Classification of gait data

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- Human Dynamics and Multimodal Interaction Lab
- Human Motion Lab
- Human Seeing Lab
- Human Facial Modeling Lab
- Human Microexpression Lab
- Wearable Technologies

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Gait

Periodic sequence of moves of lower limbs resulting in person motion

Classification of gait data

- Person identification
- Pose recognition
- Motion/action recognition
- Diagnosis of neurological / orthopedic disorders
- Rehabilitation / training monitioring
- Estimation of therapeutic / training gain
- Therapy / training scheduling

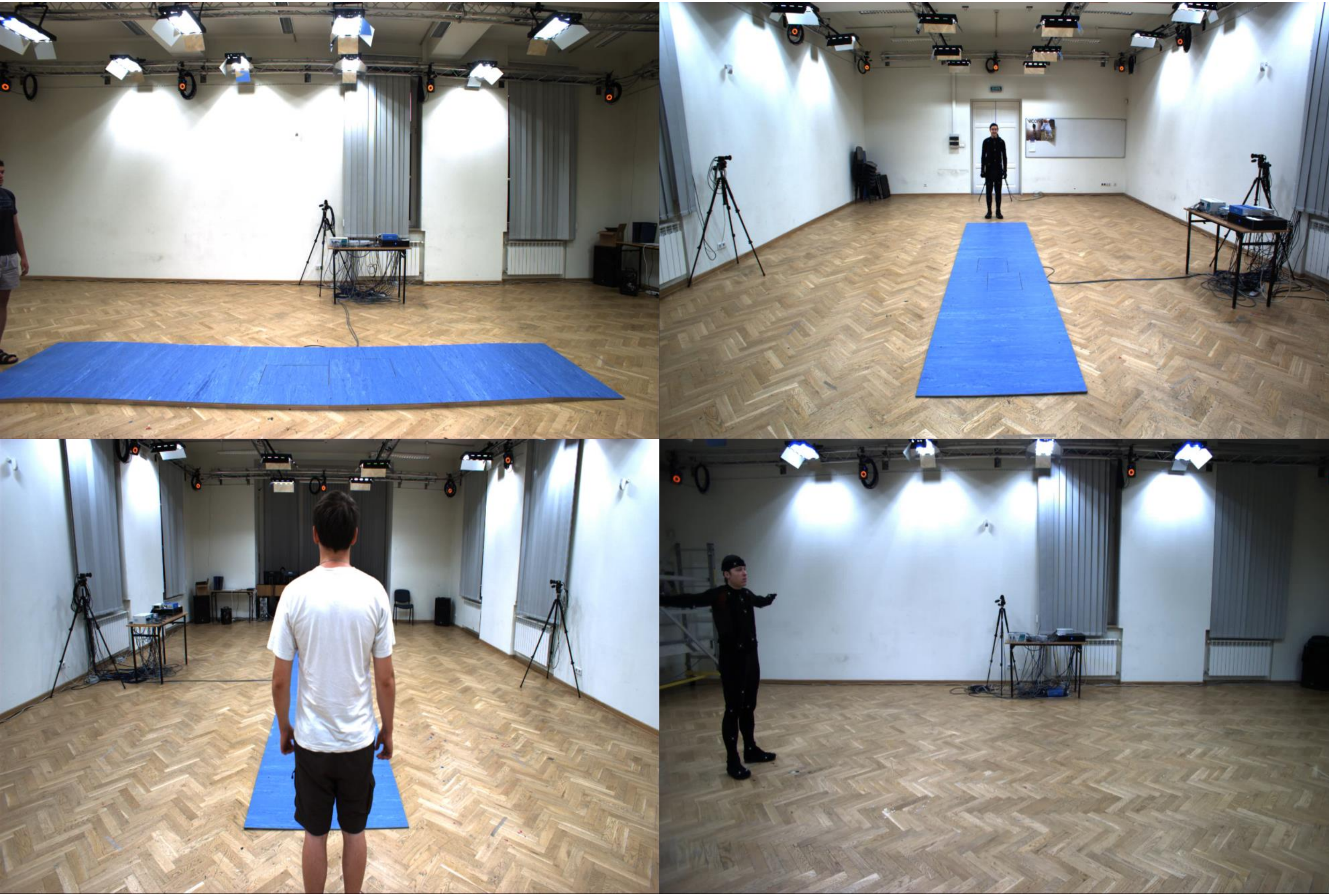
Aim

Show a spectrum of issues / problems related to gait description, platforms of gait recording / mapping / measuring, models of gait kinematics and dynamics, classification of gait data

Plan

- Gait, measurements platforms, databases
- Gait models, kinematic, cyclic, dynamic
- Features for gait classification
- Results of gait classification
- Summary / conclusions

Gait



Gait – body parts

- The neuromuscular and skeletal system
- skeletal system - skeleton:
- axial part of the skeleton - (spine, skull, chest)
- limbs - allow locomotion (lower limbs supported by the activity of the trunk and upper limbs)
- movable joints of individual bones
- ligaments - structures supporting joints
- Muscles controlled by the nervous system – driving system

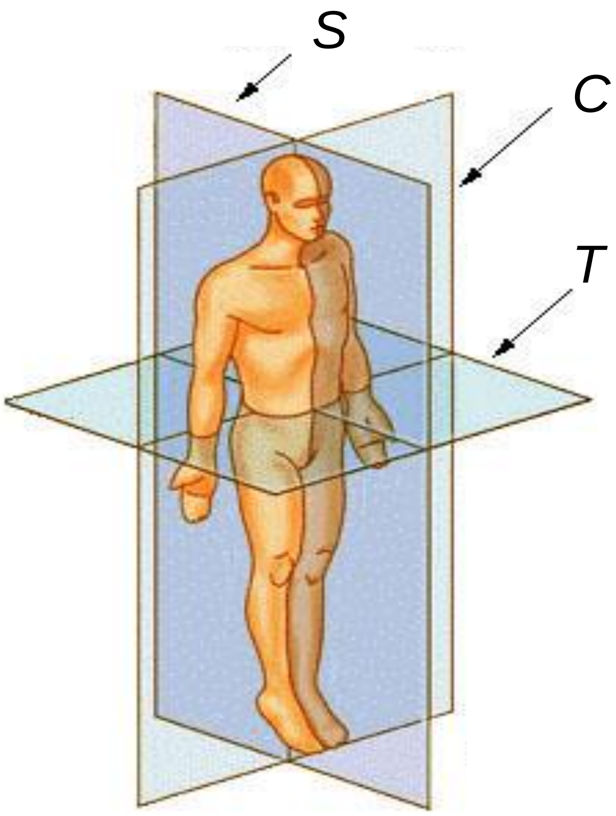
N. A. Bernstein, *The co-ordination and regulation of movements*, 1967

Gait, control

- Motion control and regulation system:
- central nervous system – brain (cerebral cortex, cerebellum), spinal cord
  - peripheral nervous system
  - muscular system (effectors)
  - receptors - in mechanics of motion the most important are: muscle, joint and skin mechanoreceptors as well as telereceptors: sight, other senses, deep feeling, vestibular system
  - Central generator of locomotion
  - Locomotion patterns of muscle activity
  - Neuromuscular coordination

Gait, geometry

- Layout of the main body planes:
  - *sagittal* (*S*)
  - *coronal* (*C*)
  - *transversal* (*T*)
- Locomotion moves mainly in the sagittal plane
- Moves:
  - in the sagittal plane: flexion / extension
  - in the coronal plane: adduction / abduction
  - in the transversal plane: rotations

