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SEMI-AUTOMATED QUANTITATIVE GAIT ANALYSIS USING VR MOTION TRACKING DATA AND POWER BI: A PILOT STUDY

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Abstract:

This paper presents a pilot semi-automated framework for quantitative gait analysis based on motion data acquired from commercially available virtual reality tracking devices. The objective of the study is to evaluate the feasibility of using VR motion tracking technology for experimental quantitative assessment of human gait characteristics and to demonstrate a methodological workflow capable of transforming raw positional data into analytically interpretable outputs.

The proposed approach combines motion data acquisition using HTC Vive Tracker devices, signal preprocessing, Savitzky–Golay filtering, derivation of kinematic parameters, and semi-automated segmentation of characteristic gait-related motion segments. An important component of the framework is analytical visualisation and signal interpretation implemented in the Power BI environment, enabling efficient comparison of repetitive movement patterns and extraction of selected motion characteristics.

Pilot results indicate that commercially available VR tracking devices can provide sufficiently stable and interpretable motion data for experimental quantitative gait analysis. The proposed framework enables identification of characteristic gait segments, extraction of movement-related characteristics, and establishes a methodological basis for future comparative studies of motor behaviour. Although the presented approach does not represent a clinical diagnostic tool, it demonstrates a promising direction for further applications at the intersection of virtual reality, motion analytics, and movement assessment.

Keywords:

Virtual reality, gait analysis, motion tracking, kinematic analysis, signal processing, semi-automated movement assessment, Power BI.

Introduction

Objective assessment of human movement represents an important area of research with applications in biomechanics, rehabilitation, sports diagnostics, and potential future clinical support applications. Traditional gait assessment methods are often based on visual observation by trained specialists or on specialised motion capture systems that provide high measurement accuracy. However, such systems are frequently financially demanding, technically complex, and less accessible for broader experimental or practical deployment [1,2,5,7].

With the rapid development of virtual reality technologies, new opportunities have emerged for the use of commercially available motion tracking devices beyond their original purpose. Devices such as the HTC Vive Tracker enable continuous real-time tracking of spatial movement and provide motion tracking data that may serve not only for interaction within virtual environments, but also as a source of quantitative information for movement analysis [4,6].

Acquisition of motion data alone is insufficient for meaningful analytical interpretation. A major challenge lies in the transformation of raw positional measurements into interpretable movement characteristics. Motion tracking signals are commonly affected by measurement noise, tracker orientation variability, and short-term instability, while derivative-based calculations such as velocity and acceleration are particularly sensitive to signal imperfections. In addition, manual identification of individual movement events is time-consuming and may introduce inconsistencies caused by subjective interpretation [3,4,5].

For these reasons, there is an increasing need for semi-automated analytical approaches capable of improving the efficiency, consistency, and repeatability of motion data processing. The present study proposes a pilot semi-automated framework for quantitative gait analysis based on data acquired using VR motion tracking technology. The proposed workflow combines motion data acquisition, signal preprocessing, Savitzky–Golay filtering, derivation of kinematic parameters, semi-automated segmentation of characteristic gait-related motion segments, and analytical visualisation in the Power BI environment [5,7].

The main contribution of this work lies in demonstrating a practical and scalable analytical workflow capable of identifying repetitive gait patterns and extracting selected movement characteristics from commercially available VR tracking data. Although the presented approach is not intended as a clinical diagnostic system, it establishes a methodological basis for future comparative movement assessment and further research in objective motor behaviour analysis [1,5,7].

1 Materials and Methods

1.1 Data Acquisition

Experimental motion data used in this study were acquired using commercially available virtual reality motion tracking technology, specifically HTC Vive Tracker devices. These devices enable continuous real-time spatial tracking of a selected body segment and provide time-dependent positional coordinates suitable for subsequent movement analysis [4,6].

The experimental measurements focused on recording repetitive gait movement under controlled experimental conditions. Motion data were collected as sequential spatial coordinate measurements representing the movement trajectory of the tracked body segment during the experimental walking procedure. The pilot dataset consisted of motion recordings obtained from ten participants and was used for methodological framework verification to evaluate the feasibility of semi-automated gait analysis rather than clinical validation [1,5,7].

Particular attention was given to selecting the most analytically suitable coordinate axis for gait signal interpretation. Based on experimental observation, the vertical movement component was identified as the most stable and informative signal source. Compared to horizontal movement axes, the vertical coordinate demonstrated clearer periodic behaviour corresponding to repetitive gait cycles and was less affected by tracker orientation variability or individual participant positioning. This characteristic made it particularly suitable for subsequent segmentation and quantitative analysis [1,5,7].

