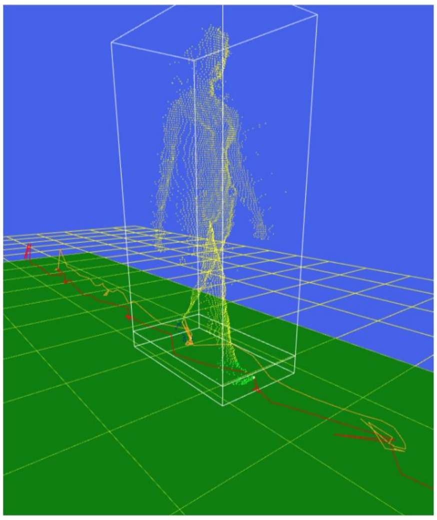
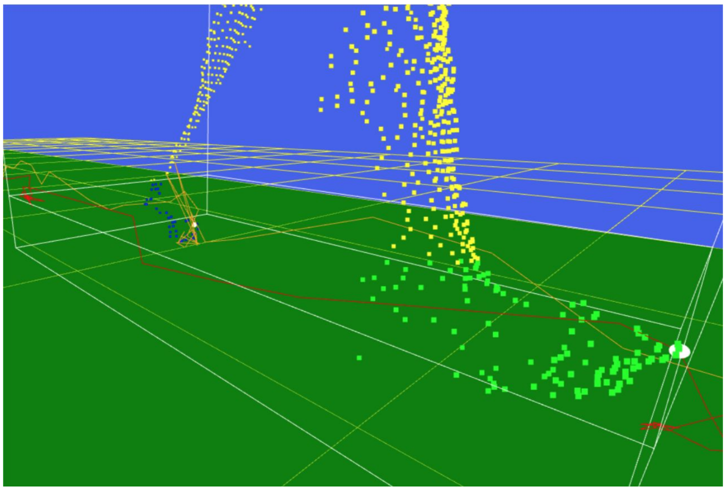
Geometric Modeling of Human Walking for Medical Rehabilitation via Data Fitting and Machine Learning

Pre-thesis Internship at Inria Sophia Antipolis,
in collaboration with [Ekinnox]

Abstract. *This internship is part of a research project whose aim is to develop an innovative solution for medical diagnostic and monitoring of walking ability disorders. Its main objective is the determination of a parametric continuous model that provides a good representation of walking from 3D camera acquisitions. This model should be simple albeit sufficiently rich to yield a reliable approximation of all possible walking patterns. Furthermore, a fitting algorithm will also be devised in order to identify the best instance of this model for a wide range of data sets. This algorithm will have to exhibit robustness to variable noise and occultations, two defects that are inherent to 3D point acquisitions from depth maps. This internship is a first step of a CIFRE Ph.D. thesis.*





Context

Physiotherapists and rehabilitation physicians have only few quantitative automatic tools for the diagnostic of a disease and for the record of patient progresses in order to tailor treatments. This deficiency is particularly important for walking disabilities that occur after trauma, stroke or other ailments. For practitioners, the current available solutions hinge on complex and costly systems that are based on several sensors and cameras (Vicon system) or pressure sensor mats (Gaitrite system). Ekinnox's offer is an innovative lightweight solution which relies upon a single 3D camera.

The current algorithm used by Ekinnox to determine the trajectory of a point of interest (such as the toe of the foot) from depth maps suffers from important robustness and precision issues. These difficulties are mostly due to variable noise in the measurements and to false positives that appear in certain images due to visibility occlusions. Consequently, the current estimation of the trajectories does not allow the extraction of all possible walking patterns with sufficient precision and stability, which prevents its use for a reliable diagnostic assistance and a relevant monitoring of medical treatments. The main objective of this internship is to develop a new approach for estimating this trajectory.

