Tracking Moving Objects in Image Sequences

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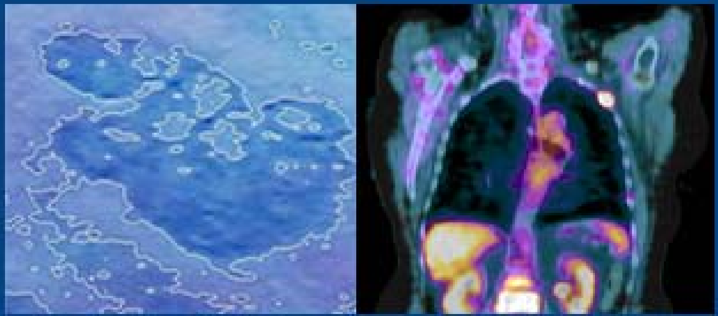
Coimbra, Portugal



Medical Images: DM-FCTUC, FMUC and ICNAS - University of Coimbra

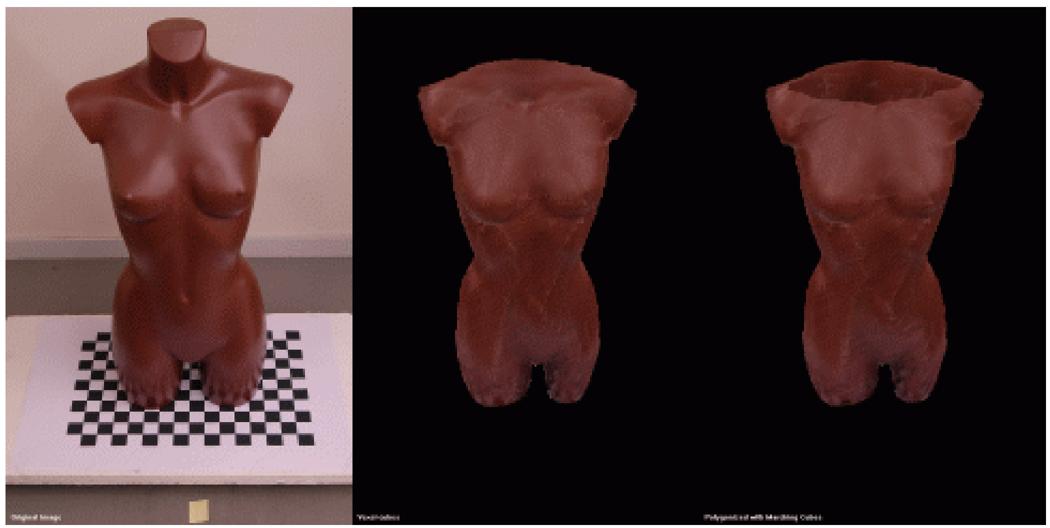
Outline

- Motion Tracking
  - Introduction
  - Kalman and Unscented Kalman Filters
  - Matching, Registration and Morphing
- Research Team
- Conclusions and Future Work

Introduction

Introduction

- The researchers of the Computational Vision domain aim the development of algorithms to perform operations and tasks carry out by the (quite complex) human's vision system in a full or semi-automatic manner



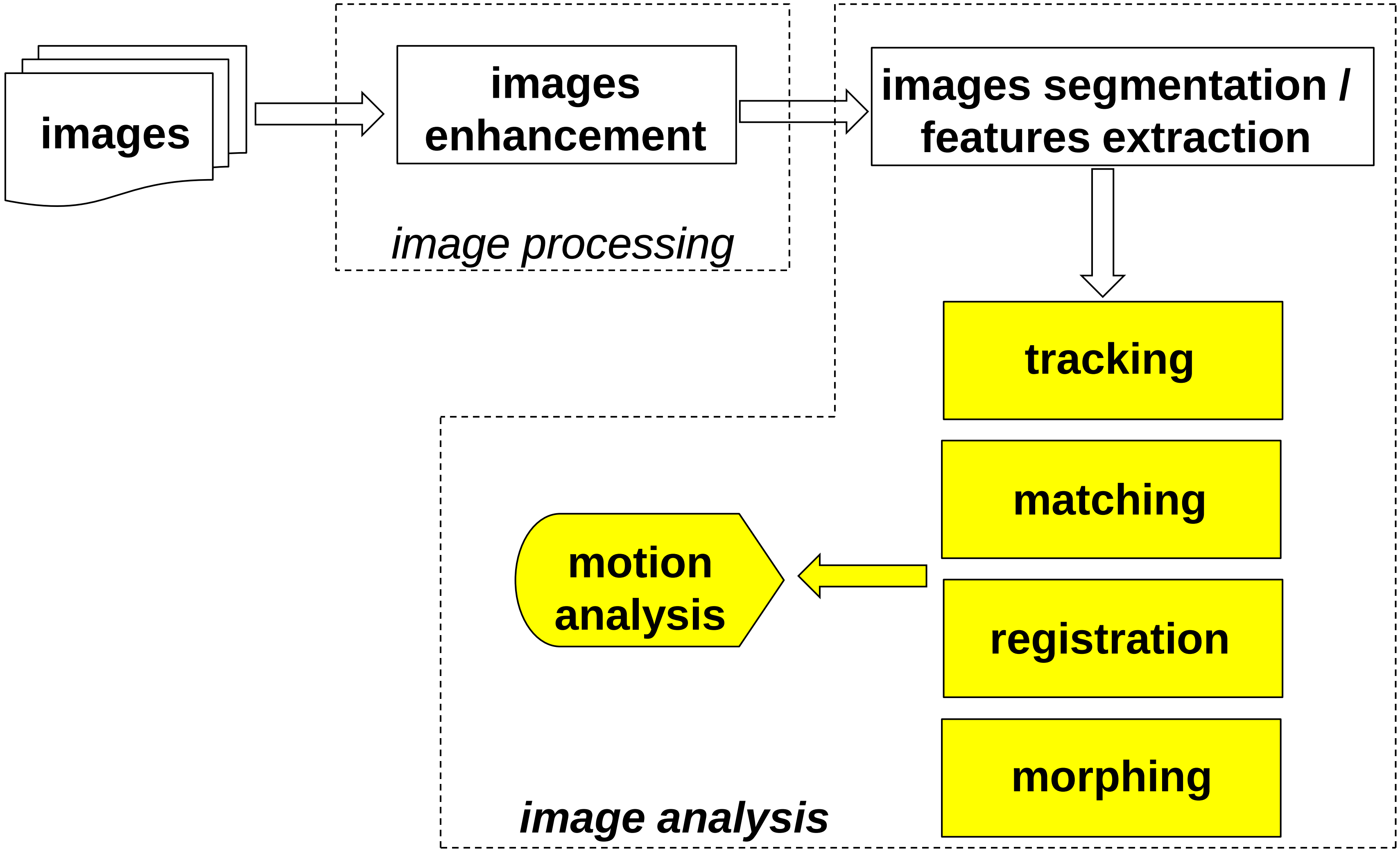
Original images ***Computational 3D model built voxelized and poligonized***

Azevedo et al. (2010), Three-dimensional reconstruction and characterization of human external shapes from two-dimensional images using volumetric methods, Computer Methods in Biomechanics and Biomedical Engineering 13(3): 359-369

Introduction

- Motion tracking and analysis of objects in images are topics of the most importance in Computational Vision
- Algorithms of motion tracking and analysis of objects in image sequences are frequently used, for example, in:
  - Medicine
  - Biology
  - Industry
  - Engineering
  - and Biomechanics
- Examples of common tasks involved in computational motion tracking and analysis of objects in images are:
  - noise removal
  - geometric correction
  - segmentation (2D/3D)
  - motion tracking and analysis, including matching, registration and morphing (2D-4D)

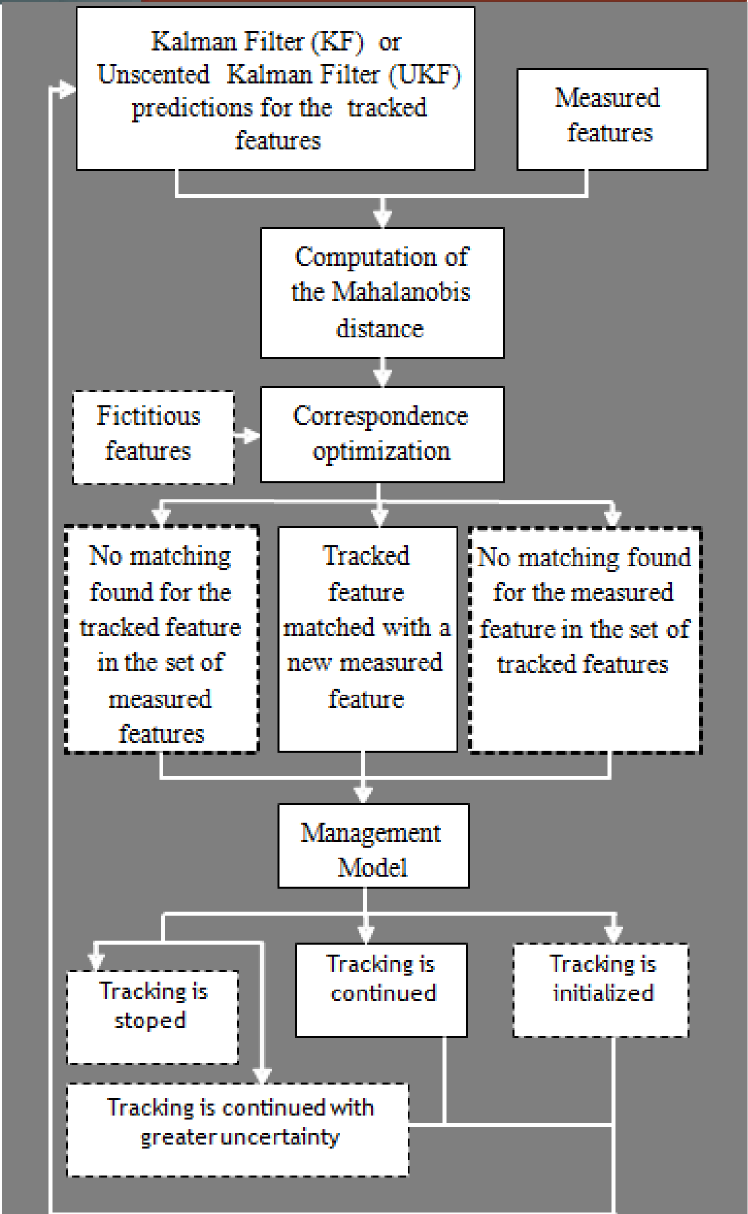
Introduction: Usual Computational Pipeline for Motion Tracking and Analysis



