# Measuring Foot Clearance Through Video-Based Methods: A Metrological Comparison

**Student: Luca Ceriola**

Industrial and Civil Engineering, PhD level, Department of Engineering,
Niccolò Cusano University, Rome, 00166, Italy
luca.ceriola@unicusano.it

**Mentors: Ilaria Mileti, Fabrizio Patanè**

Department of Engineering, Niccolò Cusano University, Rome, 00166, Italy
{ilaria.mileti, fabrizio.patane}@unicusano.it

***Abstract***. *In health care and sports, gait analysis and the evaluation of its kinetic parameters are widely used tools. Among them, we evaluated an important parameter for the assessment of drop foot event: foot clearance. In this study, two video-based methods for estimating heel clearance were compared. In the experiment, a healthy subject walked on a treadmill at 3.6 km/h while being recorded by two RGB cameras. One was positioned sagittal to the treadmill and the other at 45°. Two video-based algorithms were used to extrapolate the 2D heel trajectories for each recording. The first algorithm uses a deep learning approach (TC-Former), and the other a passive marker approach (blob analysis). Subsequently, an algebraic triangulation was performed. A 6-camera optoelectronic system was used as the gold standard for comparing the results. TC -Former performed worse than blob analysis with a root mean square error of 32.1±13.0 mm, while blob analysis had Blob Analysis showed a root mean square error of 20.1±6.1 mm. In all gait cycles, the mean and standard deviation of the maximal foot clearance was 32.1±12.8 mm for TC -Former and 20.1±13.0 mm for Blob Analysis.*

**Keywords.** Metrological assessment, computer vision, deep learning, gait analysis, foot clearance

University of Maribor Press

DOI https://doi.org/10.18690/um.4.2023.23
ISBN 978-961-286-783-6

# 1 Introduction

Human motion tracking, gait analysis and its kinetic parameters are one of the most commonly used indicators to determine the health status of a person, as any deviation from normal gait may indicate an underlying problem [1]. In particular, foot clearance assessment is an important tool for evaluating the risk of falls, especially in older people. Foot clearance is a key parameter in the assessment of the drop foot event in stroke survivors [2]. Several studies focused on new affordable and reliable clinical solutions for human motion tracking and gait analysis, but it is still quite a challenging task.

# 2 Background and Motivation

For motion tracking and estimation of human kinematic parameters, infrared marker-based motion capture (MoCap) systems are considered the gold standard. However, these systems can be costly and occasionally intrusive, require skilled personnel and need to be placed in a limited and controlled space [3]. Nowadays, wearable inertial sensors are validated tools for estimating human kinematic parameters and can be a cost-effective alternative to Mocap systems, including outdoor assessment. However, in recent years, there has been increasing interest in developing methods for measuring human kinematics based on vision systems. The clinical potential of video-based systems for gait analysis is promising because they are non-invasive, low-cost, and can be used in a variety of environments. One of the simpler approaches to assess the 2D trajectory of key human points based on an RGB camera is blob analysis [4]. However, no studies have yet been conducted to compare the measurement accuracy of gait analysis methods based on blob analysis with methods based on Deep Learning. This study aims to evaluate the accuracy of two video-based methods for analysing 3D heel trajectories to measure foot clearance. Specifically, a metrological comparison was performed to evaluate the performance of a markerless algorithm based on a Deep Learning neural network for pose estimation (TC -Former) [5] with a marker-based method based on a colour threshold filter and blob analysis [4].

# 3 Materials, Methods and Preliminary Results

A healthy adult (age: 26 years, weight: 72 kg, height: 172 mm) participated in the experiment, walking on a treadmill at 3.6 km/h while being recorded by two RGB cameras. As shown in Figure 1c, the first camera was pointed at the subject's sagittal plane, which was at (-2000, 0) mm with respect to the origin. The second camera was positioned at an angle of 45° behind the subject at (-1500, -1500) mm with respect to the origin s0. Using a Vicon optoelectronic system as the gold standard, we placed 39 markers on the participant according to the plug-in gait model. For the marker technique, we implemented a colour threshold filter in HSV colour space, which allowed us to identify the centres of six green passive markers positioned on the joint centres of the left limb using blob analysis. In this study, we only used the passive marker of P4 and reflective markers on the heel.

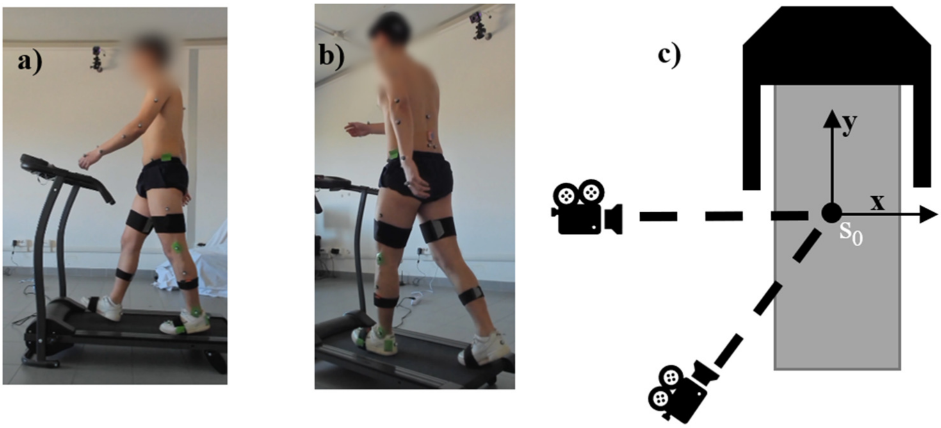


**Figure 1.** a) Sagittal camera view of the subject displaying the reflective and six green passive markers, b) 45° Posterior camera view, c) Camera positioning

