# GAIT EVENTS DETECTION IN ABSENCE OF THE TOES' AND HEELS' POSITION

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## Introduction

With the fast-paced technological developments, less expensive systems for gait analysis based on RGB-D cameras have emerged that are portable, markerless, and less intrusive in terms of occupied space, which facilitates their use for clinical applications [1,2]. However, their accuracy is usually lower than the gold-standard systems [3]. The state-of-the-art methods utilizing a single RGB-D camera in the frontal plane are inaccurate, unreliable, and gait events detection is still a challenging problem in this setting due to lack of heels position and inaccurate localization of the toes by most of the human pose estimation algorithms. Hence, we present a novel kinematic-geometric model for gait analysis, relying only upon distance-to-camera data (depth) of the ankles in the frontal plane [4].

## Methods

This approach proceeds in three main steps: Identification of the gait pattern and modelling by parameterized curves (Fig.1a, 1b), model fitting through optimization, and computation of spatiotemporal parameters. The proposed algorithm applies on both ankles' depth data simultaneously, by minimizing through numerical optimization some geometric and biomechanical error functions. The utilized parametric curve is cubic Bézier curve (Fig.1b) which its formulation is as follows:

$$B(u) = (1-u)^3 P_0 + 3u(1-u)^2 P_1 + 3u^2(1-u) P_2 + u^3 P_3 \quad , \quad P_i = \begin{pmatrix} x_i \\ y_i \end{pmatrix} \quad , \quad 0 \le u \le 1$$

The model (Fig.1b) consists of a straight line with a zero slope to model from the mid-flat foot to the beginning of the push-off phase, a cubic Bézier curve to model the push-off, swing, and heel-strike phases, and a straight line with a zero slope to model from the end of the heel-strike to the next mid-flat foot. This model applies in between two consecutive intersection points on ankles depth data, since these points are the only biomechanically deducible information from the raw data. These intersection points are the points where both ankles have the same depth and their curves intersect each other, showing the mid-flat foot for one leg and mid-swing for the other. In this model, gait events are the extremities of the curves relative to the interpolated line IL (Fig.1.d), obtained by fitting a line to the intersection points at the same time as fitting the model on data. To validate the model, 15 subjects were asked to walk inside the walkway of the OptoGait, while the OptoGait and an RGB-D camera (Microsoft Azure Kinect) were both recording.

## Results & Discussion

Validation results (Table.1) show that the proposed model yields good to excellent absolute statistical agreement in spatiotemporal gait parameters (0.86 ≤ Rc ≤ 0.99). The first advantage of the proposed kinematic-geometric model is that it only uses the ankles' depth data to extract gait events, without requiring other joints' trajectories. Second, other types of RGB-D cameras or pose estimation algorithms can also be utilized. Third, utilization of the cubic Bézier curve enables obtaining different patterns based on its control points' locations, opening the door to the applicability to various pathologies.

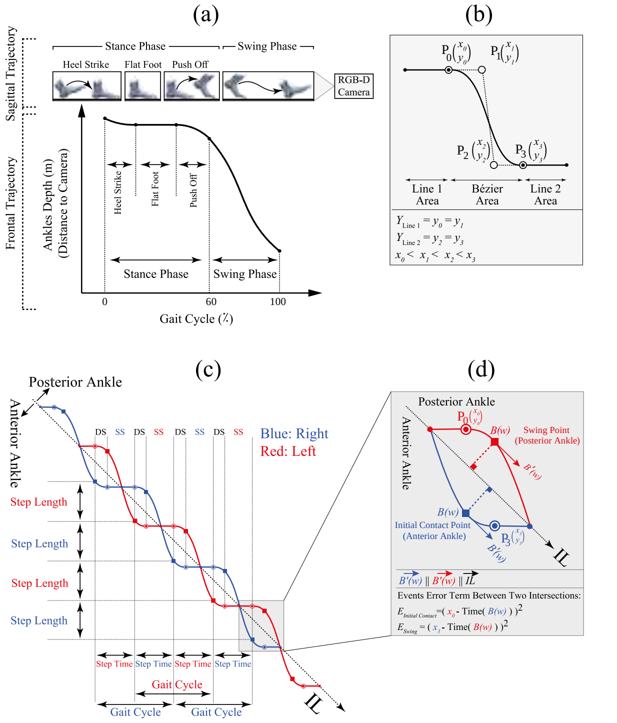


***Figure 1***- *(a) Ankle's sagittal and frontal plane trajectory in a gait cycle, (b) Proposed model, (c) Applied model on ankles' distance to camera (depth) data, and (d) Gait events on the model.*

***Table 1:*** *Validation results for overall spatio-temporal parameters. PE% refers to percentage error and Rc is the Lins' concordance correlation coefficient.*

| Parameter | PE% | Rc |
|---|---|---|
| Step Time (s) | 2.3% | 0.98 (0.97 to 0.99) |
| Step Length (m) | 2.5% | 0.98 (0.97 to 0.99) |
| Stride Time (s) | 2.3% | 0.98 (0.97 to 0.99) |
| Stride Length (m) | 2.8% | 0.98 (0.97 to 0.99) |
| Gait Speed (m/s) | 2.2% | 0.99 (0.98 0.99) |
| Cadence (steps/minute) | 2.2% | 0.98 (0.97 to 0.99) |
| Stance Phase (%) | 1.5% | 0.94 (0.90 to 0.98) |
| Swing Phase (%) | 2.8% | 0.90 (0.84 to 0.96) |

## References

1. Ross A. Clark et al., J Biomechanics, 46(15), 2013.
2. Ana Patrícia Rocha et al., J PLOS ONE, 13(8), 2018.
3. Robert M. Kanko et al., J Biomechanics, 121, 2021.
4. Mehran Hatamzadeh et al., J Biomechanics, 145, 2022.