Partners. This project is a collaboration between the Inria project-team Aromath, the Inria project-team Titane and the start-up Ekinnox. The Inria project-team Aromath develops algebraic methods and representations for complex shapes, including parameterized curves and surfaces. The Inria project-team Titane conducts researches on the modelisation and numerical treatment of 3D geometry, with a focus on simple representations such as triangle or tetrahedron meshes. Ekinnox is a recent spin-off from Inria founded in April 2017. Using a minimalist system comprising a computer and a depth camera, its objective is to offer simple, objective and fast quantitative evaluation and visual feedback of human movements for rehab centers and physiotherapist offices.

Objective and Scientific Challenges

First task: determination of a parametric continuous model of walking. The goal is to identify a class of parameterized space curves that provide a continuous and sufficiently faithful representation of the trajectory of some points of interest during walking. To be useful, this class of space curves should depend on a few control parameters that will have to be identified (like the B-spline curve control points used in geometric modeling [PT95]). A challenge is to find the right balance between the number of control parameters: it must be large enough to take into account the variability of the patients and the classes of pathologies studied, but it must also be small enough to be sufficiently robust to common measurement uncertainties such as noise and occultations. This first task will rely upon the existing literature on the biomechanics of walking, its mechanisms and constraints (limits, accelerations, joint angles, rigid and flexible parts). The geometric modeling of the trajectories will be based on approximation methods relying on B-splines functions [PT95], adjusted to high-precision 3D measurements, with a very low noise level and without occultation.

Second task: implementation of a data fitting algorithm from noisy data. Once the parametric model will be defined, an approximation/interpolation method will be devised to adjust its control parameters to datasets obtained from 3D camera acquisitions (depth maps). For that purpose, we will apply and combine existing methods from geometric modeling to our context (e.g. [WPL06], [BR12]). Our current hypothesis is that some specific classes of curves in this model, i.e. some specific control parameters, will enable the identification of classes of patients and pathologies. This hypothesis will be verified by testing machine learning methods adapted to our context.

Third task: extraction of locomotor indices and analysis. Once the trajectory of a point of interest is represented by an instance of the model, an analysis method will be devised to robustly and reliably extract the locomotive walking indices used by physiotherapists. In addition, this method will be extended to extract additional indices in order to accurately assess the progress of a patient, as for instance the minimum and maximum distances between the trajectories of the two feet. Our overall objective is to correlate such an automatic analysis with a diagnostic and a quantification of patient progresses during a rehabilitation period.

Evaluation Criteria. The results will be validated by comparison with ground truth data sets obtained from 3D sensors, which allows to recover the movement of the foot during walking with high accuracy and without occultation. Regarding the analysis step, the computations must be completed within a reasonable time, about less than one minute for a three-minute acquisition sequence.

References

[V04] Eric Viel, La marche humaine, la course et le saut, Masson, 2004.

[H10] Chris Hayot, Mémoire de thèse : Analyse biomécanique 3D de la marche humaine, 2010.

[PT95] Les Piegl and Wayne Tiller. *The NURBS Book*. Springer-Verlag. 1995.

[WPL06] Wenping Wang, Helmut Pottmann and Yang Liu. 2006. *Fitting B-spline Curves to Point Clouds by Curvature-based Squared Distance Minimization*. ACM Transactions on Graphics. Volume 25, 2 (2006), Pages 214-238.

[BR12] Mauro C. Beltrametti and Lorenzo Robbiano. *An Algebraic Approach to Hough Transforms*, Journal of Algebra. Volume 371 (2012), Pages 669-681.

Job description

Location. This internship will be hosted at the Inria Sophia Antipolis research center. The partner Ekinnox is also located in Sophia Antipolis.
Duration. 6 months.
Salary: 1.650€ net per month.
Required qualification: a MS degree in Computer Science, or equivalent, with education in geometric algorithms, applied mathematics and programming. Familiarity with biomechanics will be appreciated and previous experiences with image processing are highly relevant. Motivation for a CIFRE Ph.D. program in the continuity of this internship is a real plus.

Contact information and application:

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Laurent Busé, Inria Sophia Antipolis, EPI Aromath.
Mélaine Gautier, Ekinnox.

Applications must include a detailed CV and a letter of motivation.