Matlab (v.2022b, The Mathworks Inc., Natwick, USA) and the Stereo Camera Calibration app were used to calibrate the stereo camera and calculate the intrinsic and extrinsic camera parameters. The Matlab Stereo Camera Calibrator toolbox implements the calibration algorithm developed by Zhang Z [6]. To calibrate the desired volume, an 8x10 chessboard with 20 mm squares was taken by the two cameras during the calibration process. The chosen markerless algorithm uses a hierarchical strategy and is composed of two different neural networks. The first neural network acts as a detector and has the task of surrounding the object with an anchor box. The second neural network then acts as a pose estimator and determines the keypoints based on the image that is inside the anchor box. We used a faster R-CNN model [7] as the detector and the TC -former [5] as the pose estimator. After extrapolating the 2D heel trajectories using the two video-based methods, we performed an algebraic triangulation to determine the 3D heel pose. To calculate the heel clearance, we first segmented the trials into the gait cycle and considered the heel contact from OS.

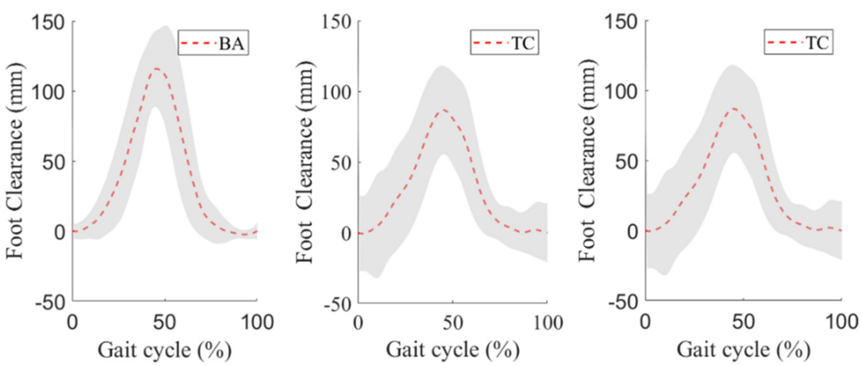


**Figure 2.** a) Foot clearance from Blob Analysis (BA); b) Foot clearance from TC-Former (TC); c) Foot clearance from Optoelectronic system (OS). The red dashed line represents the mean along the gait cycle, while the standard deviation is represented by the grey-shaded areas.

To compare the three systems, the offset above the heel height was removed for each heel contact. TC -Former performed worse than Blob Analysis with a root mean square error of 32.1±13.0 mm, while Blob Analysis had a root mean square error of 20.1±6.1 mm. The average mean and standard deviation of the extracted maximal foot clearance in all gait cycles was 32.1±12.8 mm for TC -Former and 20.1±13.0 mm for Blob Analysis.

## 4 Conclusions

Two video-based algorithms were used to extrapolate the 2D heel trajectories for each recording. Algebraic triangulation was then performed for 3D heel pose estimation. According to the literature [8], the marker-based algorithm provides an affordable and cost-effective clinical tool for estimating foot clearance. In contrast, the video-based method based on TC -Former does not provide reliable results and proves that the markerless algorithm for 3D estimation of the keypoints of the foot needs further research and investigation.

## References


[1] N. Prajapati, A. Kaur, and D. Sethi, “A Review on Clinical Gait Analysis,” in *Proceedings of the 5th International Conference on Trends in Electronics and Informatics, ICOEI 2021*, Institute of Electrical and Electronics Engineers Inc., Jun. 2021, pp. 967–974. doi: 10.1109/ICOEI51242.2021.9452951.

[2] D. Yao *et al.*, “Restoring mobility after stroke: first kinematic results from a pilot study with a hybrid drop foot stimulator,” *Musculoskelet Surg*, vol. 100, no. 3, pp. 223–229, Dec. 2016, doi: 10.1007/s12306-016-0423-2.

[3] M. Moro, G. Marchesi, F. Hesse, F. Odone, and M. Casadio, “Markerless vs. Marker-Based Gait Analysis: A Proof of Concept Study,” *Sensors*, vol. 22, no. 5, Mar. 2022, doi: 10.3390/s22052011.

[4] U. C. Ugbolue *et al.*, “The evaluation of an inexpensive, 2D, video based gait assessment system for clinical use,” *Gait Posture*, vol. 38, no. 3, pp. 483–489, Jul. 2013, doi: 10.1016/j.gaitpost.2013.01.018.

[5] W. Zeng *et al.*, “Not All Tokens Are Equal: Human-centric Visual Analysis via Token Clustering Transformer.” [Online]. Available: https://github.com/

[6] Z. Zhang, "A flexible new technique for camera calibration," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 11, pp. 1330-1334, Nov. 2000, doi: 10.1109/34.888718.

[7] S. Ren, K. He, R. Girshick, and J. Sun, “Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks,” Jun. 2015, [Online]. Available: http://arxiv.org/abs/1506.01497

[8] B. Mariani, S. Rochat, C. J. Büla, and K. Aminian, “Heel and toe clearance estimation for gait analysis using wireless inertial sensors,” *IEEE Trans Biomed Eng*, vol. 59, no. 12 PART2, pp. 3162–3168, 2012, doi: 10.1109/TBME.2012.2216263.