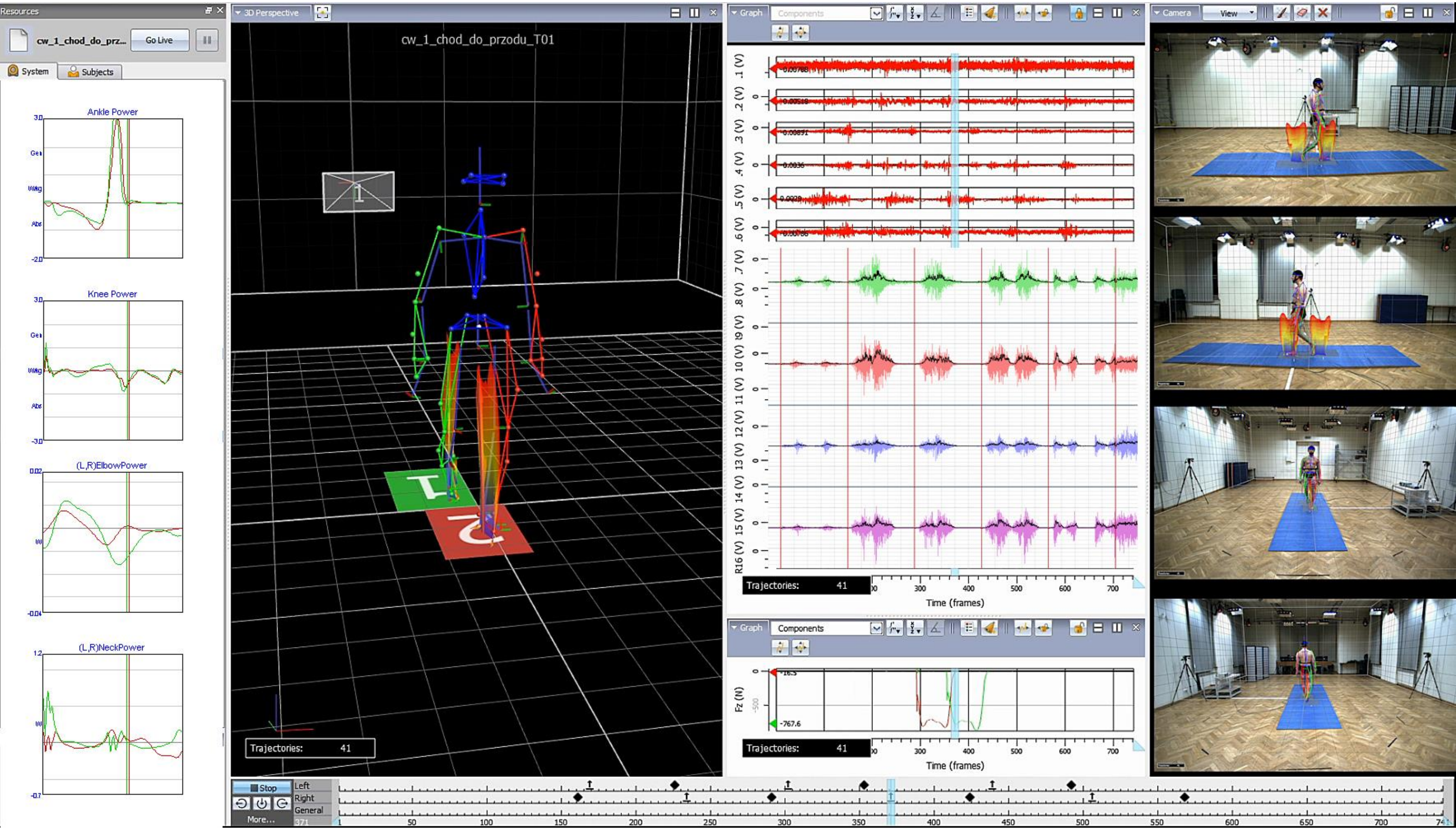


https://courses.lumenlearning.com/boundless-ap/chapter/mapping-the-body/

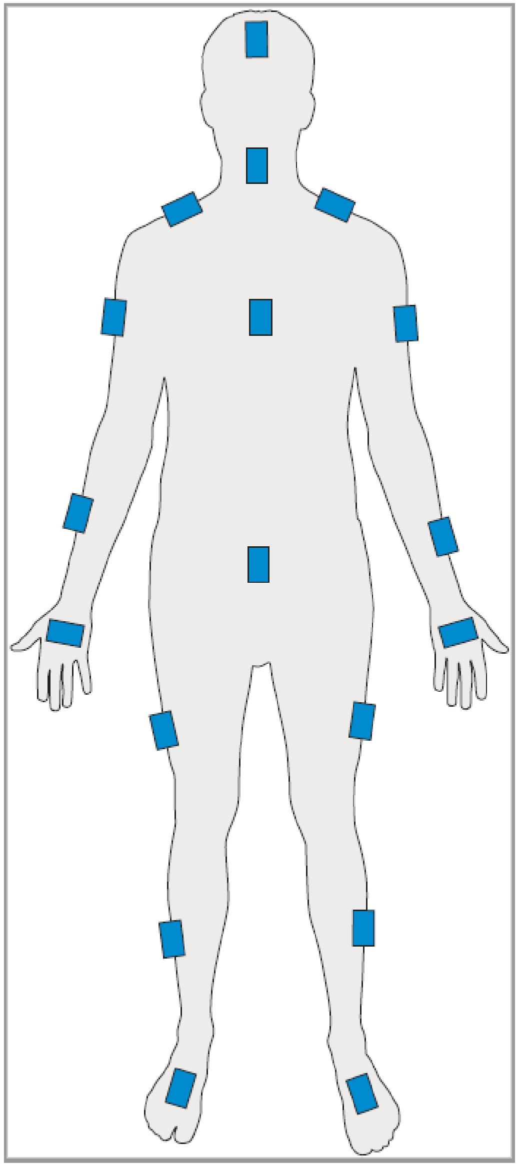
Gait measurement systems

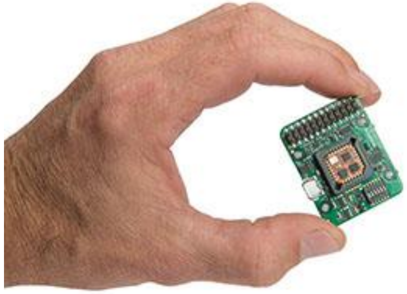
Video recording systems

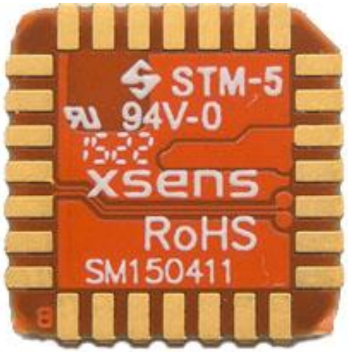
Marker systems + multi-modal measurements



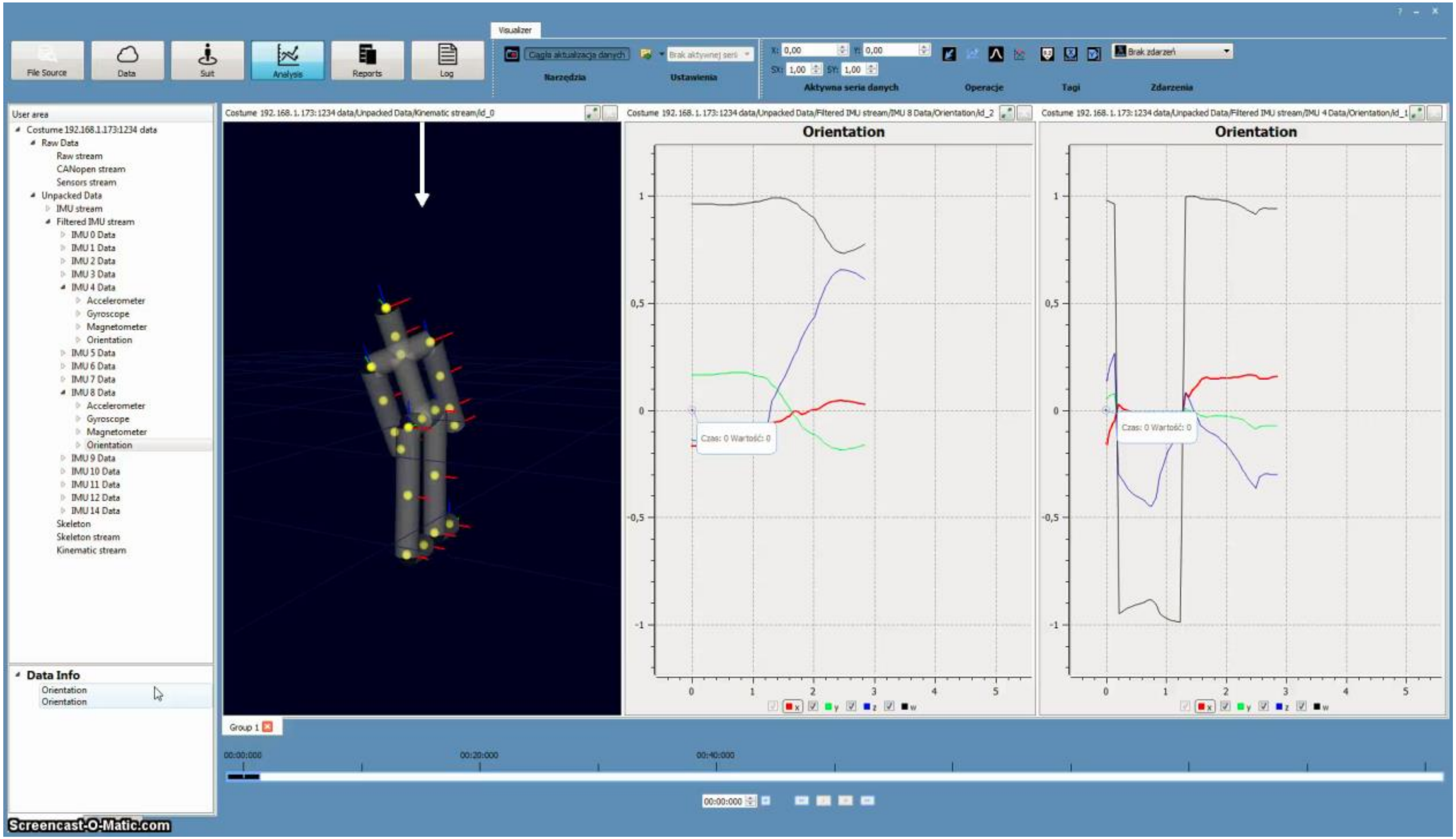
Sensor systems, IMU







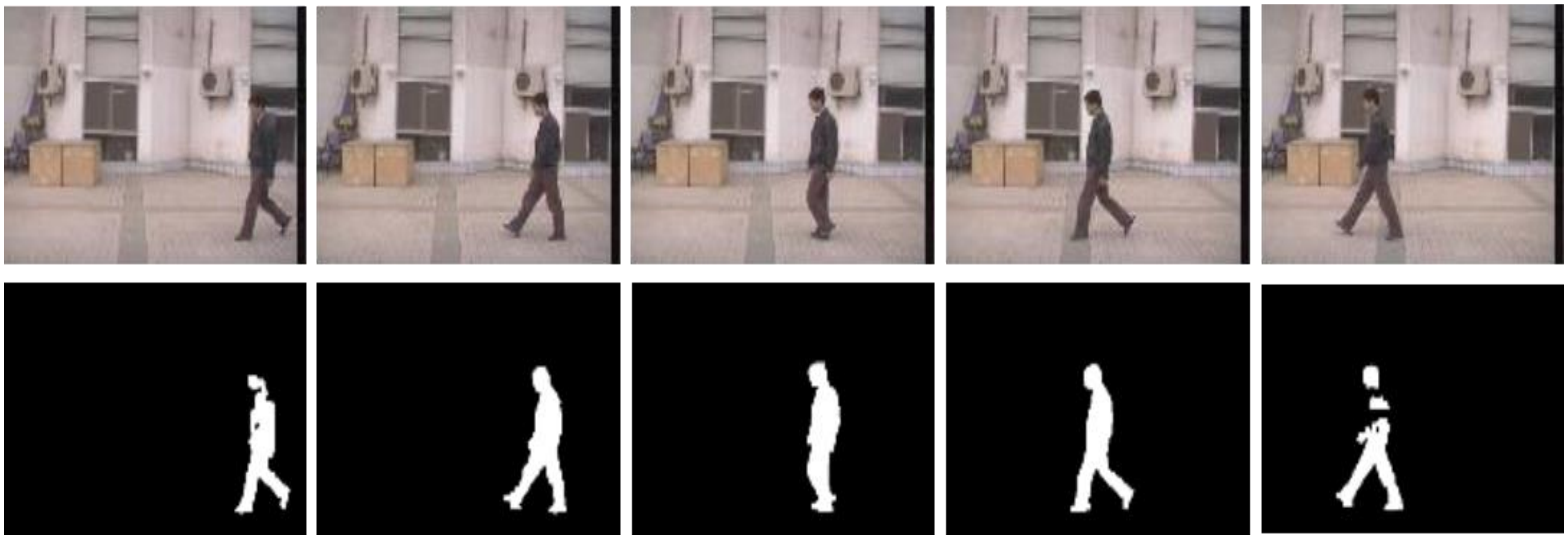
Sensor systems, IMU



Gait data / databases

Gait databases, CASIA

Video recordings Person identification



Liang Wang, Huazhong Ning, Weiming Hu, Tieniu Tan, A New Attempt to Gait-based Human Identification, International Conference on Pattern Recognition (ICPR), Vol. I, pp. 115-118, Quebec, Canada, August 11-15, 2002.