The acquired raw motion data formed the input dataset for further preprocessing, filtering, and analytical transformation described in the following sections.

1.2 Signal Preprocessing

Raw motion tracking data acquired from the VR tracking system required preprocessing before meaningful analytical interpretation could be performed.

Motion signals generated by commercially available tracking devices inherently contain measurement noise, minor positional instability, and fluctuations caused by environmental factors or temporary variations in tracker orientation. These imperfections can significantly affect subsequent analytical calculations, particularly when derivative-based kinematic parameters are involved [3,4,5].

To improve signal quality while preserving essential movement characteristics, the acquired positional data were processed using the Savitzky–Golay filtering method. This approach was selected due to its ability to smooth noisy measurement data while maintaining local signal features, including peaks and periodic trends that are critical for identification of repetitive movement patterns. Compared to conventional smoothing techniques, the Savitzky–Golay filter provides improved preservation of signal structure, making it particularly suitable for movement-related time series analysis [3].

Following signal smoothing, the positional data were transformed into derived kinematic parameters. Velocity components (Vx, Vy, Vz) were calculated using first-order temporal differentiation between consecutive measurements, while acceleration components (Ax, Ay, Az) were subsequently derived from the velocity signals. These derived quantities provided a more detailed representation of dynamic movement behaviour and enabled clearer identification of transitions between characteristic gait-related motion segments. Since derivative calculations amplify even minor measurement noise, the preprocessing stage represented a critical step in ensuring analytical reliability [1,3,5].

The resulting processed signals formed the basis for the semi-automated segmentation and movement pattern analysis described in the subsequent section.

1.3 Semi-Automated Gait Segmentation

The identification of characteristic gait-related motion segments represents one of the key challenges in quantitative movement analysis. Traditional approaches often rely on manual inspection of movement signals, where individual gait cycles or relevant movement segments are identified by the analyst. Although such methods may be effective for small datasets, they are time-consuming, difficult to scale, and prone to inconsistencies resulting from subjective interpretation [1,2,7].

To address this limitation, a semi-automated segmentation approach was implemented within the proposed analytical framework. Instead of manually identifying individual movement events, the developed workflow enabled systematic detection of characteristic repetitive movement patterns directly from the processed motion signal. The segmentation process focused on identifying representative gait-related motion segments corresponding to distinct phases within the repetitive walking cycle [1,5,7].

The analytical segmentation was based on the periodic behaviour of the processed motion signal, particularly within the selected vertical movement component, which exhibited the clearest repetitive structure. By leveraging this signal regularity, the framework allowed efficient localisation of movement transitions and segmentation of gait-related motion events without requiring repeated manual intervention [1,5].

The semi-automated nature of the approach combines computational assistance with analyst supervision, ensuring both processing efficiency and interpretability of the results. This design significantly reduces analytical workload while maintaining sufficient control over movement interpretation, making the framework suitable for experimental comparative analysis and scalable processing of larger datasets [5,7].

1.4 Data Visualisation and Analytical Processing

Analytical processing and visual interpretation of the segmented motion data were performed using Microsoft Power BI as the primary analytical environment. The platform was selected due to its ability to efficiently transform structured datasets, support analytical workflows, and generate interpretable visual representations of time-dependent movement signals [5,7].

Within the proposed framework, Power BI was used not only for visualisation, but also as an analytical processing layer enabling transformation of raw motion tracking data into structured analytical outputs. Processed signals were organised, segmented, and evaluated in a manner that allowed identification of repetitive gait patterns and comparison of selected movement phases.

A key advantage of this approach lies in the integration of data transformation and visual analytics within a single environment. This significantly simplifies the analytical workflow compared to fragmented multi-tool processing approaches and supports repeatable evaluation of movement characteristics across multiple datasets. Visual representations of processed gait signals enabled efficient interpretation of periodic movement behaviour, identification of characteristic gait events, and qualitative comparison between segmented movement phases [5,7].

The resulting framework demonstrates that commercially available business intelligence tools can serve as effective analytical instruments for experimental motion analysis when combined with appropriate preprocessing and segmentation methodologies.

2 Results

The proposed semi-automated analytical framework was experimentally evaluated using motion data acquired during the pilot gait measurement procedure. Following preprocessing, filtering, and segmentation, the resulting signals exhibited clear and sufficiently stable periodic behaviour suitable for quantitative interpretation [4,5,7].

One of the primary findings of the study was that motion data acquired from commercially available VR tracking devices provided analytically usable information for experimental gait analysis. Despite the fact that the employed tracking technology was not originally designed as a specialised biomechanical motion capture system, the acquired signals demonstrated recognisable repetitive gait-related patterns that enabled systematic processing and interpretation.

