SET:

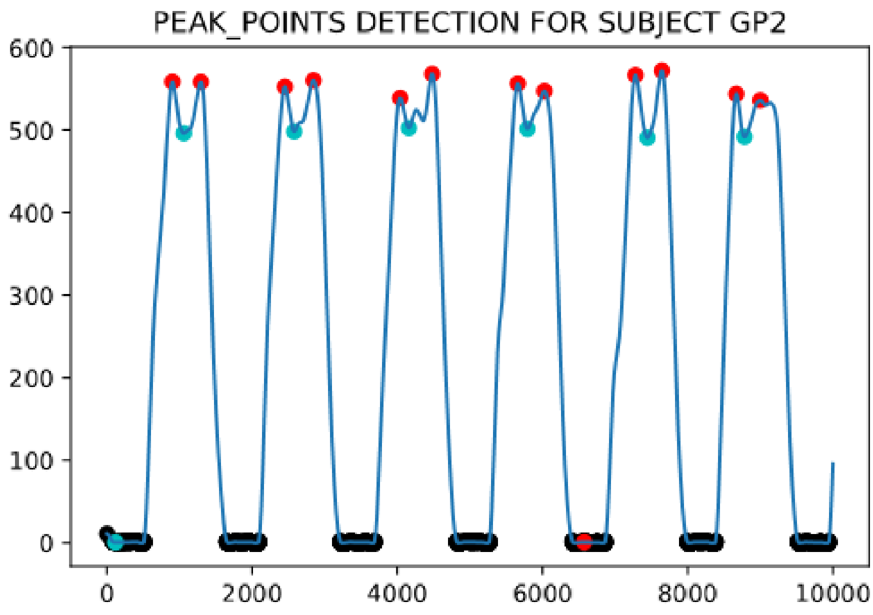
Although the above proposed algorithm is accurate enough to detect and label automatically different GAIT EVENTS present in kinetic dataset, but the proposed algorithm requires pre-processed kinetic dataset. Hence it cannot be used for real time application. We are developing a reliable model using the well-known concept of time series feature-engineering concept to overcome the real time prediction issue. To build the Machine Learning model we have used the rolling mean of two windows on the kinetic dataset to detect the SWING PHASE. From previous analysis we can say that except swing phase rest of the GAIT EVENTS occurs at peak points of vertical force data. For the peak detection purpose, we have used the already available signal processing scientific libraries of SCIPY, and the results were very much reliable. The above-mentioned technique of rolling mean and peak detection can easily be applied to real time data series.



From the above figure we can interpret that all the GAIT EVENT related points (marked with orange colour) that we have to detect are either lying somewhere on the line of zero diff value or on the line of zero vertical force value. This analysis helps us to come with rolling mean theory to detect the swing phases.

But this machine learning time series feature engineering model, that we have proposed here to detect different GAIT EVENT have certain limitations. It can only detect the peak points and the plateau zone for swing phase, but it cannot label those points according to their respective GAIT EVENTS.

RESULTS OF AUTONOMOUS FEATURE EXTRACTION MODEL:


PEAK_POINTS DETECTION FOR SUBJECT GP2
600
500
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2000
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6000
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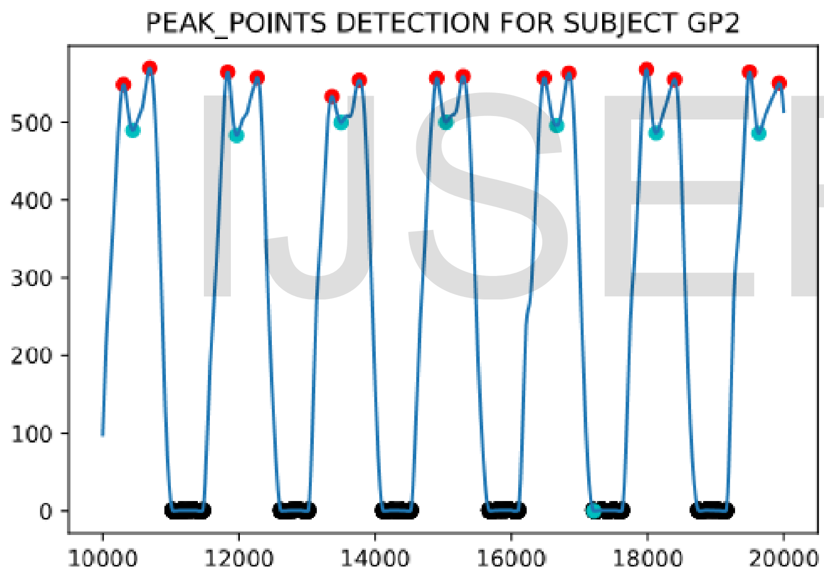
PEAK_POINTS DETECTION FOR SUBJECT GP2
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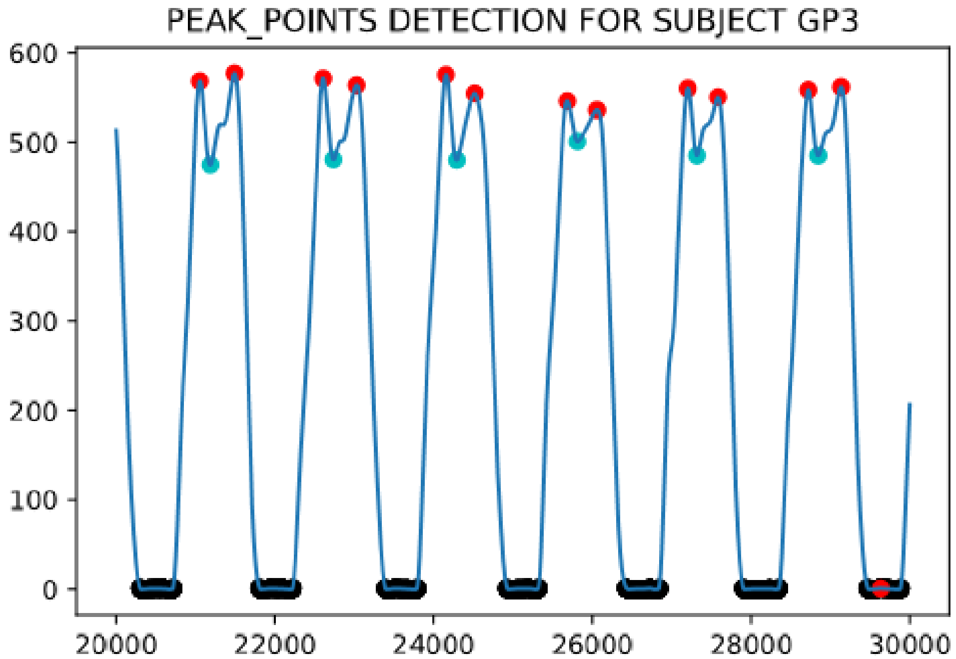

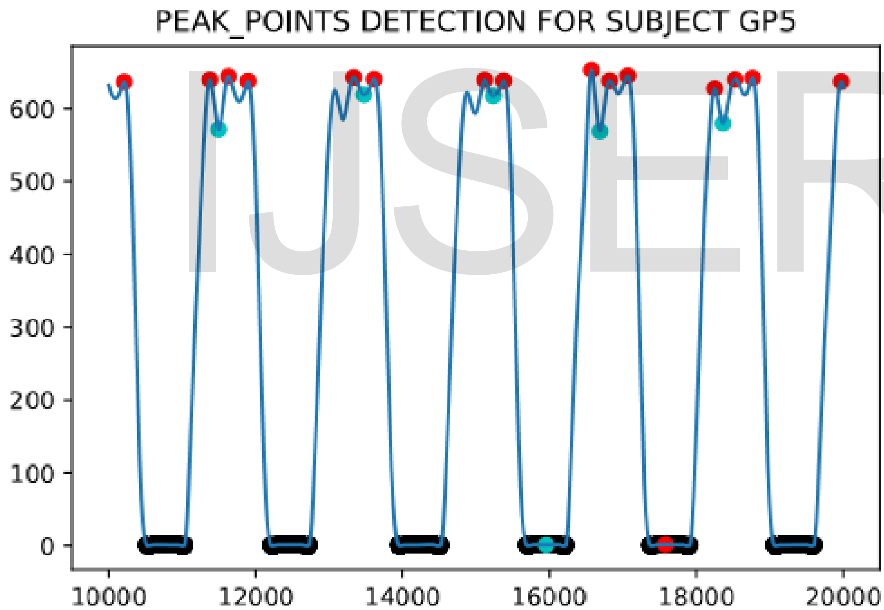

From the above figures it is clear that the autonomous feature extraction machine learning model is good at detecting peak points(at which most of the GAIT EVENT occurs except swing) and plateau zone for swing phase but it has certain drawback like capturing unnecessary peak points. This machine learning model is still in developing phase.

REFRENCES:

1.Hebenstreit et al. (2015) Hebenstreit F, Leibold A, Krinner S, Welsch G, Lochmann M, Eskofier BM. Effect of walking speed on gait sub phase durations. *Human Movement Science.* 2015;43:118–124.doi: 10.1016/j.humov.2015.07.009.

2.Gait Analysis in Orthopedic Foot and Ankle Surgery—Topical Review, Part1: Principles and Uses of Gait Analysis[D. Joshua Mayich, MSc, MD1, Alison Novak, MSc, PhD2, Daniel Vena, MSc2, Timothy R. Daniels, MD3, and James W. Brodsky, MD]

3. Muscles that support the body also modulate forward progression during walking.[May Q. Liua,b, Frank C. Andersona,, Marcus G. Pandyc,d, Scott L. Delpa,b,e][Journal of Biomechanics 39 (2006) 2623–2630]