Shuai Zheng, Junge Zhang, Kaiqi Huang, Ran He and Tieniu Tan. Robust View Transformation Model for Gait Recognition. Proceedings of the IEEE International Conference on Image Processing, 2011.[dataset]

Gait databases, CASIA

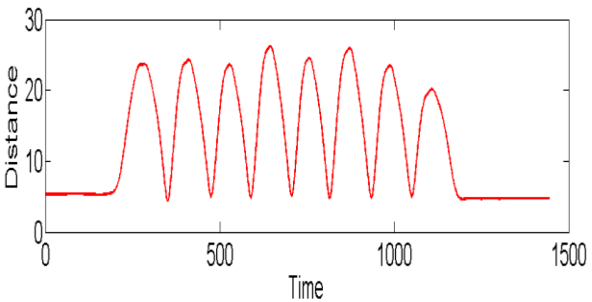
Dataset A (Dec. 10, 2001), 20 persons.
Each person has 12 image sequences, 4 sequences for each of the three directions, i.e. parallel, 45 degrees and 90 degrees to the image plane.
The length of each sequence is not identical for the variation of the walker's speed, ranges from 37 to 127 image frames.
The size of Dataset A is about 2.2GB and the database includes 19139 images.

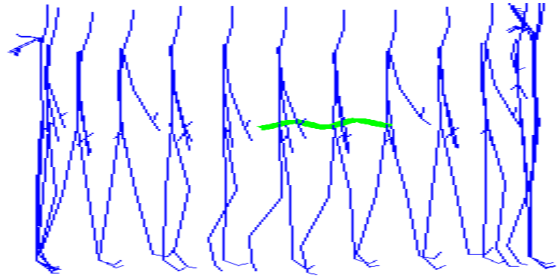
Dataset B - large multiview gait database, (January 2005).
124 subjects, gait data captured from 11 views.
Variations in view angle, clothing and carrying condition changes. Besides the video files, human silhouettes extracted from video files are provided.

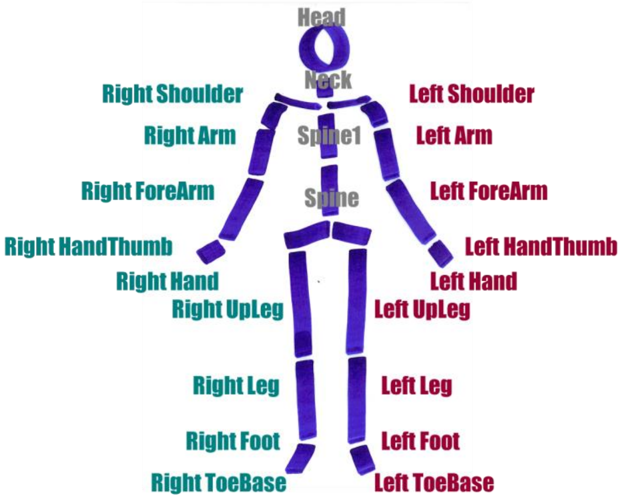
Dataset C / D (153 / 88 subjects) infrared camera, different walking speed and conditions, wide age distribution.

Gait databases, HML
3D marker models + Video recordinngs

- HML PJACT
- 60 persons / 35 male / 25 female
- 600 walks
- Vicon Blade, format Acclaim
  - 72 dimensional pose space
- Repeated calibration

