Evaluation of Classification Accuracy for Abnormal Gait Patterns Using Quaternion Waveforms

Akifumi Sugimoto[1], Hirofumi Hori[2], Mitsunori Matsushita[3]

[1]Faculty of health science, Aino University, Japan,
[2]Faculty of Nursing and Rehabilitation, Konan women's University, Hyogo Japan ,
[3]Faculty of Informatics, Kansai University, Japan

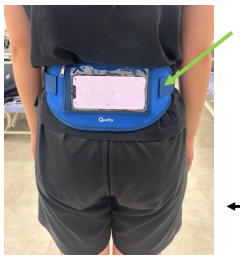
E-mail adless ; a-sugimoto@pt-u.aino.ac.jp

Introduction

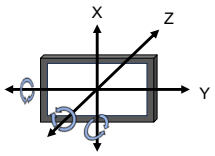
Gait analysis in physiotherapy has required not only visual observation but also the introduction of technology to quantitatively and accurately assess movement. Conventional accelerometers and camera-based measurements have limitations, such as difficulty in capturing subtle changes in motion and constraints related to installation and environment. In this study, we focused on quaternion waveforms obtained from inertial measurement units (IMUs) embedded in smartphones as a means to address these issues, and investigated the accuracy of identifying abnormal gait patterns.

Methods

Set up motion senser



Mobile device
(iphone iOS17.4.1)
Frame rate ; 68Hz



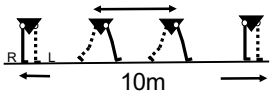
Mobile device axis	Axis of motion	Pelvic motion
X	vertical	rotation
Y	Mediolateral	anterior / posterior tilt
Z	Anteroposterior	elevation / depression

Analysis of the data

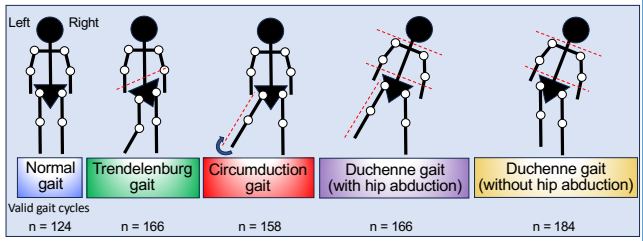
Subject ; 22 healthy adults

- 9 males 13 females
- age : 20.9 ± 0.5 years
- height : 164.5 ± 8.1cm
- weight : 56.7 ± 6.7kg

Analysis interval ;
1 gait cycle (right)



Task ; five simulated gait patterns



Raw data ;
- Acceleration (X Y Z)
- Angular velocity (X Y Z)
- Quaternion data (X Y Z W)

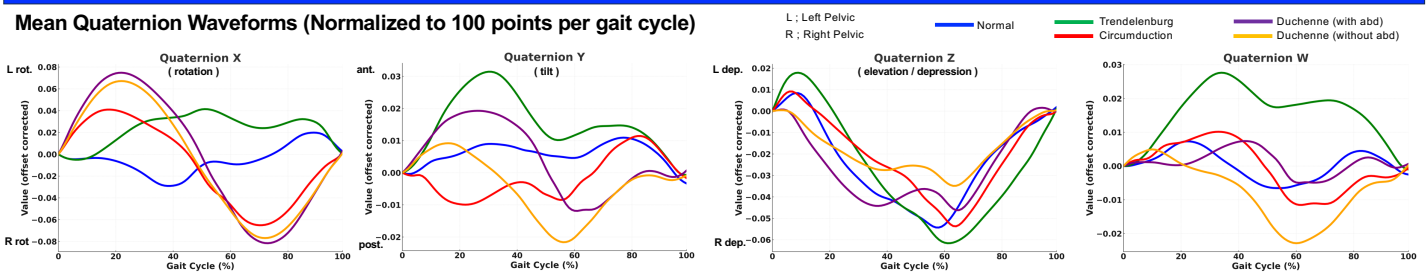
Data processing ;
- Segmentation based on Z-axis acceleration
- Normalization and resampling (100 points per cycle)

Extracted data ;
Quaternion waveforms (X, Y, Z, W),
100 points per gait cycle (400 dimensions)

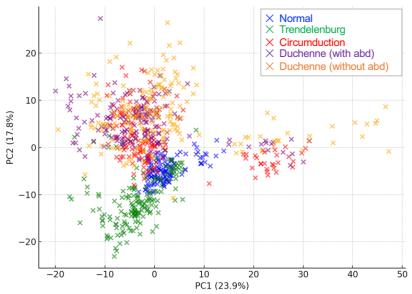
Analysis methods ;
- PCA
- clustering (k=5)
- SVM classification (5-fold CV)

Results

Mean Quaternion Waveforms (Normalized to 100 points per gait cycle)

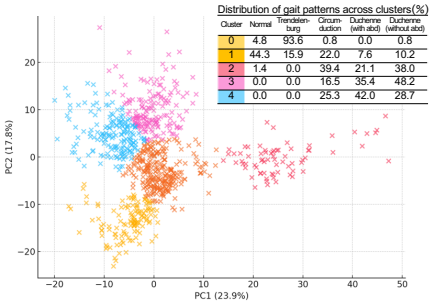


PCA of Quaternion waveforms (400D → 2D)



The PCA yielded a cumulative explained variance of 41.7%, with the Z-axis (pelvic elevation and depression) contributing the most.

K-means Clustering of PCA-transformed Quaternion Data



Distribution of gait patterns across clusters(%)

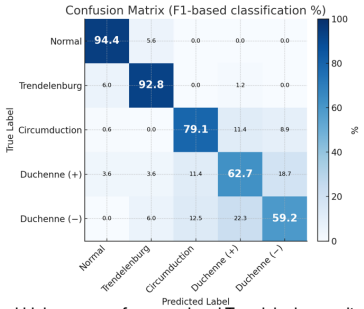
Cluster	Normal	Trendelenburg	Circumduction	Duchenne (with abd)	Duchenne (without abd)
0	4.8	93.6	0.8	0.0	0.8
1	44.3	15.9	22.0	7.6	10.2
2	1.4	0.0	39.4	21.1	38.0
3	0.0	0.0	16.5	35.4	48.2
4	0.0	0.0	25.3	42.0	28.7

K-means clustering on PCA-transformed data showed that the Trendelenburg gait was most clearly separated from other patterns, whereas Duchenne gaits overlapped with other classes.

SVM Classification of gait patterns

Accuracy = **0.763**
(95% CI: 0.72–0.80)
Macro-F1 = **0.769**

Per-class Performance (F1-score)	
Normal	0.91
Trendelenburg	0.90
Circumduction	0.77
Duchenne (with abd)	0.63
Duchenne (without abd)	0.65



SVM classification achieved high accuracy for normal and Trendelenburg gaits, but misclassification remained high for Duchenne gaits, indicating differences in discriminability among gait types.

Conclusions & Clinical Relevance

PCA and clustering revealed variability in waveform structures and classification challenges among abnormal gait patterns. Moreover, the SVM analysis demonstrated that discrimination performance varied across gait types, suggesting that specific features in quaternion waveforms play a critical role in classification accuracy.

Time-series analysis based on quaternion waveforms can support clinical assessment of gait and the development of assistive technologies by enabling the visualization and classification of abnormal movements.