The processed motion signal revealed clear characteristic periodic behaviour corresponding to repetitive walking movement. This periodicity provided the basis for subsequent segmentation and movement phase identification. The visual representation of the processed signal is shown in (Fig.1), where repetitive gait cycles can be clearly observed [1,5,7].

A second significant outcome of the study was the successful application of semi-automated gait segmentation. Based on the processed signal structure, characteristic gait-related motion segments could be systematically identified without requiring full manual annotation. This enabled clearer interpretation of the movement cycle and reduced analytical workload compared to purely manual segmentation approaches [1,2,7].

The segmentation output is illustrated in (Fig.2), where characteristic gait-related motion segments are visually distinguished within the analysed signal. The results demonstrate that repetitive motion events can be efficiently identified and analytically separated using the proposed framework.

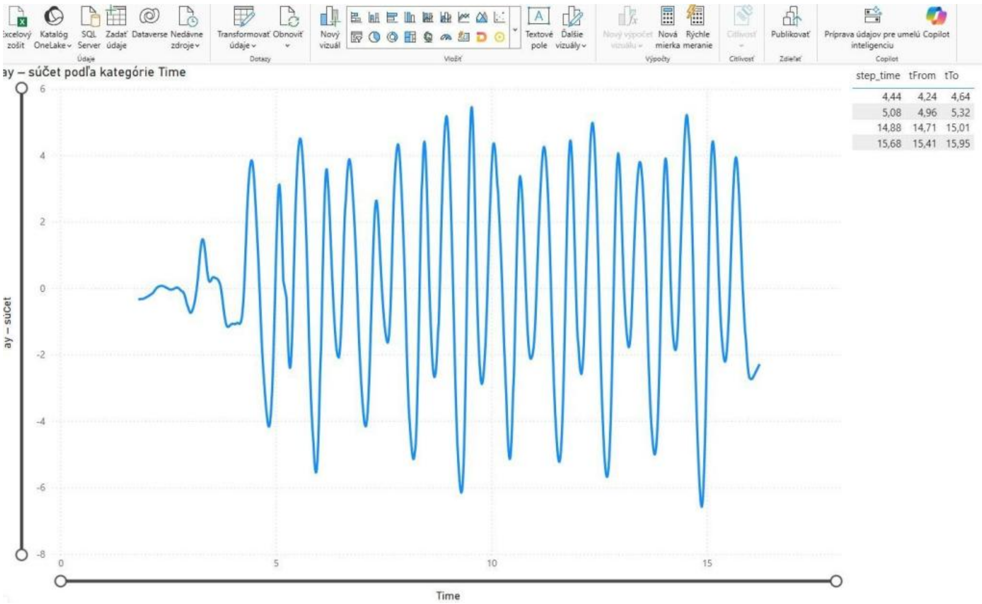

Fig.1. Processed periodic motion signal obtained from VR motion tracking during the pilot gait experiment.