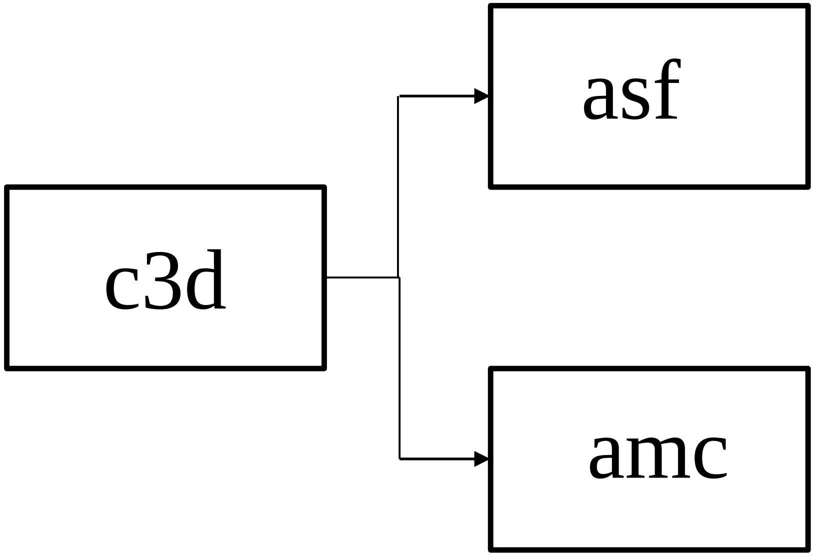




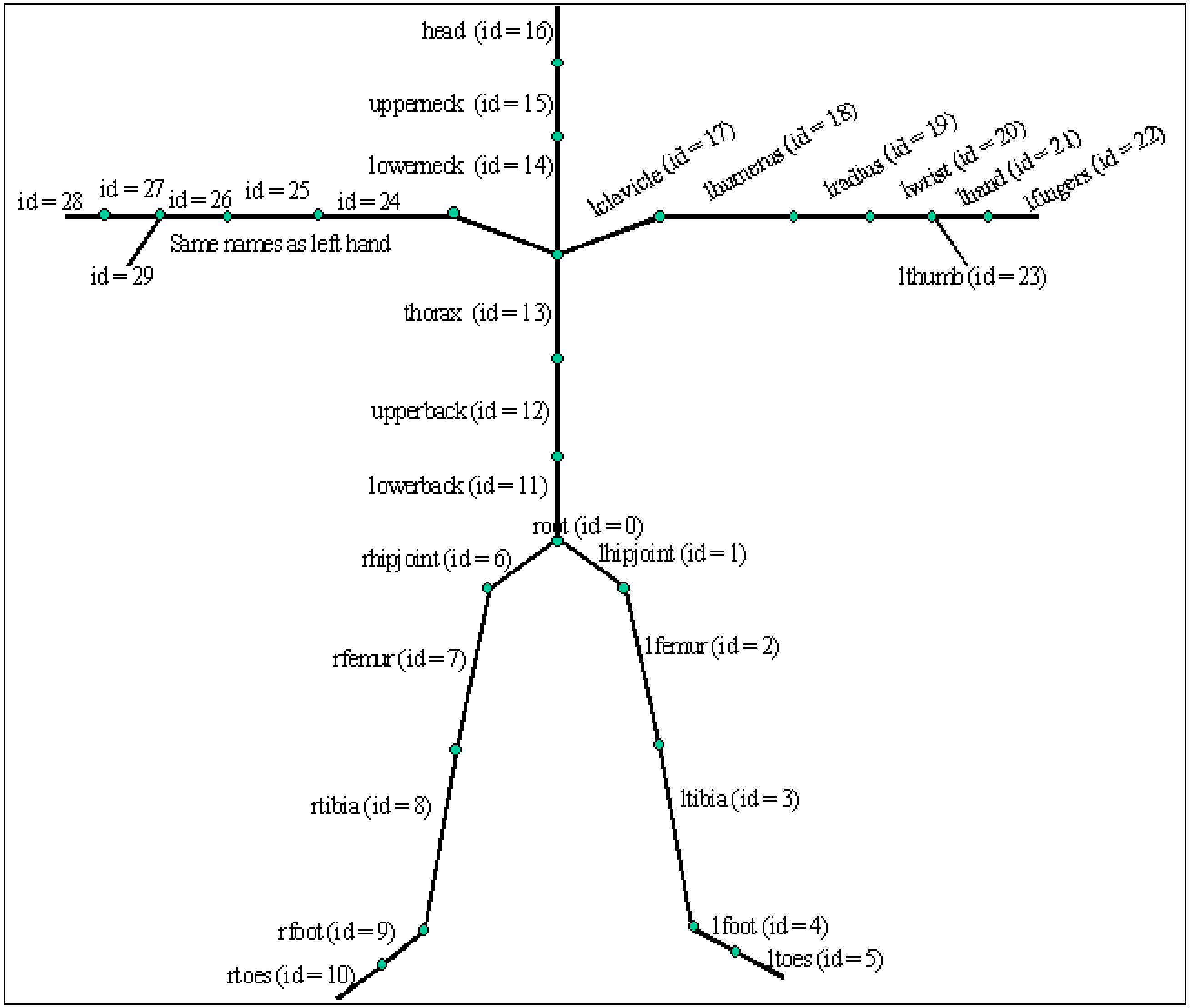


Gait kinematics

Kinematic model, Acclaim, c3d, asf, amc

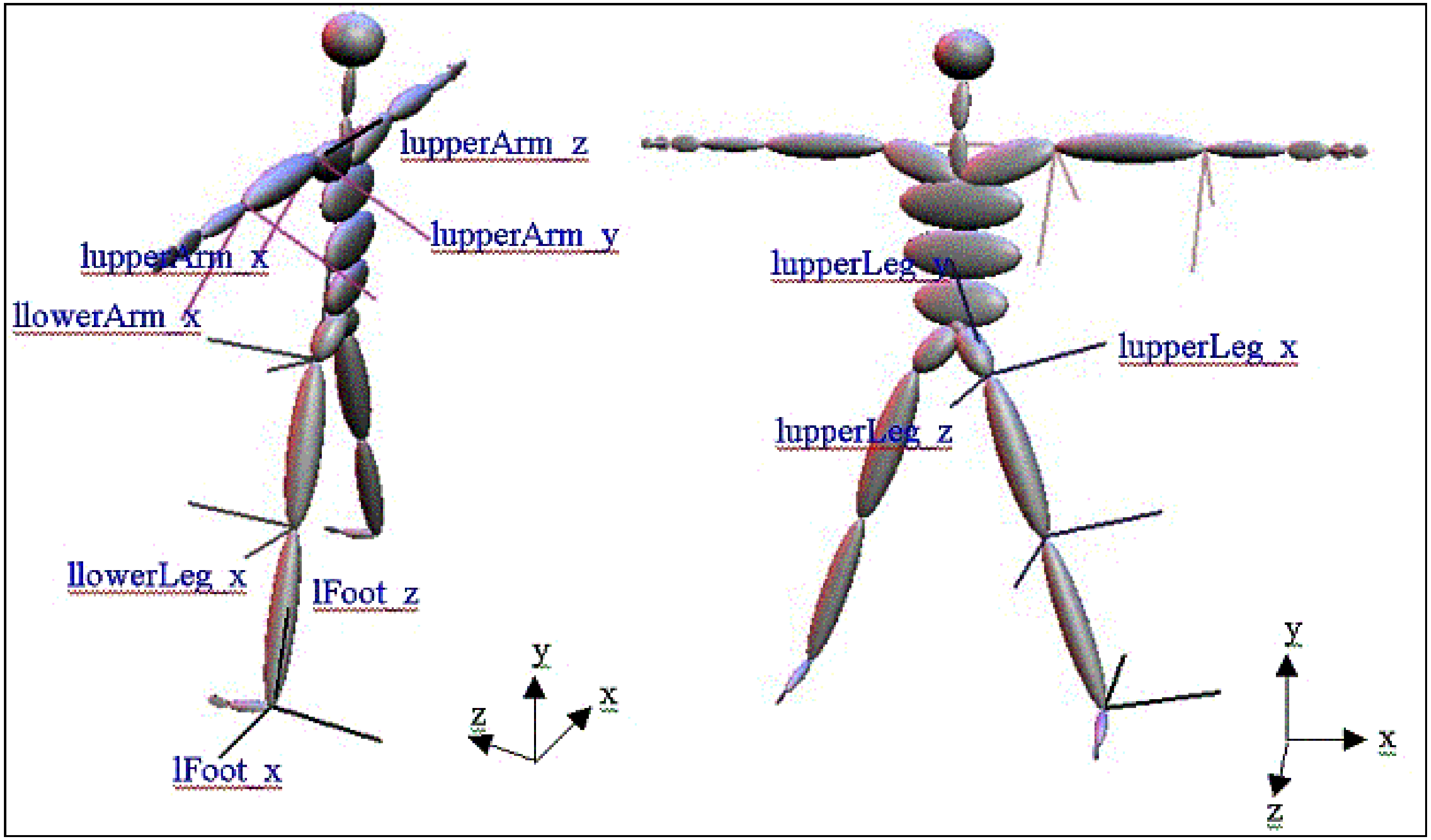


Kinematic model, Acclaim, asf, amc



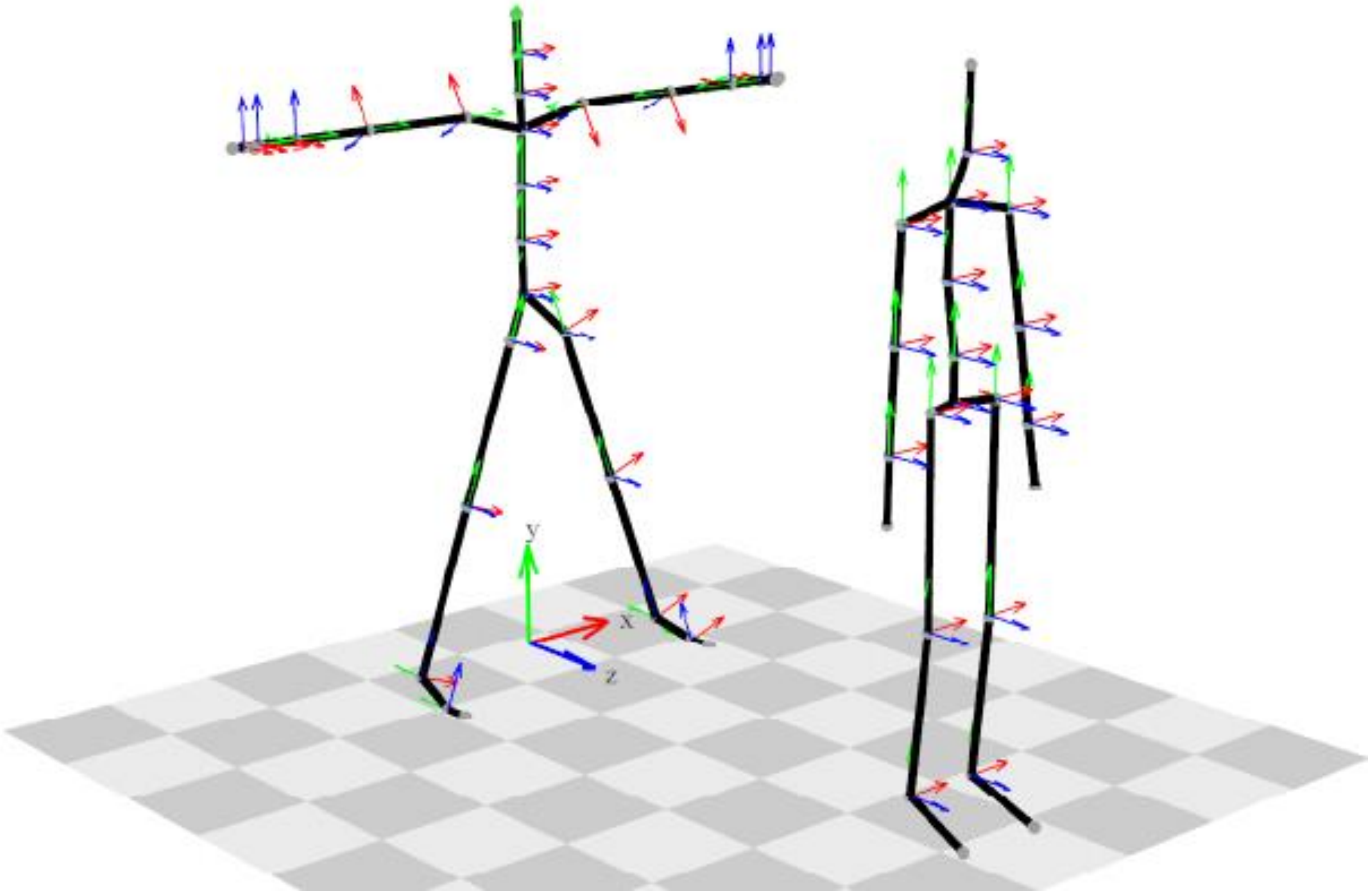
http://research.cs.wisc.edu/graphics/Courses/cs-838-1999/Jeff/ASF-AMC.html

Kinematic model, Acclaim, asf, amc

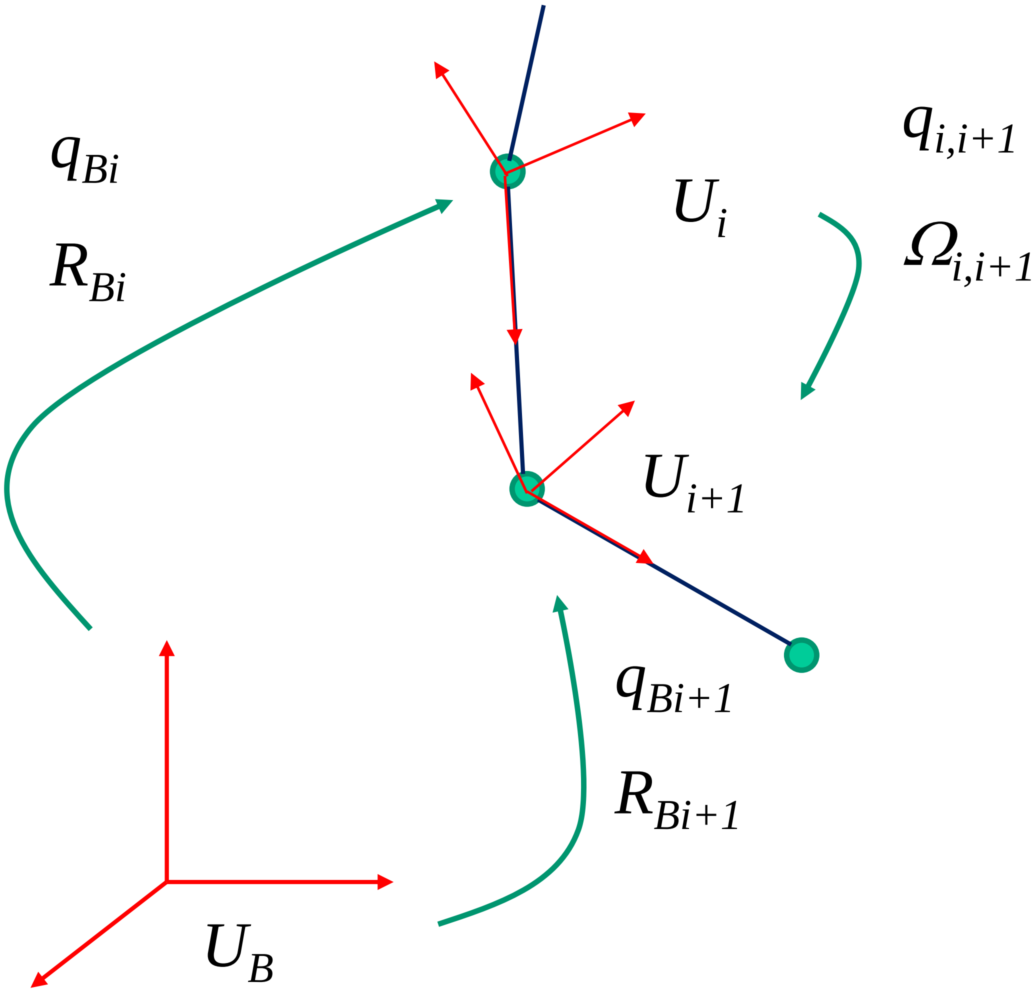


http://research.cs.wisc.edu/graphics/Courses/cs-838-1999/Jeff/ASF-AMC.html

Kinematic model



Kinematic chains, rotations, translations



Denavit Hartenberg notation

….

$$q_{Bi+1} = q_{i,i+1} * q_{bi}$$

$$R_{Bi+1} = \Omega_{i,i+1} R_{Bi}$$

….