Motion Tracking

Motion Tracking

- Computational framework to track features in image sequences (Kalman Filter or Unscented Kalman Filter, optimization, Mahalanobis distance, management model)

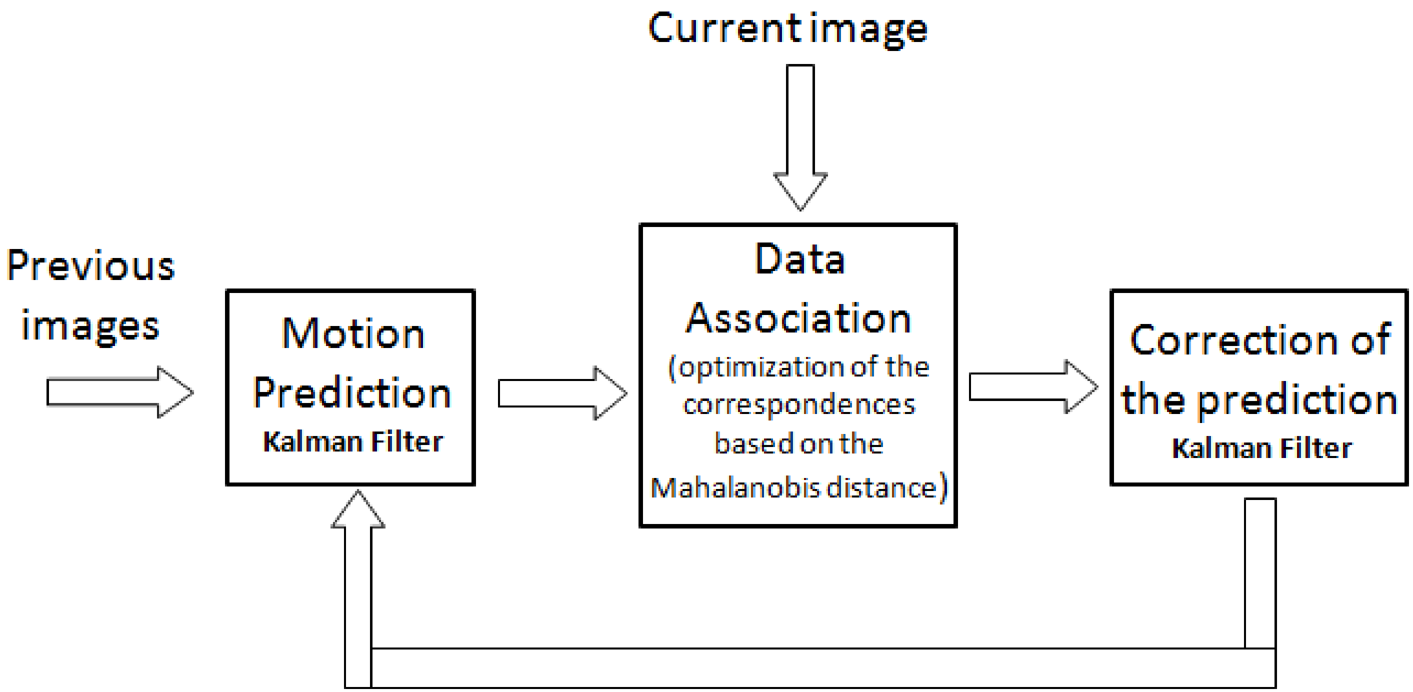


Pinho & Tavares (2009), Comparison between Kalman and Unscented Kalman Filters in Tracking Applications of Computational Vision, VipIMAGE 2009

Pinho & Tavares (2009), Tracking Features in Image Sequences with Kalman Filtering, Global Optimization, Mahalanobis Distance and a Management Model, Computer Modeling in Engineering & Sciences 46(1):51-75

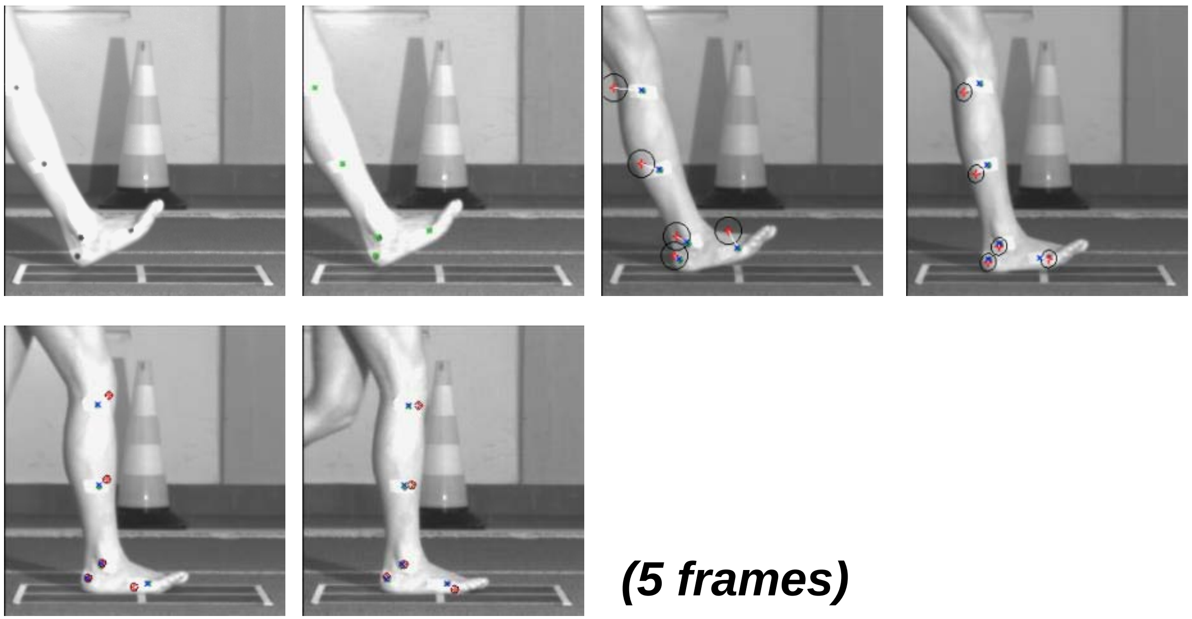
Motion Tracking

- Kalman Filter
  - Optimal recursive Bayesian stochastic method
  - One of its drawbacks is the restrictive assumption of Gaussian posterior density functions at every time step
    - Many tracking problems involve non-linear motions (i.e. human gait)



Motion Tracking

- Example: tracking marks in gait analysis (Kalman filter, Mahalanobis distance, optimization, management model)



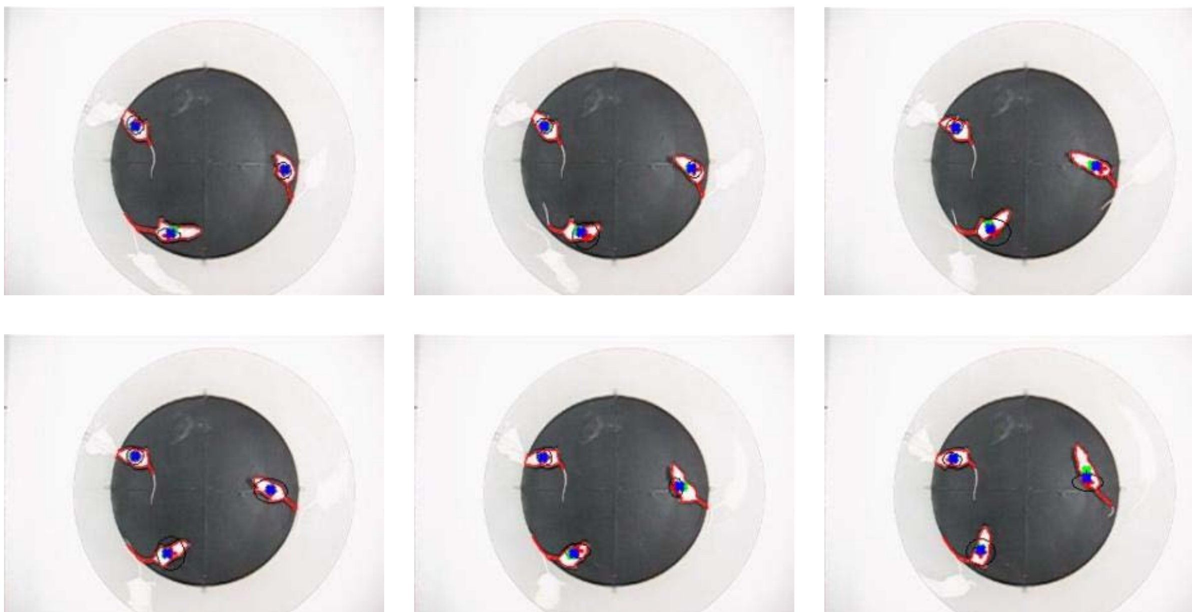
(5 frames)

Prediction **Uncertainty Area** **Measurement** **Correspondence** **Result**

Pinho et al. (2005), Human Movement Tracking and Analysis with Kalman Filtering and Global Optimization Techniques, ICCB 2005, 915-926
Pinho & Tavares (2009), Tracking Features in Image Sequences with Kalman Filtering, Global Optimization, Mahalanobis Distance and a Management Model, Computer Modeling in Engineering & Sciences 46(1):51-75

Motion Tracking

- Example: tracking mice in long image sequences (Kalman filter, Mahalanobis distance, optimization, management model)



(547 frames)

Pinho et al. (2005), A Movement Tracking Management Model with Kalman Filtering, Global Optimization Techniques and Mahalanobis Distance, LSCCS, Vol. 4A:463-466

Pinho et al. (2007), Efficient Approximation of the Mahalanobis Distance for Tracking with the Kalman Filter, International Journal of Simulation Modelling 6(2):84-92

Motion Tracking

- Unscented Kalman Filter
  - A set of sigma-points from the distribution of the state vector is propagated through the true nonlinearity, and the parameters of the Gaussian approximation are then re-estimated
  - Addresses the main shortcomings of the Kalman Filter, and of the Extended Kalman Filter, and is more suitable for nonlinear motions