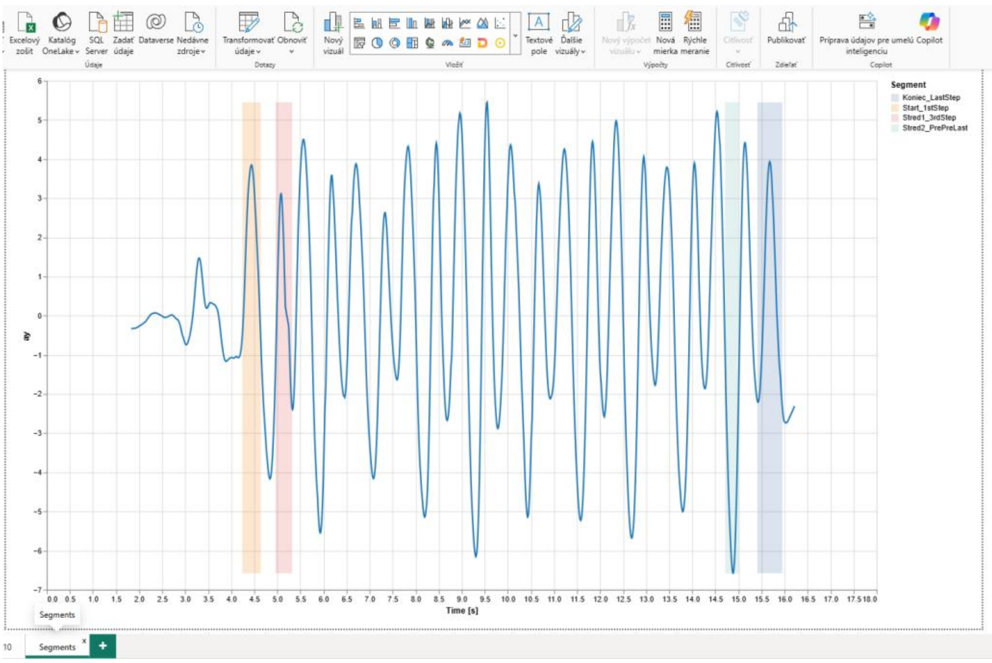

Fig.2. Semi-automated segmentation of characteristic gait-related motion events in the processed signal.

Overall, the experimental results indicate that the proposed workflow enables effective transformation of raw VR motion tracking data into structured analytical outputs suitable for experimental movement assessment. In addition to signal visualisation, the framework supports identification of repetitive gait-related motion segments and establishes a methodological foundation for future comparative quantitative analyses [5,7].

3 Discussion

The presented pilot study demonstrates that commercially available VR motion tracking technology can serve as viable source of analytically usable motion data for experimental quantitative gait analysis. Although such devices were originally developed for interaction within virtual environments rather than specialised biomechanical assessment, the obtained motion signals exhibited sufficient stability and periodic structure to support analytical processing and movement interpretation [4,5,7].

A major contribution of the proposed framework lies in the semi-automation of gait signal analysis. Manual identification of gait-related movement phases can be labour-intensive, inconsistent, and difficult to scale when processing larger datasets. By introducing a semi-automated segmentation workflow, the proposed approach reduces the analytical burden while improving consistency and repeatability of movement evaluation. This represents a practical advantage, particularly in experimental scenarios involving repeated measurements or comparative participant analysis [1,2,7].

An important methodological observation concerns the selection of the vertical movement component as the primary analytical signal source. Experimental evaluation indicated that the vertical axis provided clearer repetitive gait patterns and was less sensitive to tracker orientation variability compared to horizontal movement axes. This contributed significantly to segmentation reliability and overall interpretability of the motion signal [1,5,7].

The integration of preprocessing, segmentation, and visual analytics within the Power BI environment also proved to be a practical strength of the framework. Instead of relying on fragmented multi-tool analytical workflows, the proposed approach demonstrates that accessible business intelligence platforms can be effectively adapted for structured motion analysis tasks. This improves workflow efficiency and increases accessibility for future experimental applications [5,7].

However, several limitations must be acknowledged. The present work represents a pilot methodological study rather than a clinically validated diagnostic system. The framework was evaluated on a limited experimental dataset intended primarily for proof-of-concept verification. Consequently, the results should not be interpreted as evidence of diagnostic capability for specific pathological conditions [1,2,7].

Future work should focus on expanding the analysed dataset, incorporating a larger number of participants, and evaluating movement variability across healthy and potentially pathological gait patterns. Such extension would enable comparative quantitative analysis and support the development of more advanced movement assessment methodologies [1,2,7].

Overall, the findings suggest that semi-automated processing of VR motion tracking data repre-sents a promising direction for future research at the intersection of virtual reality technologies, motion analytics, and quantitative human movement assessment [4,5,7].

Conclusion

This paper presented a pilot semi-automated analytical framework for quantitative gait analysis based on motion data acquired from commercially available VR tracking devices.

The proposed methodology demonstrated that technologies originally intended for virtual reality interaction can also provide a practical and analytically usable source of motion data for experimental movement assessment [4,5,7].

The main contribution of the study lies in the development of a structured analytical workflow combining motion data acquisition, signal preprocessing, Savitzky–Golay filtering, derivation of kinematic parameters, semi-automated gait segmentation, and analytical visualisation using Power BI. This integrated approach enables more efficient and repeatable movement analysis compared to purely manual processing methods [1,3,4,5,7].

The experimental results confirmed that the acquired motion signals contained sufficiently stable and interpretable periodic patterns corresponding to repetitive gait movement. These characteris-tics enabled identification of representative gait-related motion segments and demonstrated the feasibility of transforming raw VR tracking data into meaningful analytical outputs [1,5,7].

Although the proposed framework does not represent a clinical diagnostic tool, it establishes a methodological basis for future comparative movement analysis. Further development may inclu-de larger participant datasets, comparative evaluation of healthy and pathological gait behaviour, and extension toward more advanced quantitative movement assessment applications [1,2,7].

The presented work demonstrates a promising interdisciplinary research direction connecting virtual reality technologies, data analytics, and quantitative human movement analysis [4,5,7].

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