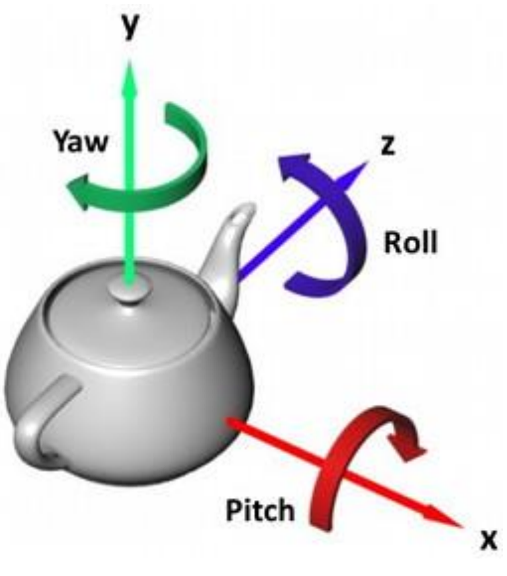
$R_{Bi+1}\ \Omega_{i,i+1}\ R_{Bi}$ - rotation matrices

$q_{Bi},\ q_{Bi+1},\ q_{i,i+1}$ - unit quaternions

Rotations represented by Euler angles

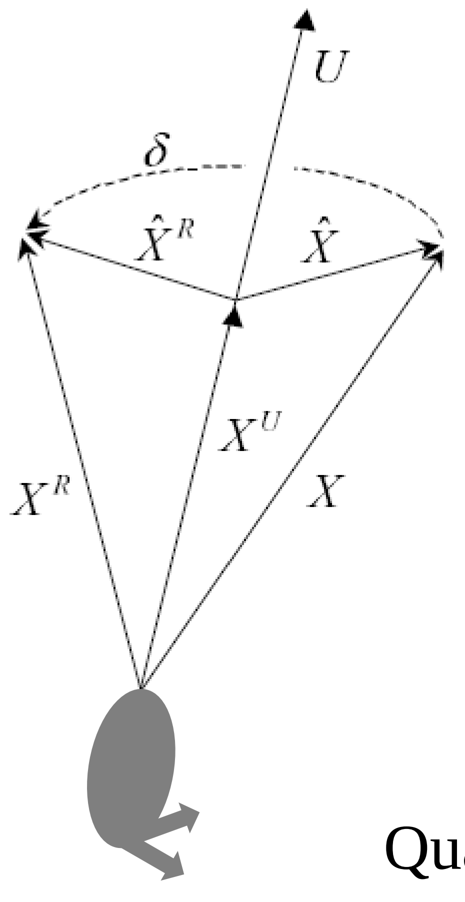
$$R_y = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_z = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotations represented by quaternions

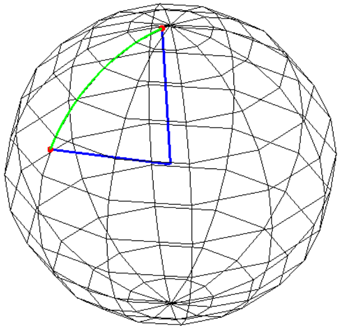


$$q = [\cos\frac{\delta}{2}, U\sin\frac{\delta}{2}]$$

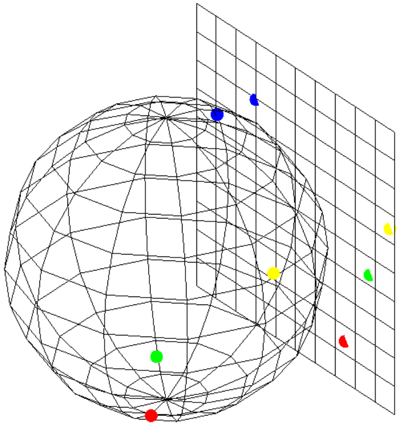
Quaternion multiplication corresponds to superposition of rotations (multiplication of rotation matrices)

Distances between rotations (quaternions), rotation (quaternion) averaging, interpolating

$$d(p,q) = \frac{2}{\pi}\arccos(p \cdot q)$$



$$d(p,q) = \|\log(p) - \log(q)\|$$



Richard Hartley, Jochen Trumpf, Yuchao Dai, Hongdong Li (2013), Rotation Averaging,
International Journal of Computer Vision, Volume 103, Issue 3, pp. 267–305.

Distances between rotations (quaternions), rotation (quaternion) averaging, interpolating

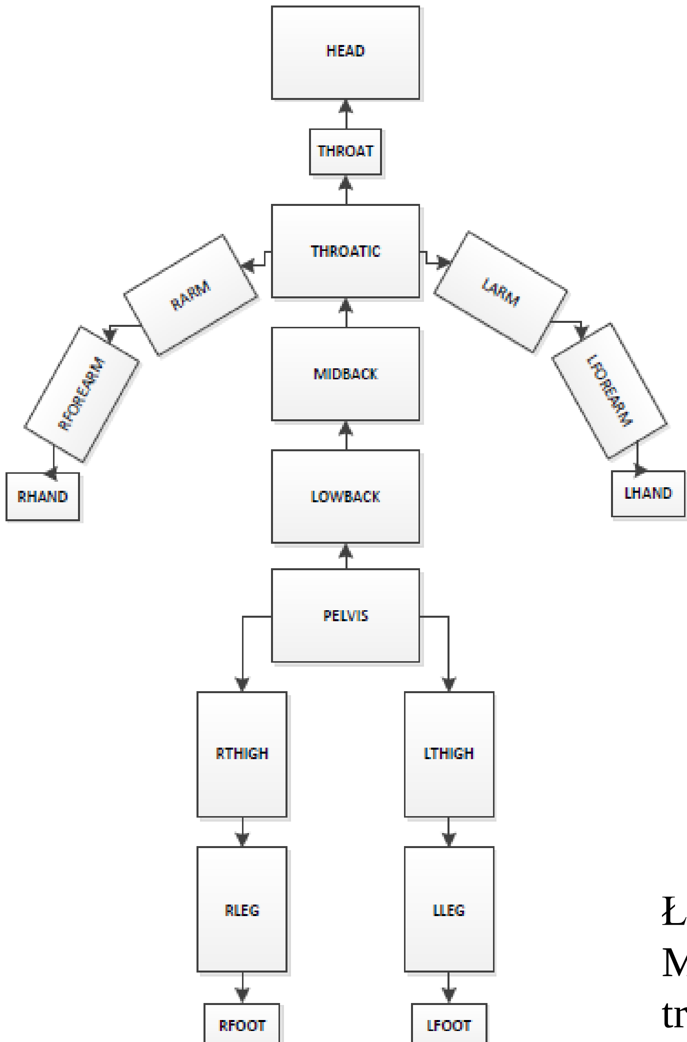
$$d(p,q) = \|p - q\|,$$

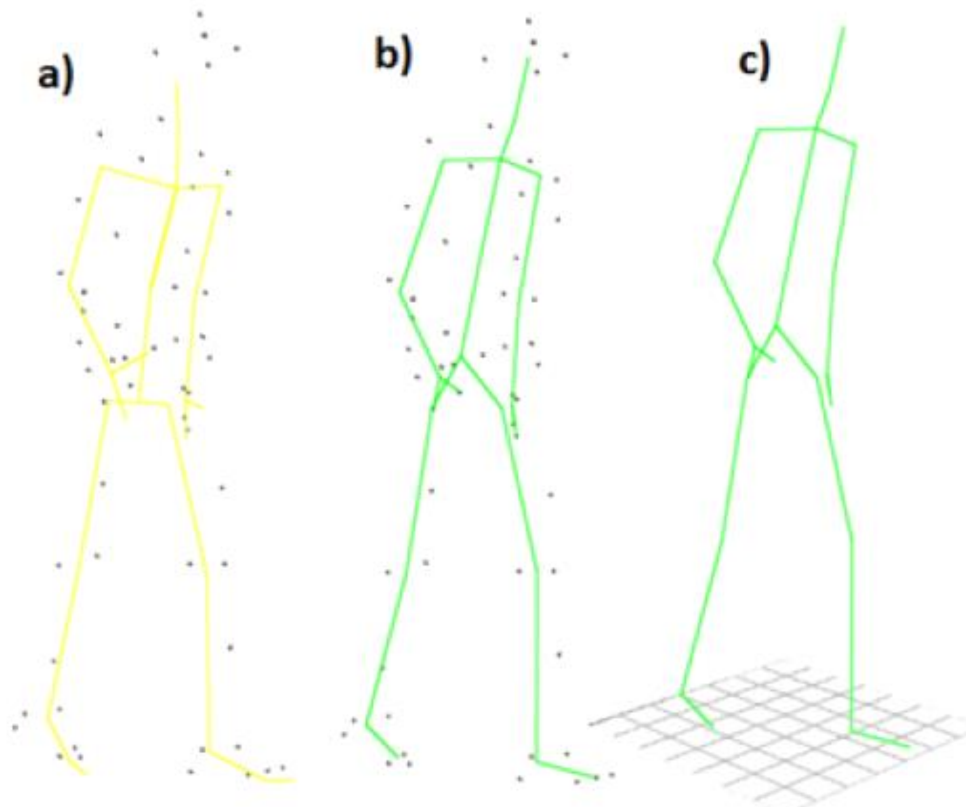
$$d(p,q) = \|\log(p * \bar{q})\|,$$

$$d(p,q) = \|R(p) - R(q)\|_F,$$

$$d(p,q) = \|\log[R(p)^T R(q)]\|_F.$$

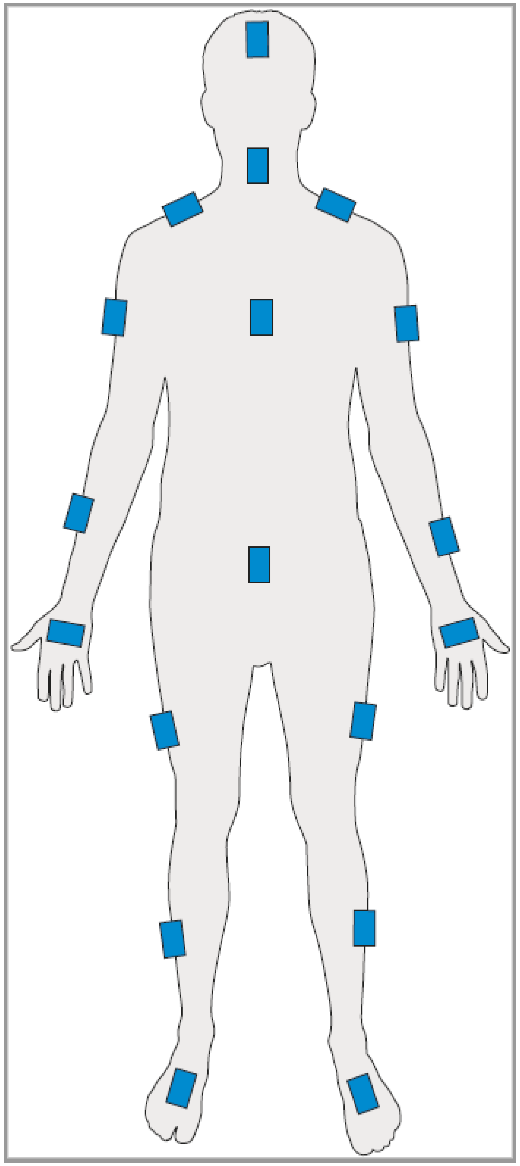
Skeleton design based on 3D markers with quaternion algebra