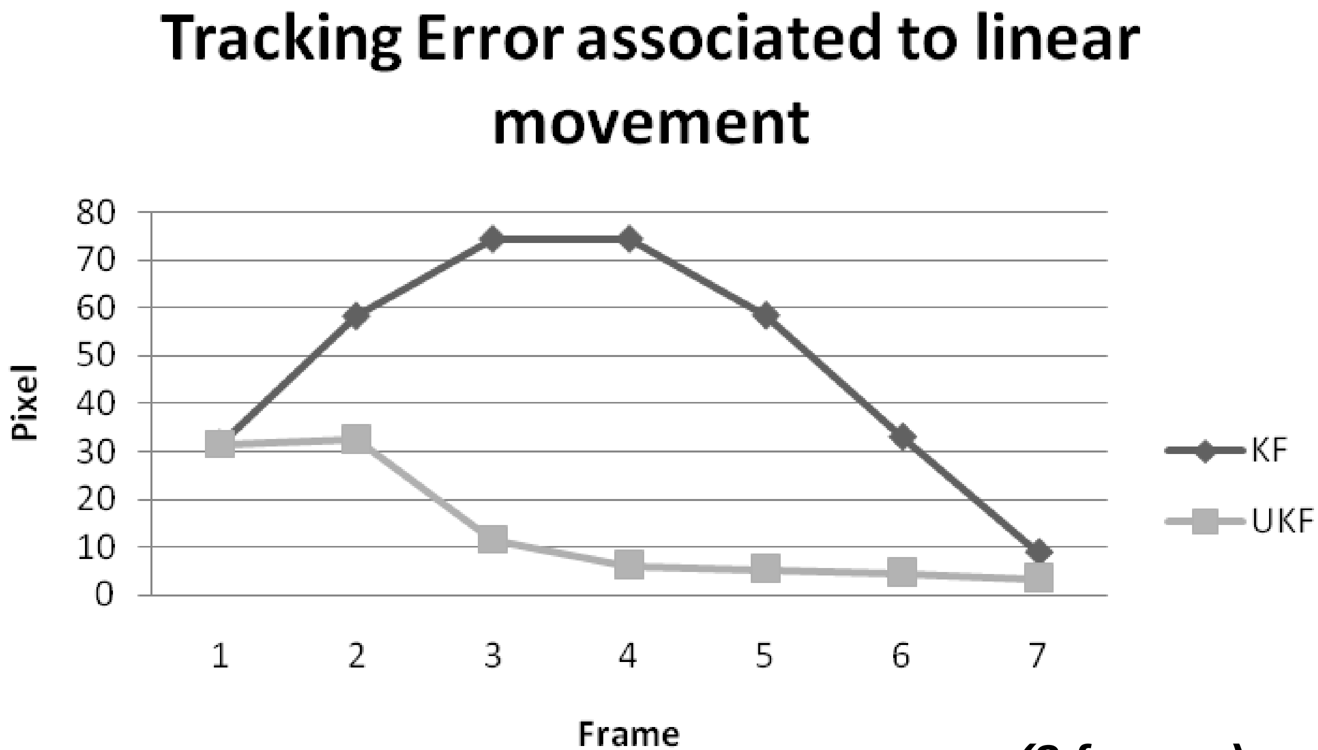
Motion Tracking

- Example: tracking the centre of a square that is moving according to a linear model (Kalman Filter (KF) and Unscented Kalman Filter (UKF))

Motion equations:

$$\begin{cases} x_i = x_{i-1} + 30 \\ y_i = y_{i-1} + 250 \end{cases},$$

with $x_0 = 5, y_0 = 250$

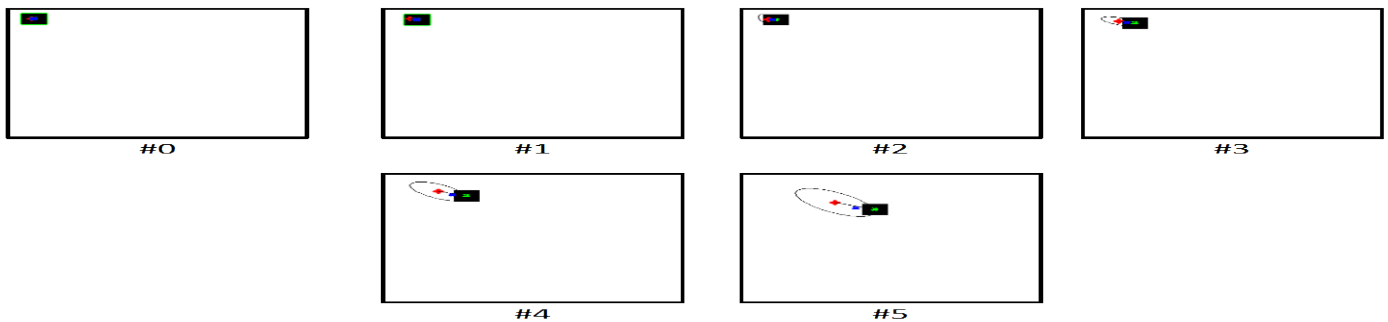


(8 frames)

Motion Tracking

- Example: tracking the centre of a square that is moving according to a nonlinear model (Kalman Filter (KF) and Unscented Kalman Filter (UKF))

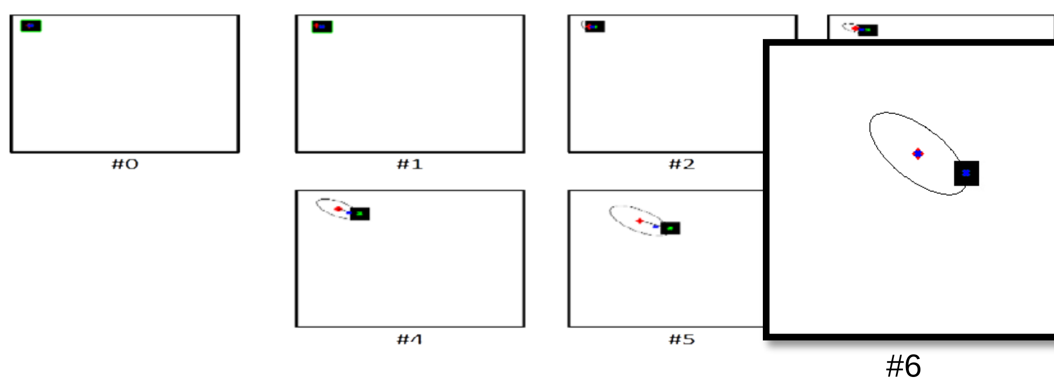
Kalman Filter results:



Motion equations:

$$\begin{cases} x_i = x_{i-1} + 2(i-1)^2 + 12.5 \\ y_i = x_{i-1} + 12.5 \end{cases},$$

with $x_0 = 6, y_0 = 10$



+ predictions
x measurements
x corrections

(8 frames)

Motion Tracking

- Example: tracking the centre of a square that is moving according to a nonlinear model (Kalman Filter (KF) and Unscented Kalman Filter (UKF)) – cont.

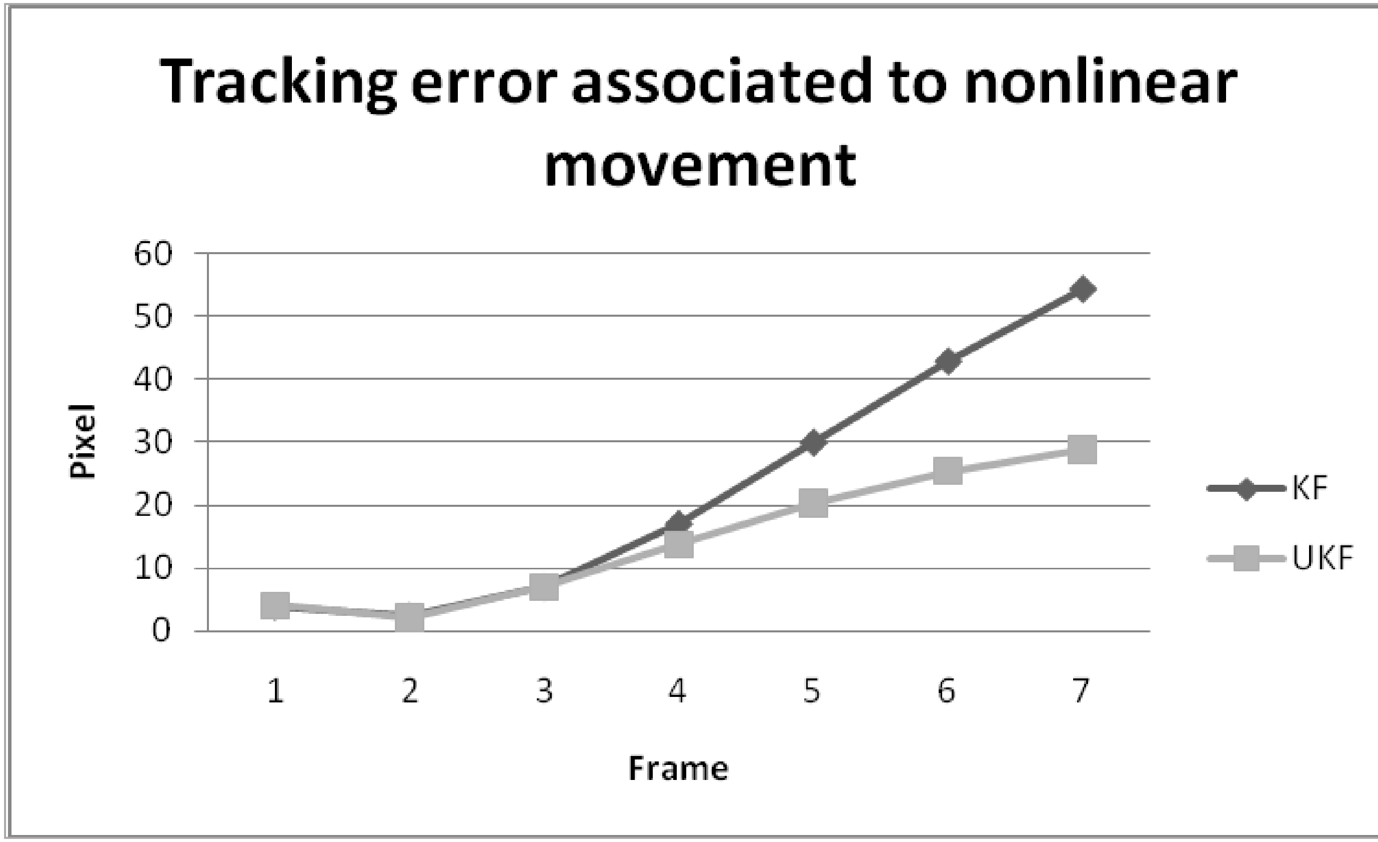
Motion equations:

$$\begin{cases} x_i = x_{i-1} + 2(i-1)^2 + 12.5 \\ y_i = x_{i-1} + 12.5 \end{cases},$$

with $x_0 = 6, y_0 = 10$

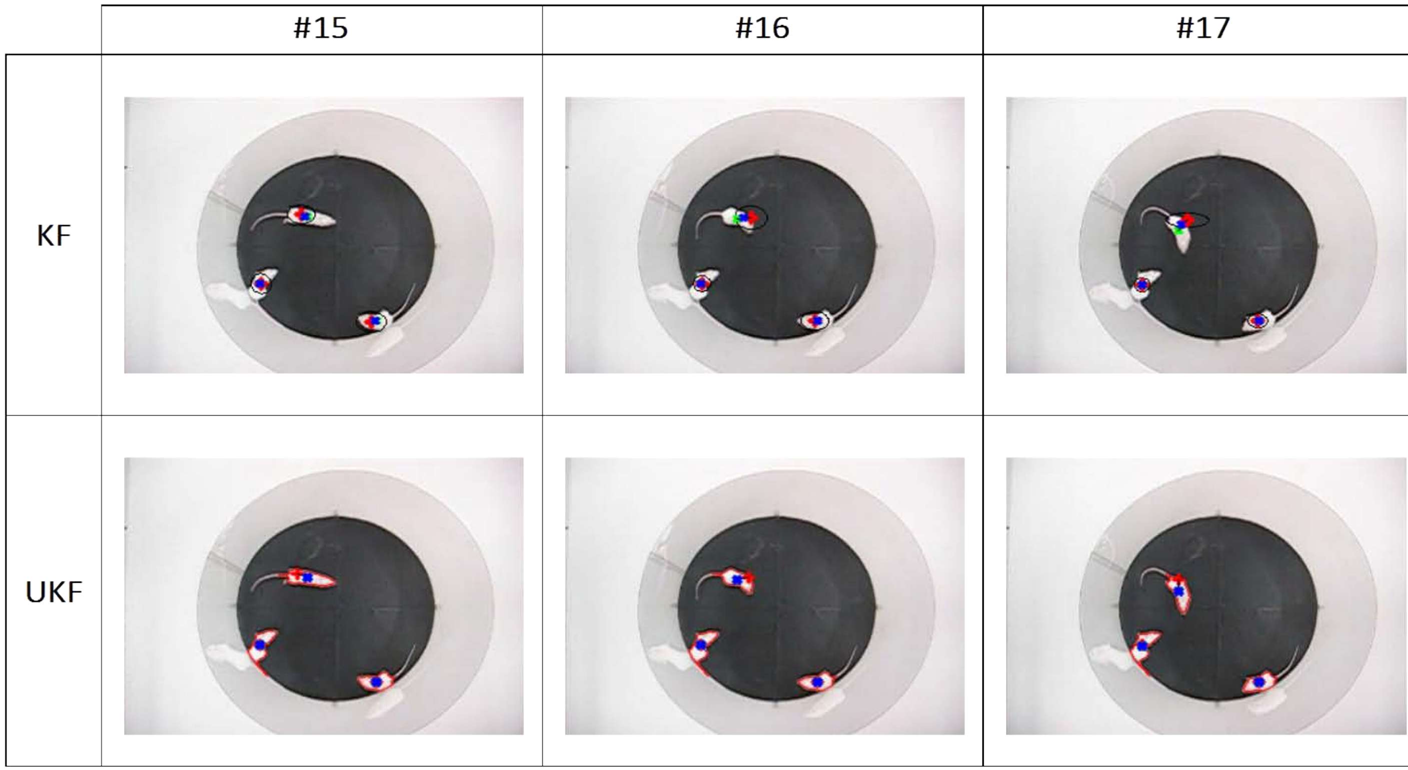
+ predictions
x measurements
x corrections

(8 frames)



Motion Tracking

- Example: tracking the motion of three mice in a real image sequence (Kalman Filter (KF) and Unscented Kalman Filter (UKF))

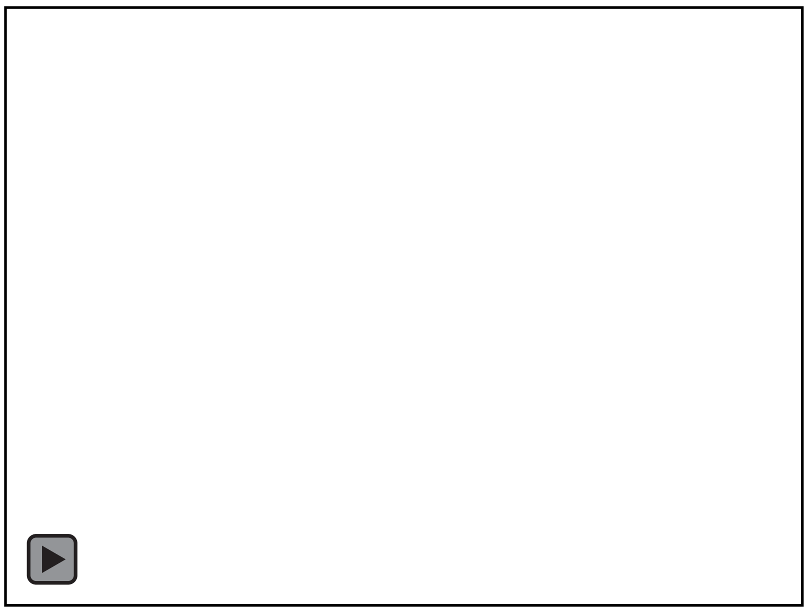


+ predictions
x measurements
x corrections

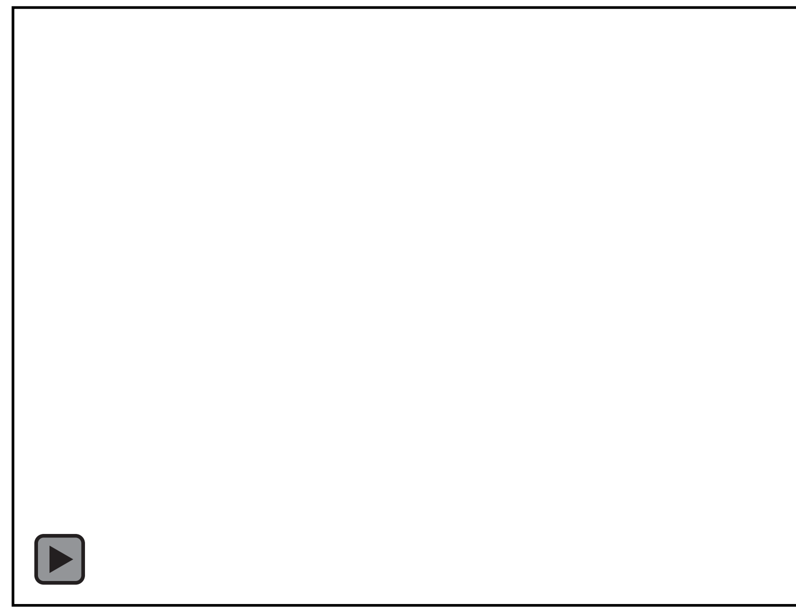
(22 frames)

Motion Tracking

- Example: tracking the motion of three mice in a real image sequence (Kalman Filter (KF) and Unscented Kalman Filter (UKF)) – cont.



Kalman Filter results

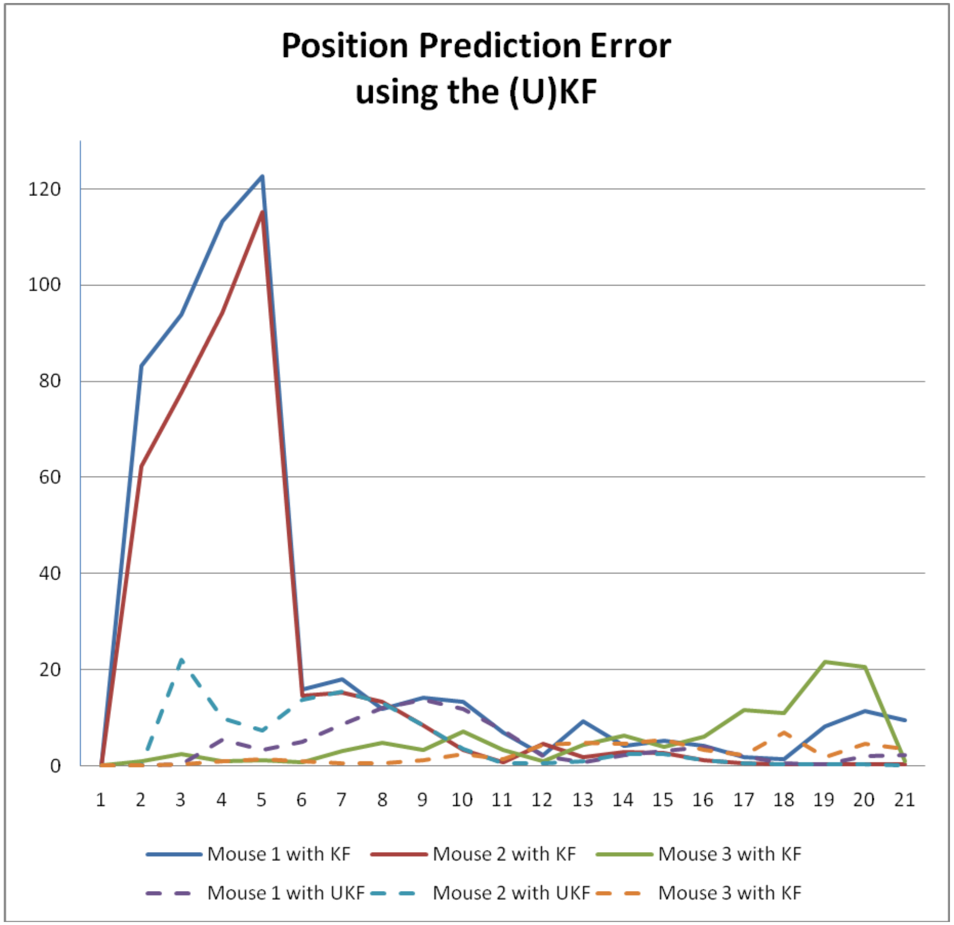


Unscented Kalman Filter results

(22 frames)

Motion Tracking

- Example: tracking the motion of three mice in a real image sequence (Kalman Filter (KF) and Unscented Kalman Filter (UKF)) – cont.