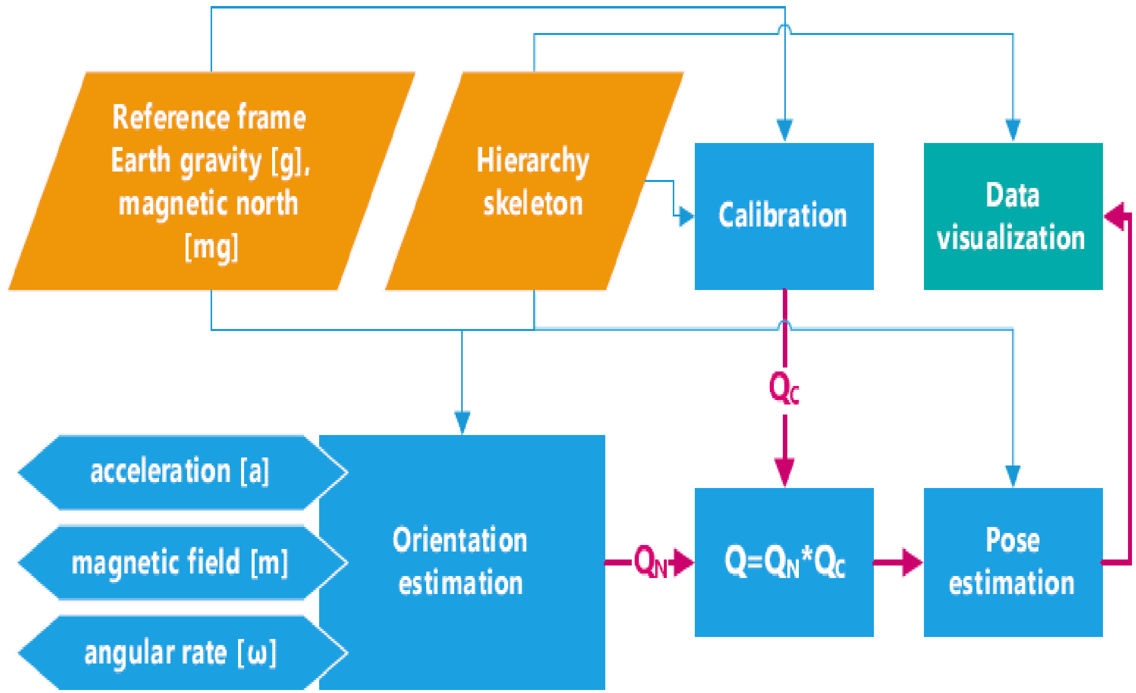




Łukasz Janik, Andrzej Polanski, Konrad Wojciechowski, (2011), Models and algorithms for human skeleton estimation from 3D marker trajectories, **Machine Graphics & Vision, Volume 20 Issue 3, Pages: 333-354**

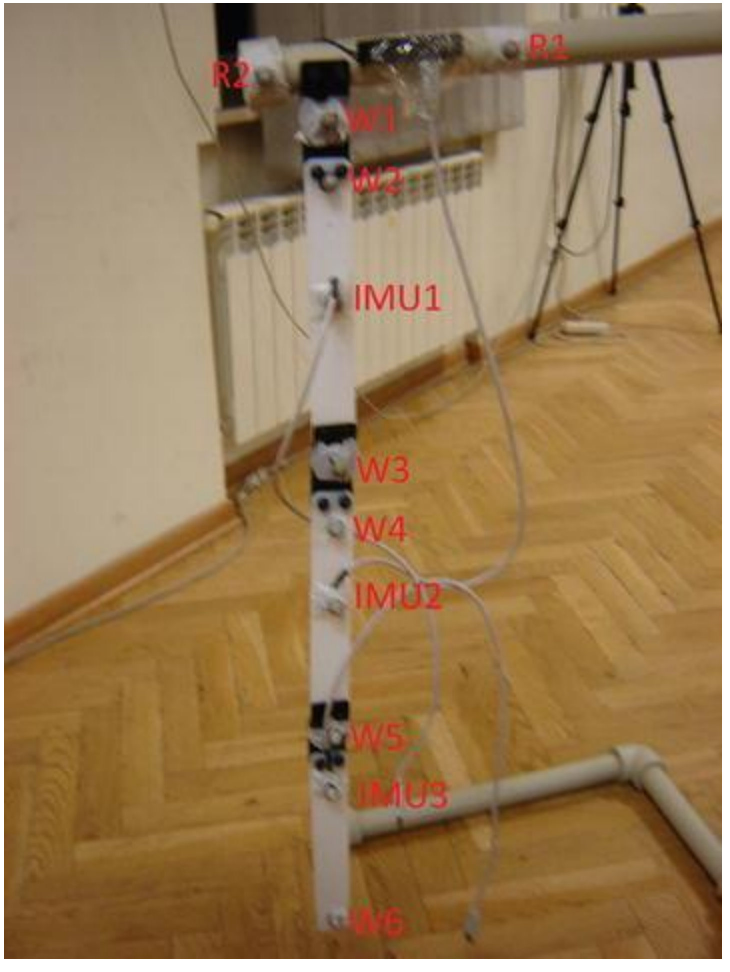
Skeleton estimation based on IMU sensors





Agnieszka Szczęsna, Przemysław Skurowski, Ewa Lach, Przemysław Pruszowski, Damian Pęszor, Marcin Paszkuta, Janusz Słupik, Kamil Lebek, Mateusz Janiak, Andrzej Polański, Konrad Wojciechowski, **(2017),** Inertial Motion Capture Costume Design Study, **Sensors, 17(3), 612; doi:10.3390/s17030612**

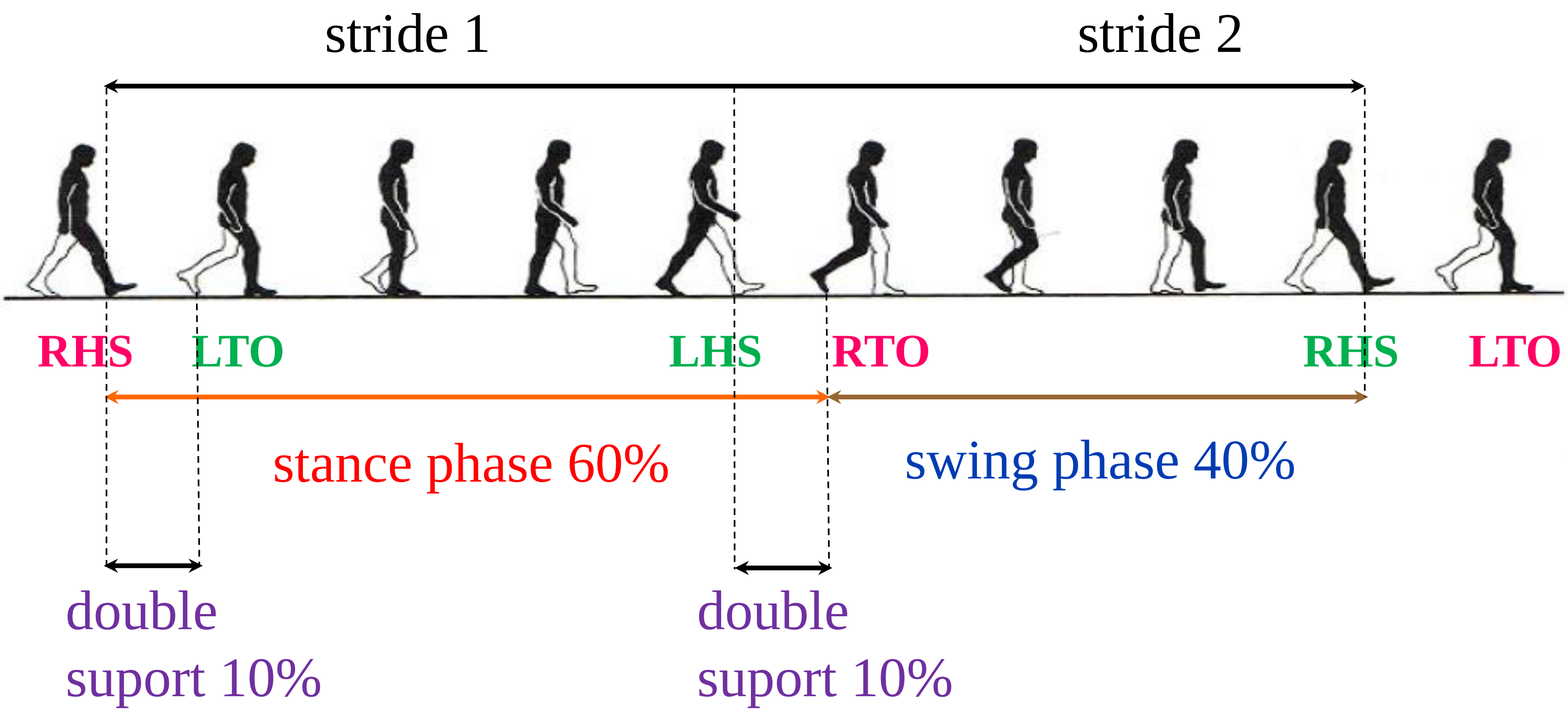
Kinematic chain estimation based on IMU sensors and 3D markers



Agnieszka Szczęsna, Przemysław Pruszowski. **(2016),** Model-based extended quaternion Kalman filter to inertial orientation tracking of arbitrary kinematic chains. **SpringerPlus, 2016 5(1), pp. 1965.**

Gait cycle

Gait cycle



RHS / LHS – Right / Left heel strike
LTO / RTO – Left / Right toe off

http://www2.warwick.ac.uk/fac/sci/eng/meng/nongps/rnd/gait/

Dynamic time warping (DTW)

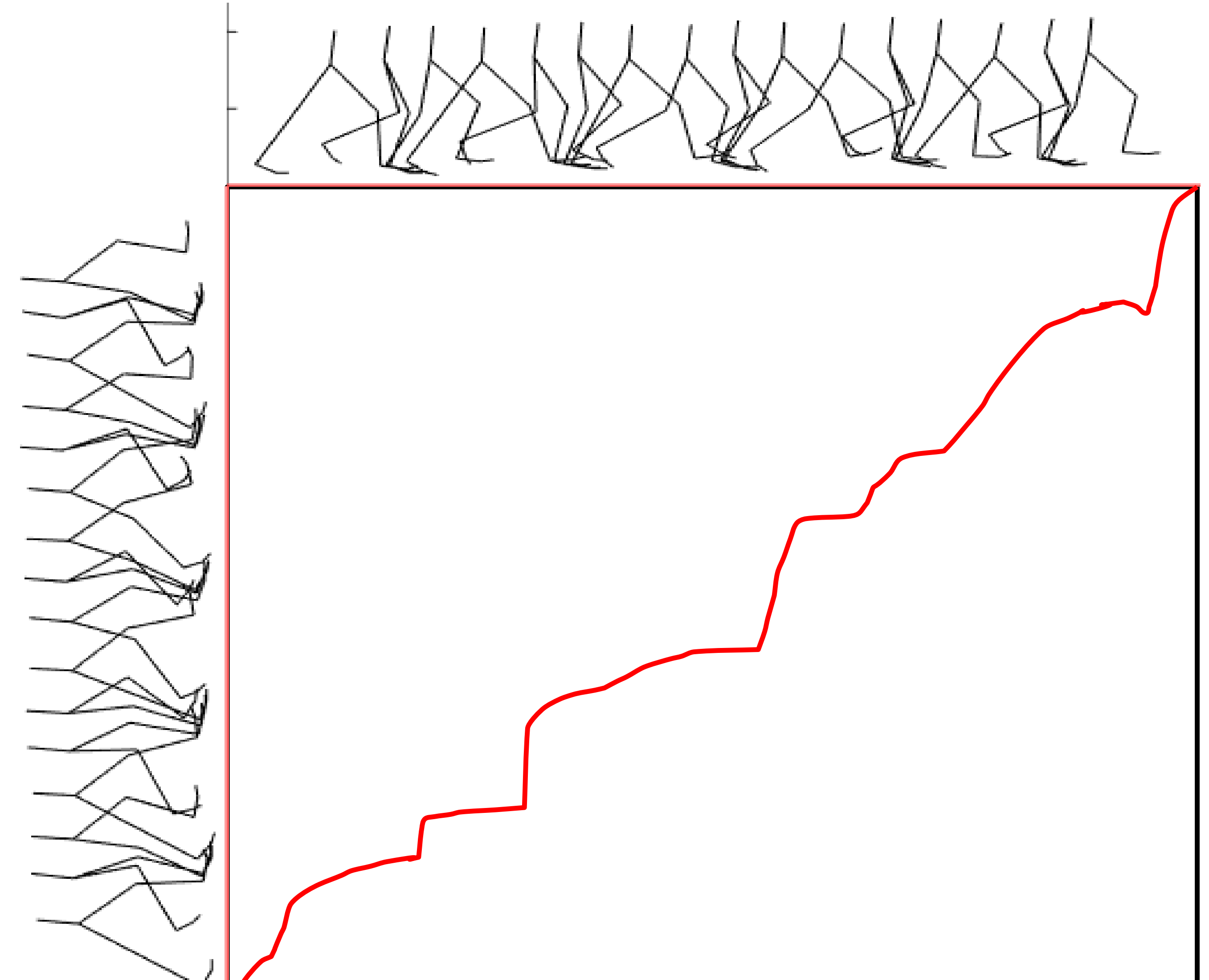
- Cycle / rhytm / similarity
- Synchronization of two time-series
- Similarity / distance matrix
- Maximum similarity path
- Dynamic programming

Bellman R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ.

Vintsyuk T. K. (1968). Speech discrimination by dynamic programming. Kibernetika. 4: 81–88.

Needleman S. B., Wunsch C. D. (1970), A general method applicable to the search for similarities in the amino acid sequence of two proteins. J. Mol. Biol., vol. 48, pp. 443–453.

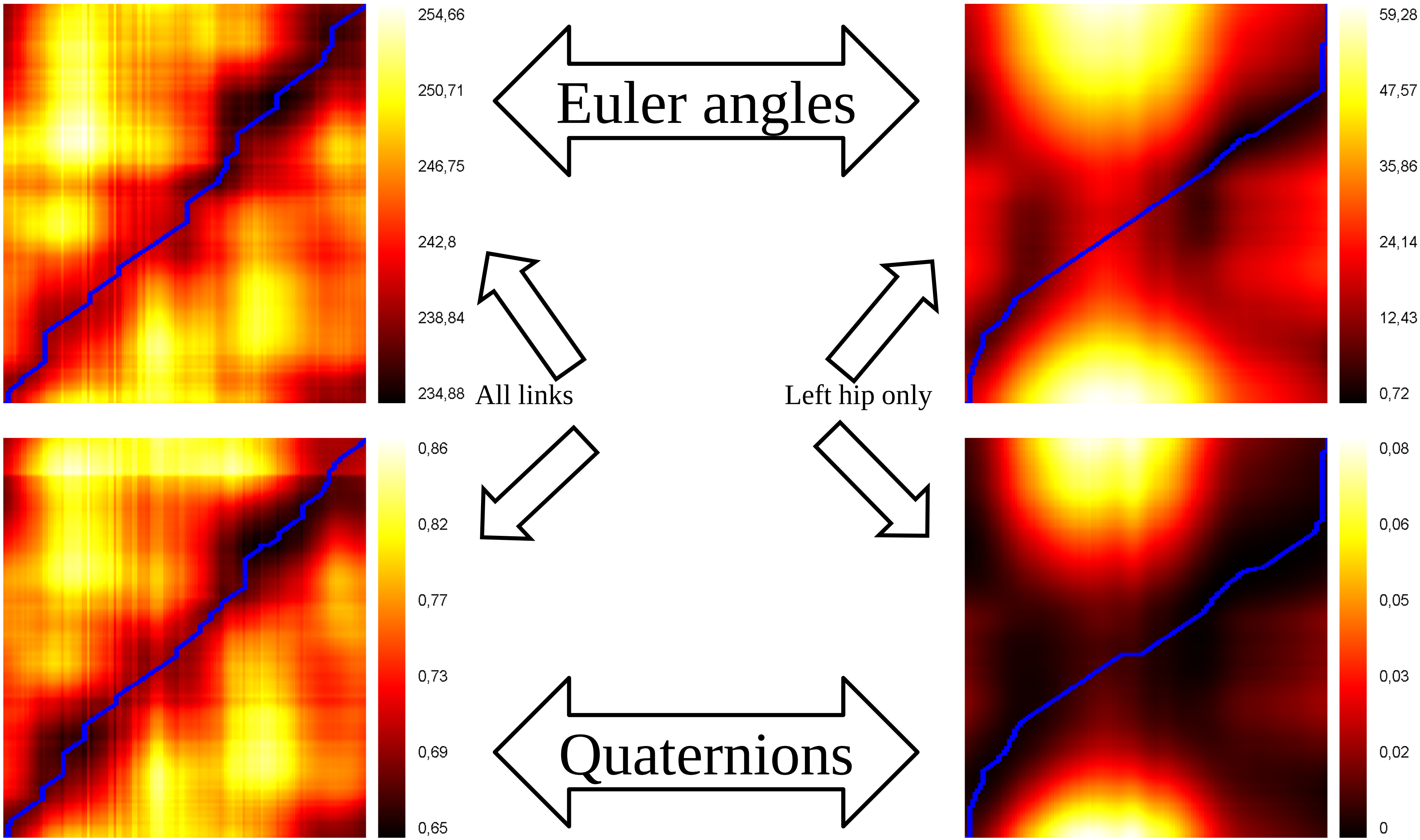
DTW for gait cycle, idea



DTW for gait cycle

- Very useful for interpreting gait data
- Pre – processing
- Detection of stride check points
- Distances between poses
- Distances between gaits
- Depends on the applied distance measures between rotations or quaternions