(22 frames)

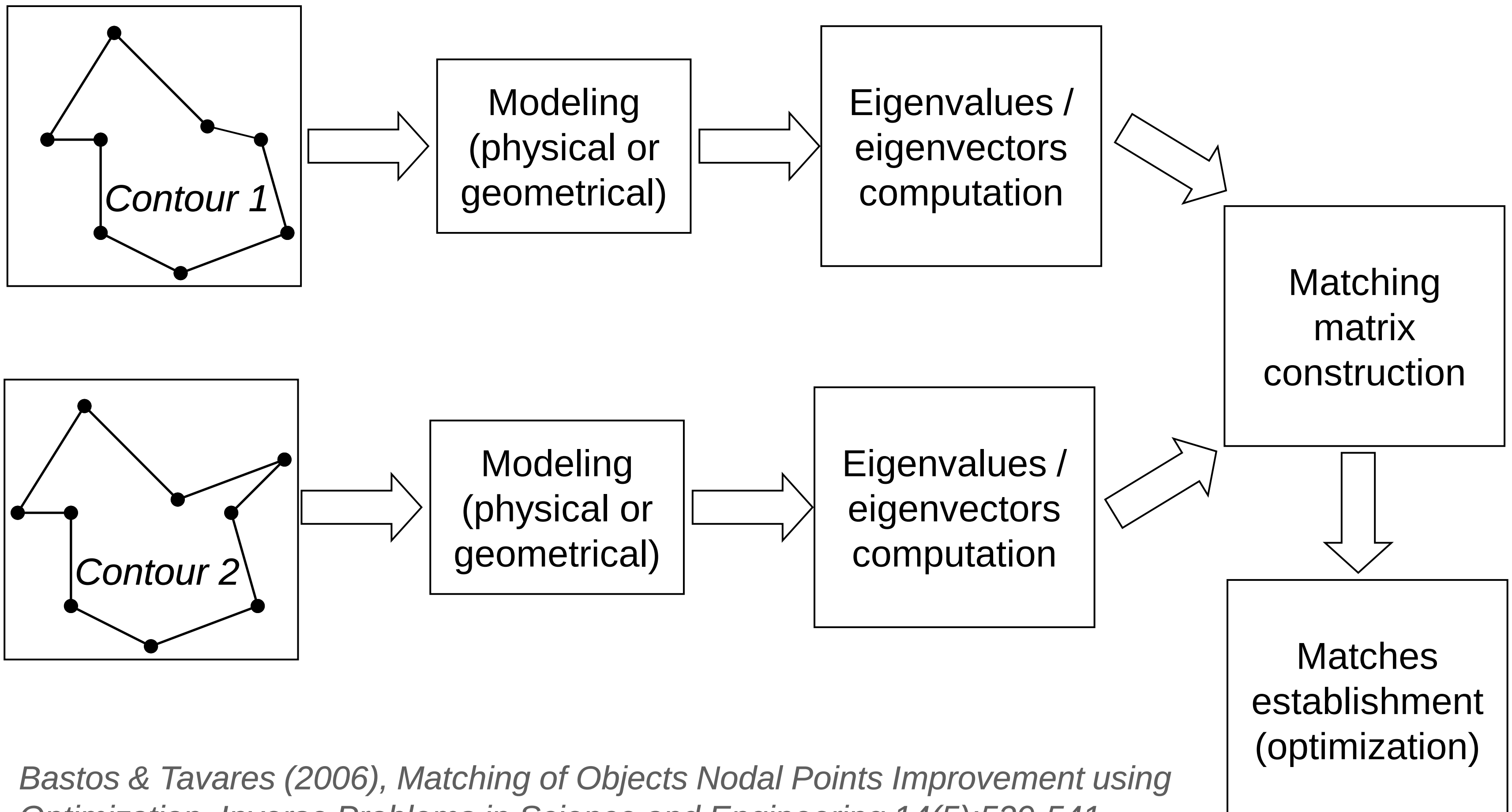
Motion Tracking

- Influence of the adopted filter: Kalman Filter (KF) and Unscented Kalman Filter (UKF)
  - If the motion is highly nonlinear, then the UKF justifies its superior computational load
  - Otherwise, the KF with the undertaken matching (association) methodology accomplishes efficiently the tracking
  - Hence, the decision between KF or UKF is application dependent
    - Frequently, the UKF gets superior results
    - However, when the computational load is somewhat constrained, the KF with a suitable matching strategy can be a good tracking solution

Motion Analysis: Matching, Registration and Morphing of Objects

Matching of Objects

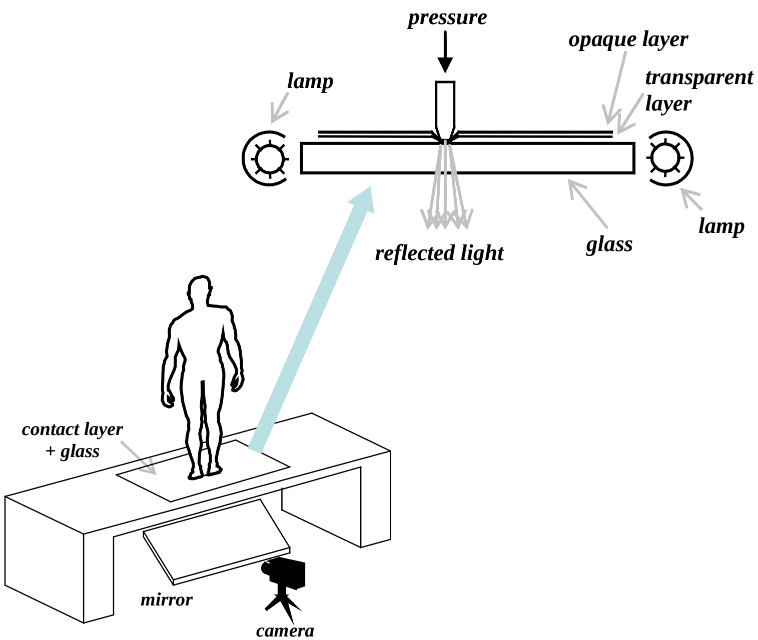
- Using physical or geometrical modeling and modal matching

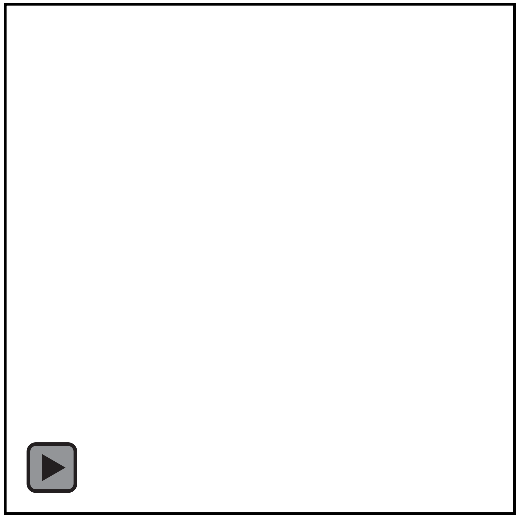


Bastos & Tavares (2006), Matching of Objects Nodal Points Improvement using Optimization, Inverse Problems in Science and Engineering 14(5):529-541

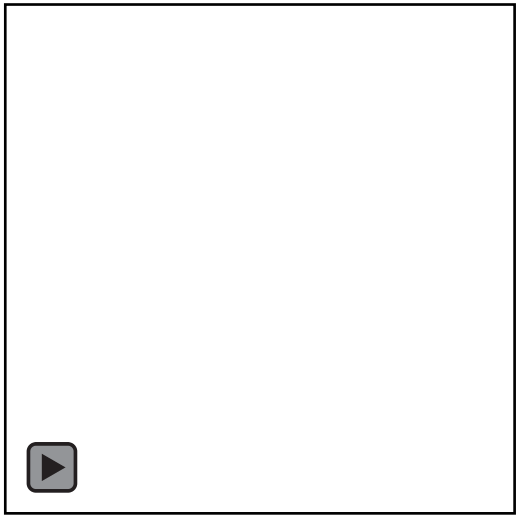
Matching of Objects

- Example: matching contours in dynamic pedobarography (FEM, modal matching, optimization)





Original images



Matched contours

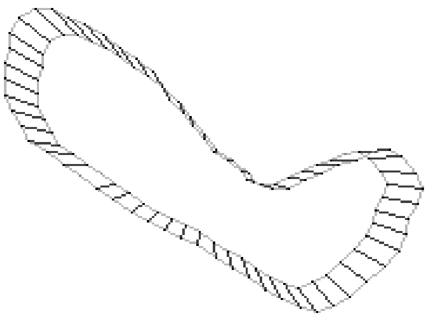
Bastos & Tavares (2004), Improvement of Modal Matching Image Objects in Dynamic Pedobarography using Optimization Techniques, Lecture Notes in Computer Science 3179:39-50

Tavares & Bastos (2010), Improvement of Modal Matching Image Objects in Dynamic Pedobarography using Optimization Techniques, Progress in Computer Vision and Image Analysis, Chapter 19, 339-368

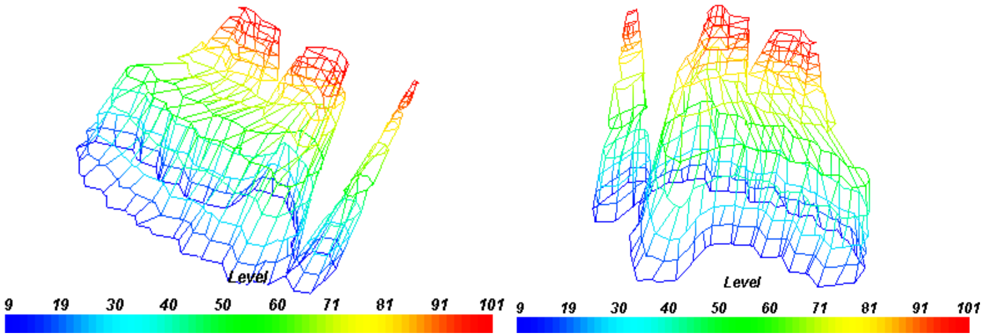
Matching of Objects

- Example: matching contours and surfaces in dynamic pedobarography (FEM, modal analysis, optimization)

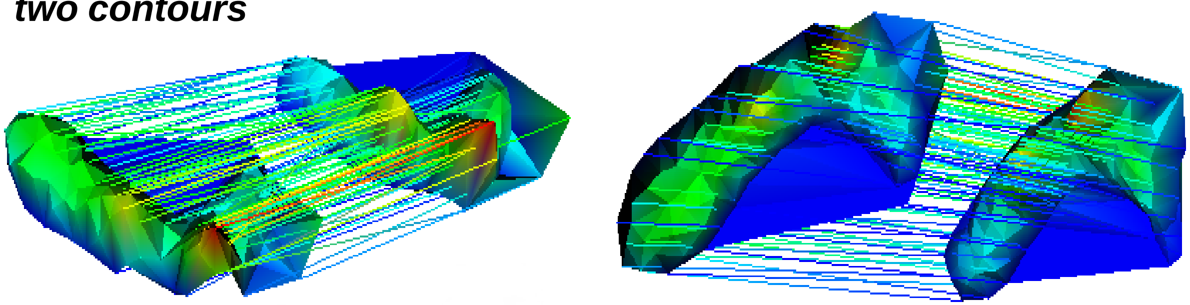
Image of dynamic pedobarography



Matching found between two contours



Matching found between iso-contours (two views)

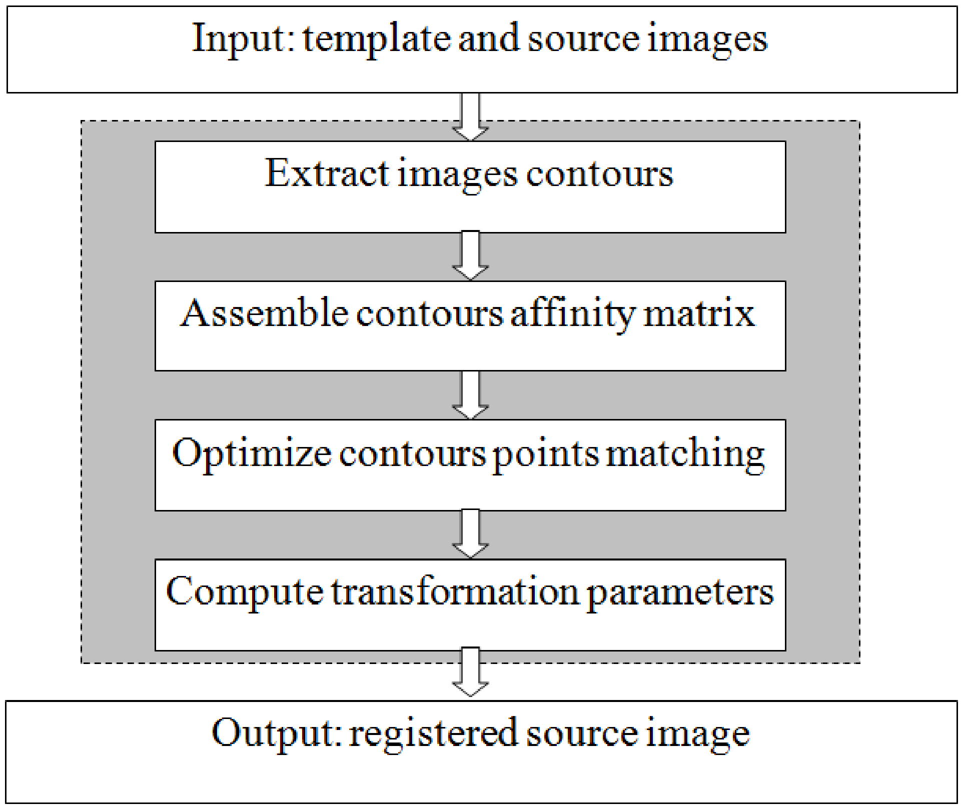


Matching found between two intensity (pressure) surfaces (two views)

Tavares & Bastos (2005), Improvement of Modal Matching Image Objects in Dynamic Pedobarography using Optimization Techniques, Electronic Letters on Computer Vision and Image Analysis 5(3):1-20

Registration of Objects

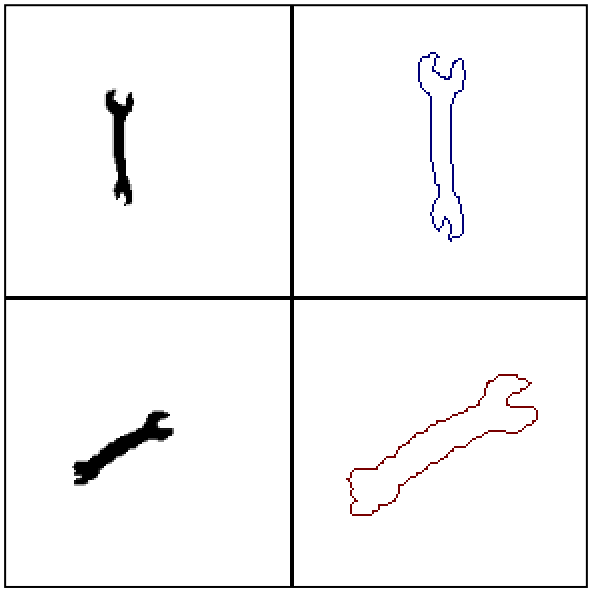
- Registration of contours in images (geometrical modeling, optimization, dynamic programming)



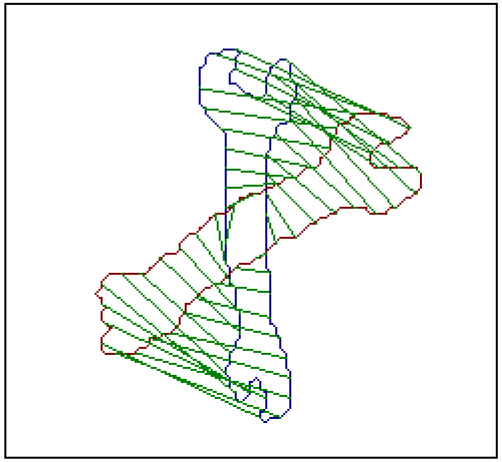
Oliveira & Tavares (2008), Algorithm of dynamic programming for optimization of the global matching between two contours defined by ordered points, Computer Modeling in Engineering & Sciences 31(11):1-11

Registration of Objects

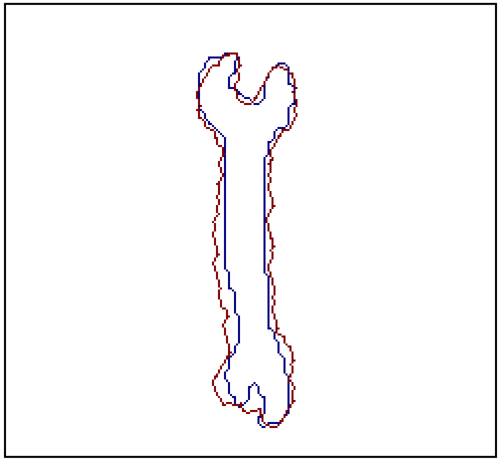
- Example: registration of contours in images (geometrical modeling, optimization, dynamic programming)



Original images and contours



Matched contours before registration

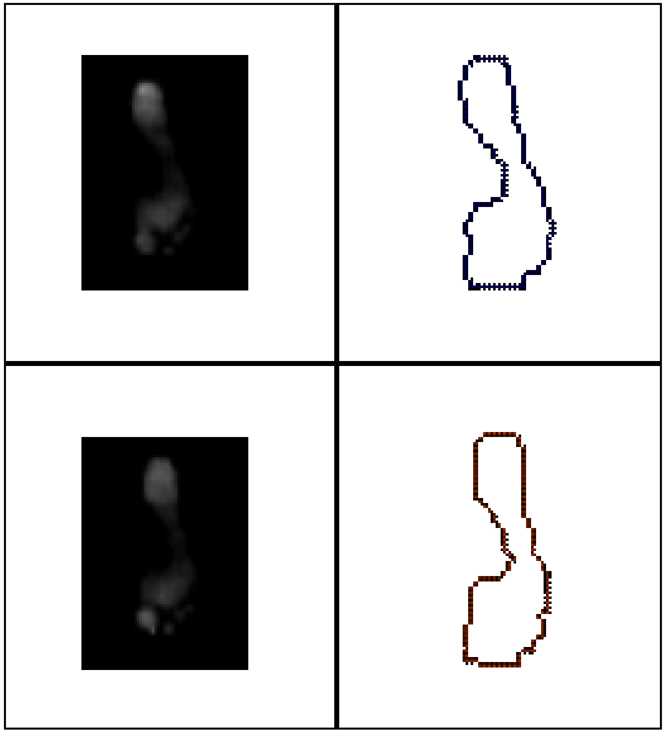


Matched contours after registration

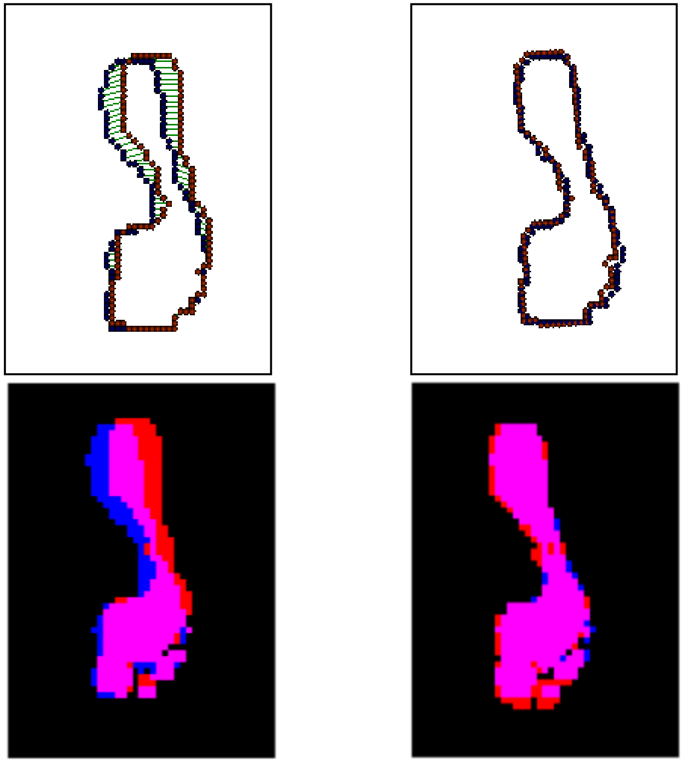
Oliveira & Tavares (2009), Matching Contours in Images through the use of Curvature, Distance to Centroid and Global Optimization with Order-Preserving Constraint, Computer Modeling in Engineering & Sciences 43(1):91-110

Registration of Objects

- Example: registration of images in pedobarography
  (geometrical modeling, optimization, dynamic programming)



Original images and contours

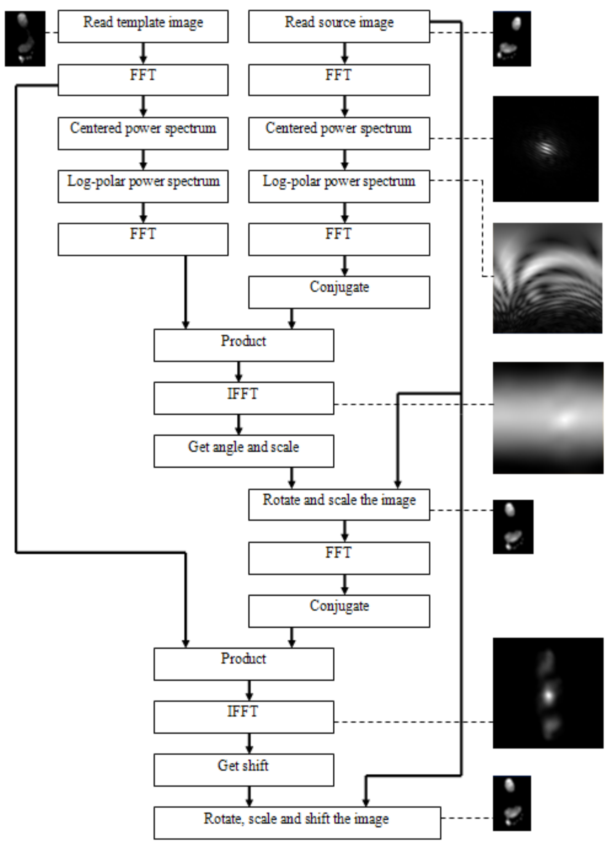


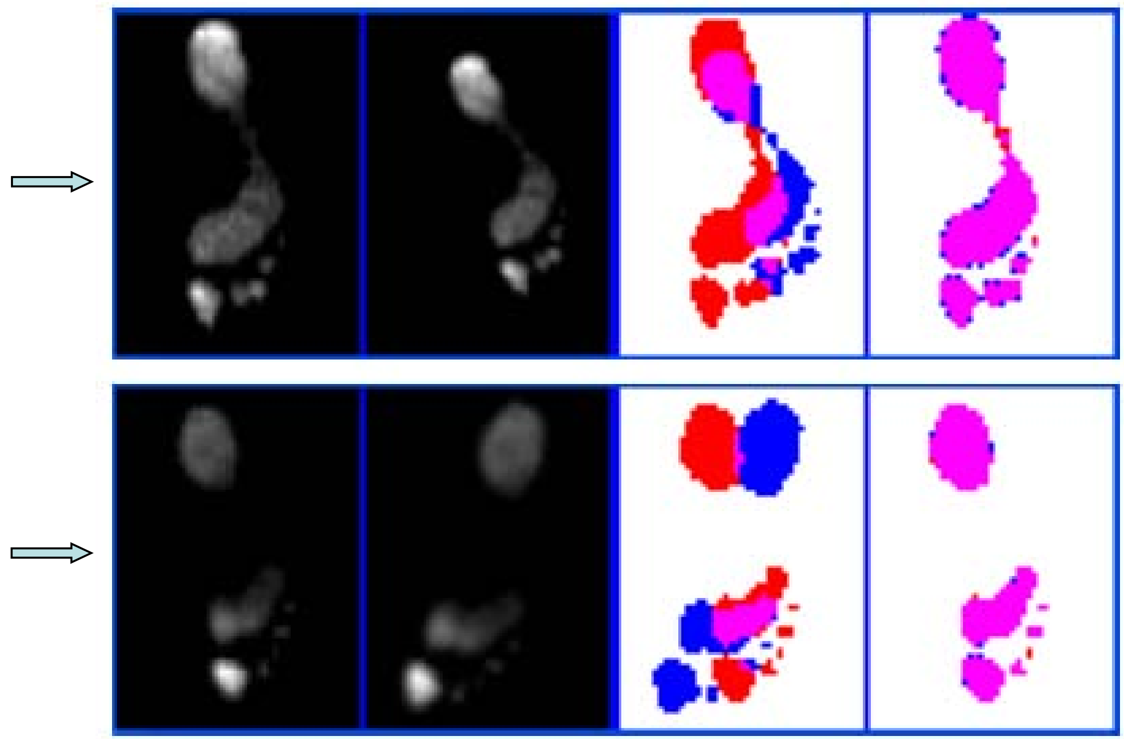
Contours and images before and after registration

Oliveira et al. (2009), Rapid pedobarographic image registration based on contour curvature and optimization, Journal of Biomechanics 42(15):2620-2623

Registration of Objects

- Example: registration of images in pedobarography (Fourier transform)



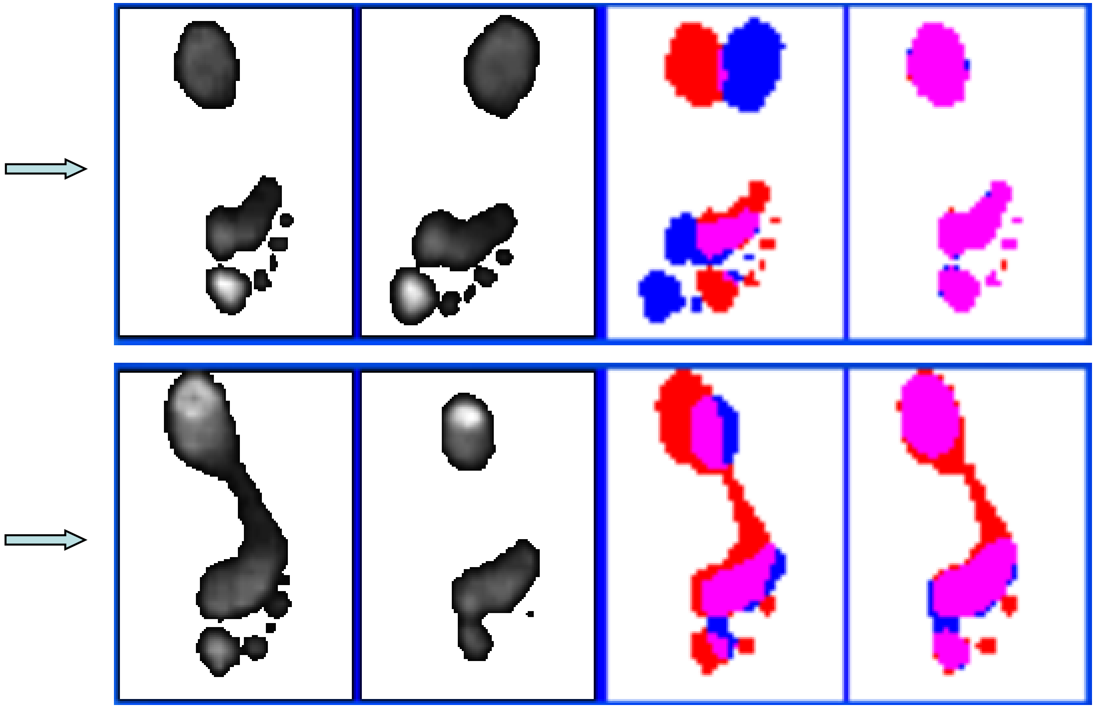


Original images ***Images before and after registration***

Oliveira et al. 2010, Registration of pedobarographic image data in the frequency domain, Computer Methods in Biomechanics and Biomedical Engineering (in press)

Registration of Objects

- Example: registration of images in pedobarography (Hybrid method: Contours registration or Fourier transform based registration + Optimization of a Similarity Measure – MSE, MI or XOR)

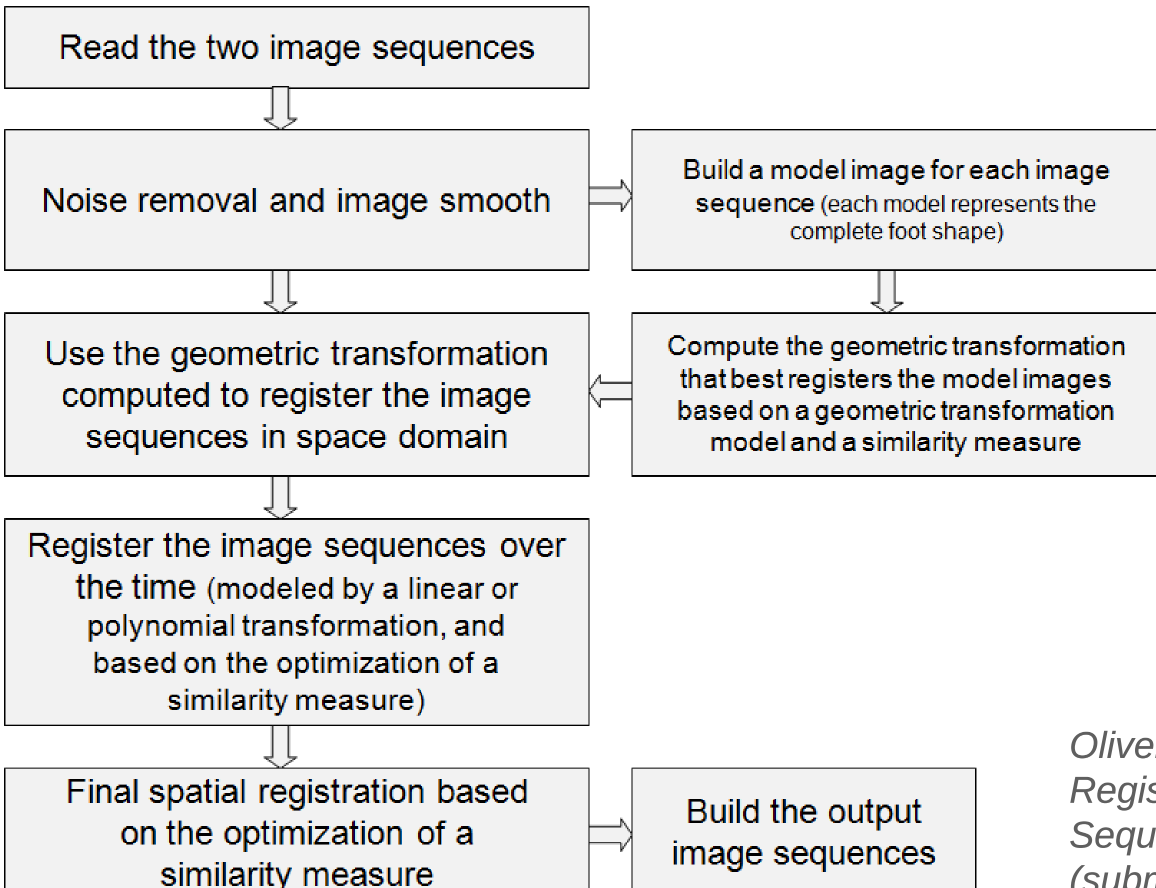


Original images ***Images before and after registration***

Oliveira & Tavares 2010, Novel Framework for Registration of Pedobarographic Image Data, Medical & Biological Engineering & Computing (submitted)

Registration of Objects

- Registration of image sequences in dynamic pedobarography (spatial and temporal registration)



Oliveira & Tavares 2010, Spatio-temporal Registration of Pedobarographic Image Sequences, Journal of Biomechanics (submitted)

Registration of Objects

- Example: registration of image sequences in dynamic pedobarography (spatial and temporal registration)

Original image sequences

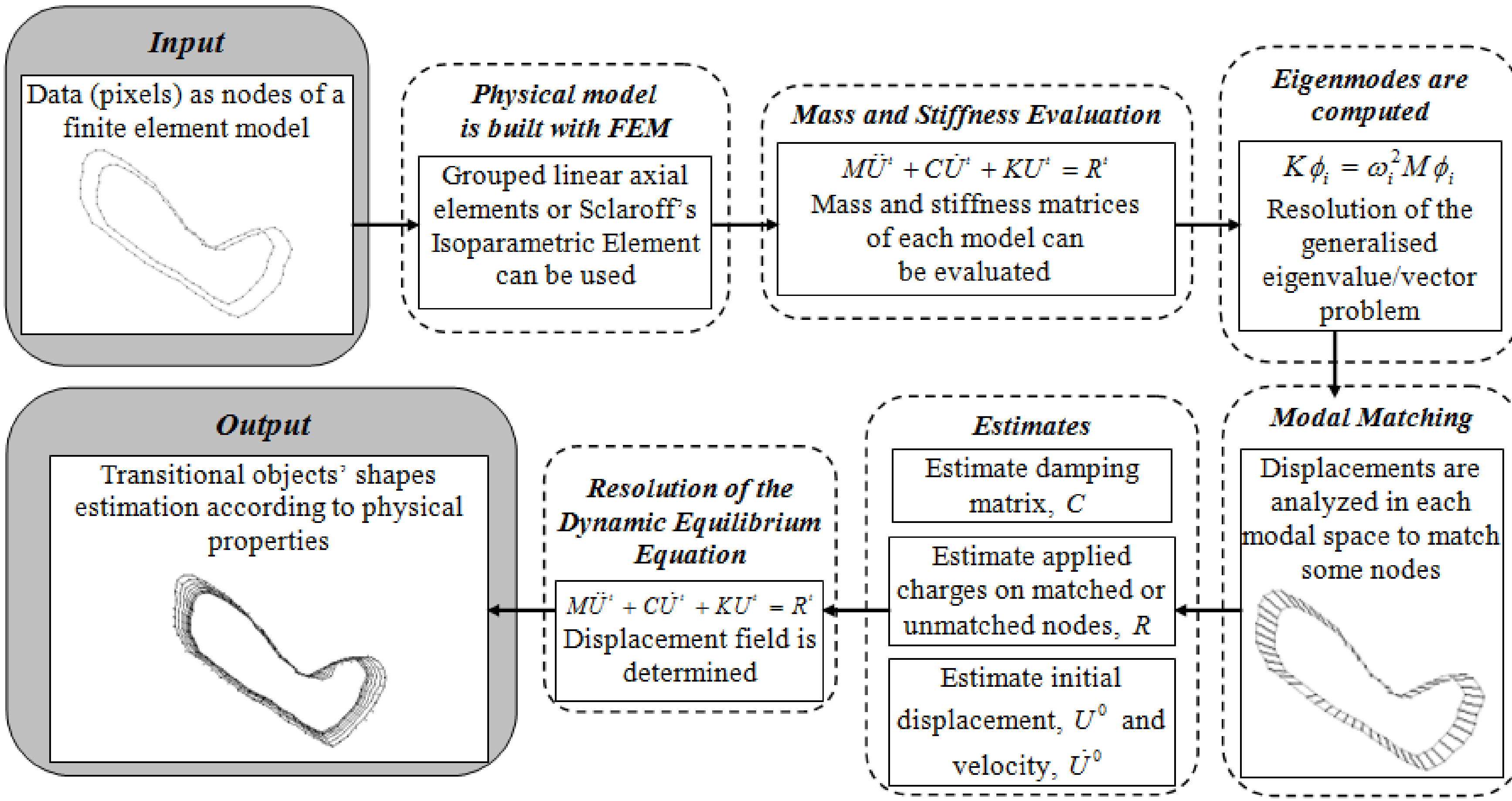
Original sequences before registration

Preprocessed sequences

Sequences after registration

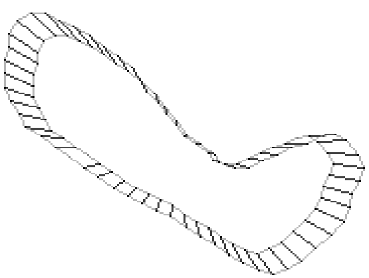
Morphing of Objects

- Physical morphing/simulation of contours in images (FEM, modal analysis, optimization, Lagrange equation)



Morphing of Objects

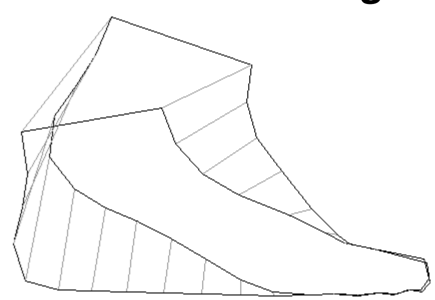
- Example: morphing contours in images (FEM, modal analysis, optimization, Lagrange equation)



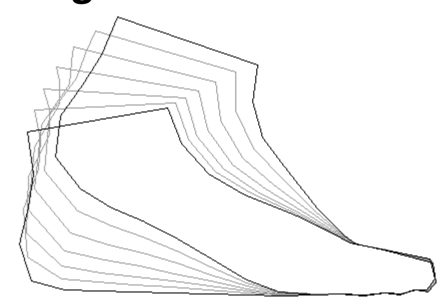
Contours matched

Estimated deformations

Original images



Matching found



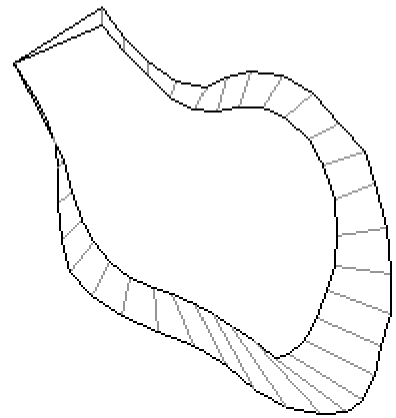
Estimated deformations

Tavares & Pinho (2005), Estimação Temporal da Deformação entre Objectos utilizando uma Metodologia Física, InfoComp 4(1):9-18

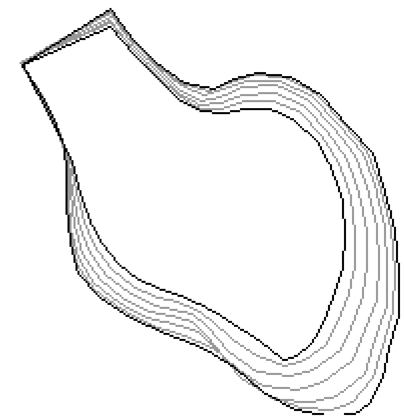
Gonçalves et al. (2008), Segmentation and Simulation of Objects Represented in Images using Physical Principles, Computer Modeling in Engineering & Sciences 32(1):45-55

Morphing of Objects

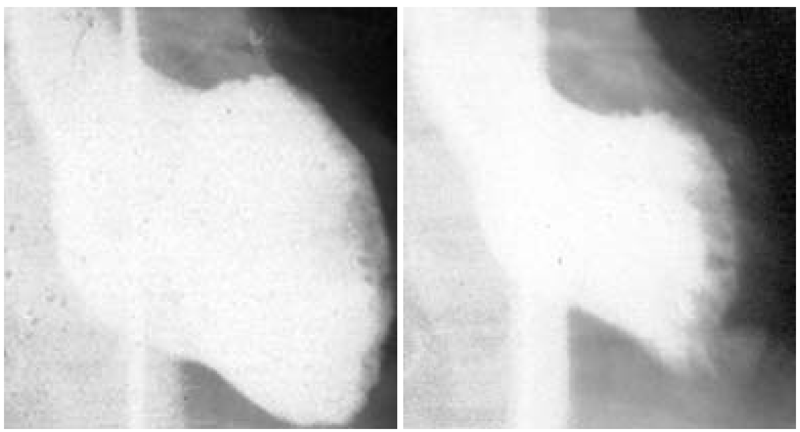
- Example: morphing contours in images (FEM, modal analysis, optimization, Lagrange equation)



Matching found



Deformations estimated



Original images

Gonçalves et al. (2008), Segmentation and Simulation of Objects Represented in Images using Physical Principles, Computer Modeling in Engineering & Sciences 32(1):45-55

Research Team (Computational Vision)

Research Team (Computational Vision)

- PhD students (15):
  - In course: Raquel Pinho, Patrícia Gonçalves, Maria Vasconcelos, Ilda Reis, Teresa Azevedo, Daniel Moura, Zhen Ma, Elza Chagas, Victor Albuquerque, Francisco Oliveira, Eduardo Ribeiro, António Gomes, João Nunes, Alex Araujo, Sandra Rua
- MSc students (13):
  - In course: Carlos Faria, Elisa Barroso, Ana Jesus, Veronica Marques, Diogo Faria
  - Finished: Daniela Sousa, Francisco Oliveira, Teresa Azevedo, Maria Vasconcelos, Raquel Pinho, Luísa Bastos, Cândida Coelho, Jorge Gonçalves
- BSc students (2)
  - Finished: Ricardo Ferreira, Soraia Pimenta

Conclusions and Future Work

Conclusions and Future Work

- The motion tracking and analysis of objects in image sequences is a very complex task, but of raised importance in many domains
- Numerous hard challenges exist, as for example, objects with topological variations, complex motions, occlusions, adverse conditions in the image acquisition process, etc.
- Considerable work has already been developed, but important and complex goals still to be reached
- Methods and methodologies of other research areas, as of Mathematics, Computational Mechanics, Medicine and Biology, can contribute significantly for their attainment
- For that, **collaborations are welcome**

Thank you!

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