DTW for gait cycle, examples of maximum similarity paths



Gait dynamics

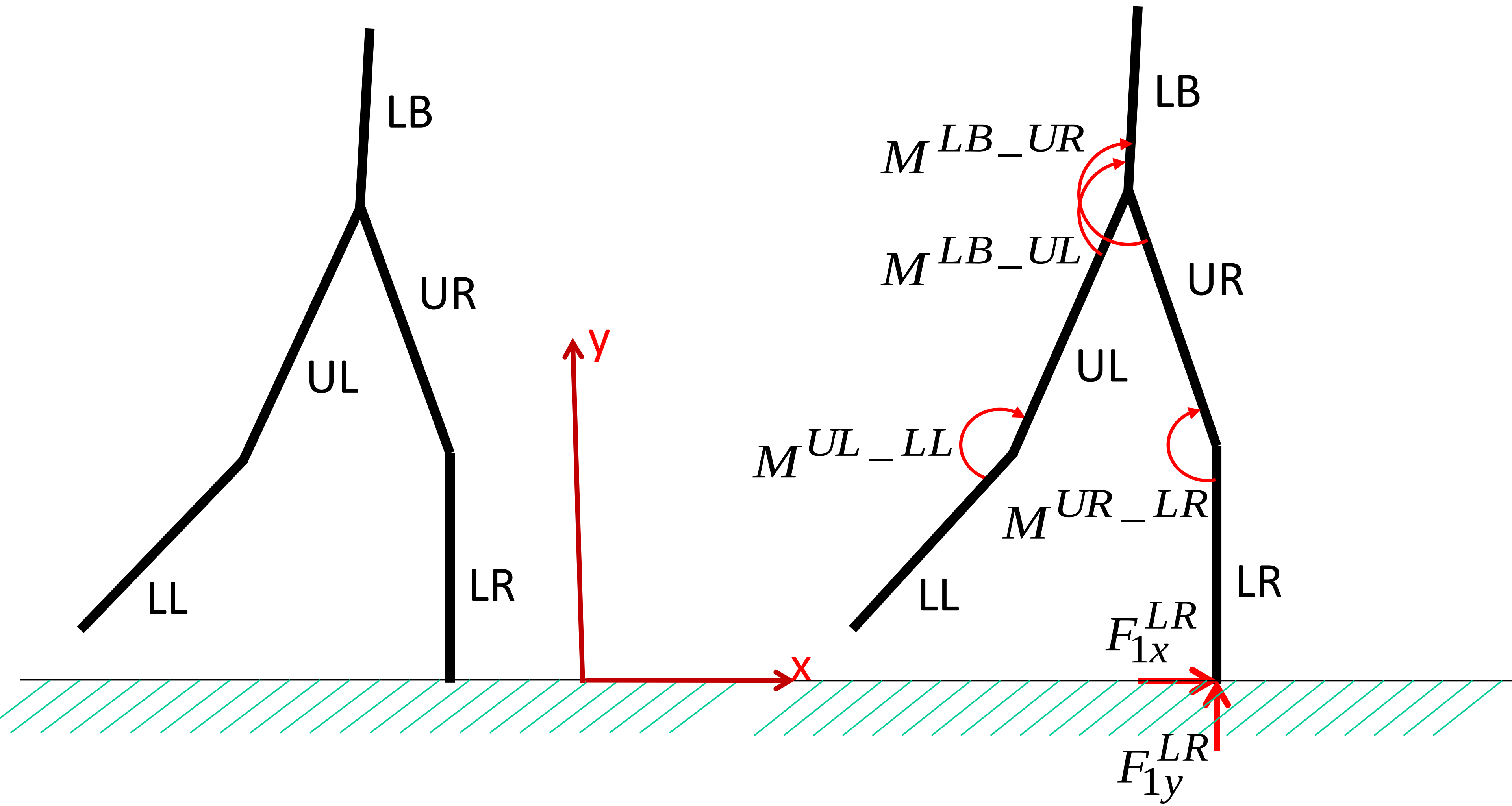
Gait dynamics models

- Lagrange equations
- Newton, Euler equations

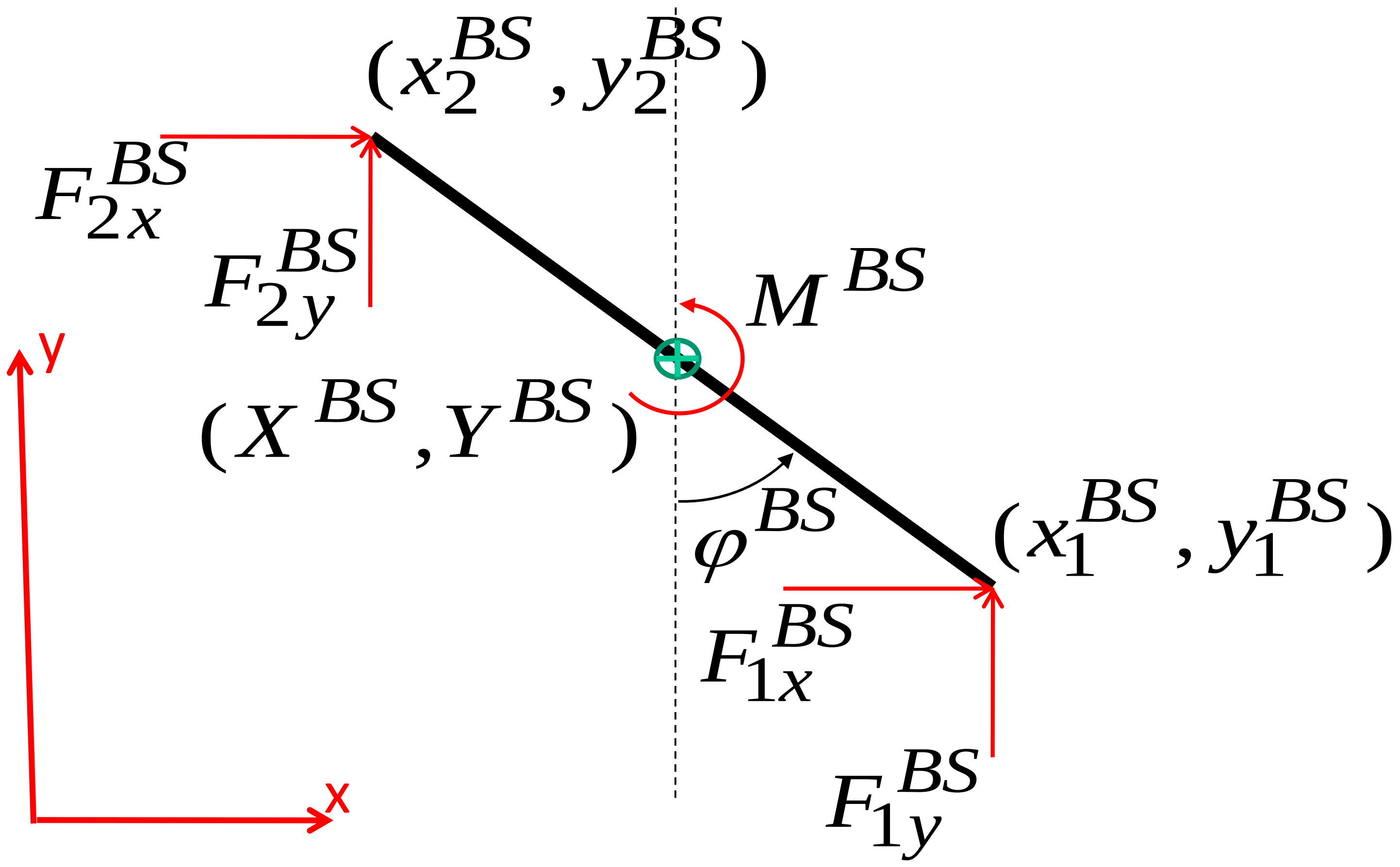
Roy Featherstone, (2007), Rigid Body Dynamics Algorithms, Springer, 2007

Gait dynamics models

- Five link biped model 2D

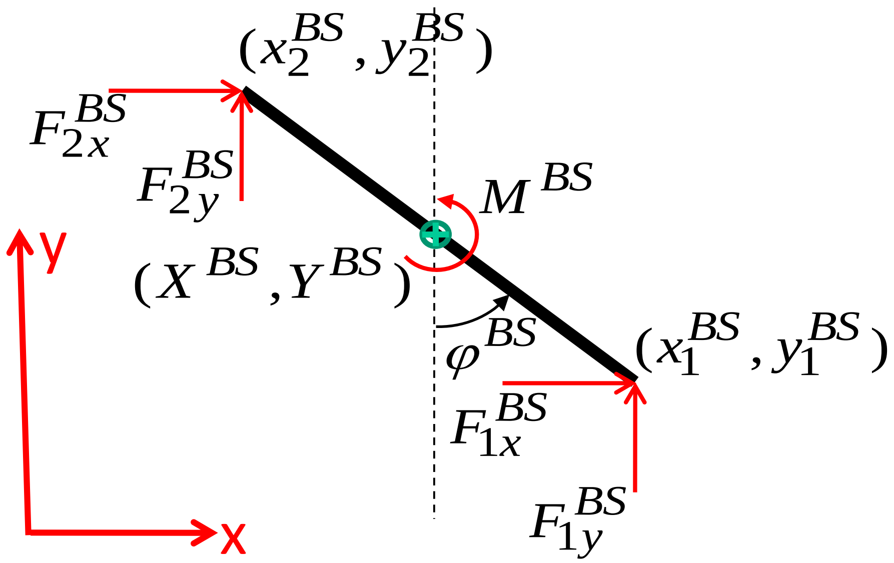


One segment



(x_2^{BS}, y_2^{BS})
F_{2x}^{BS}
F_{2y}^{BS}
M^{BS}
y
(X^{BS}, Y^{BS})
φ^{BS}
(x_1^{BS}, y_1^{BS})
F_{1x}^{BS}
F_{1y}^{BS}
x

One segment



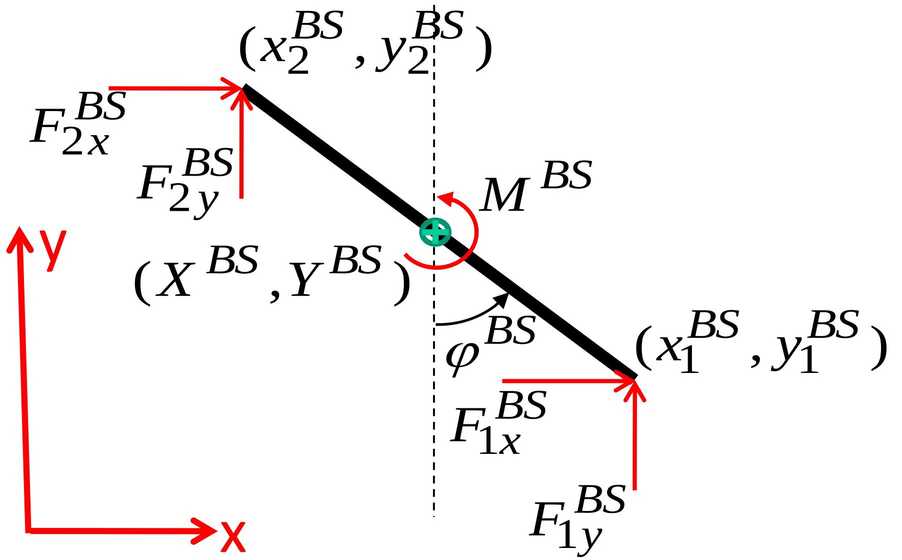
$$\ddot{X} = \frac{F_{1x} + F_{2x}}{m}$$

$$\ddot{Y} = \frac{F_{1y} + F_{2y}}{m} - g$$

$$\ddot{\varphi} = \frac{l[(F_{1x} - F_{2x})\cos\varphi + (F_{1y} - F_{2y})\sin\varphi]}{2I} + \frac{M}{I}$$

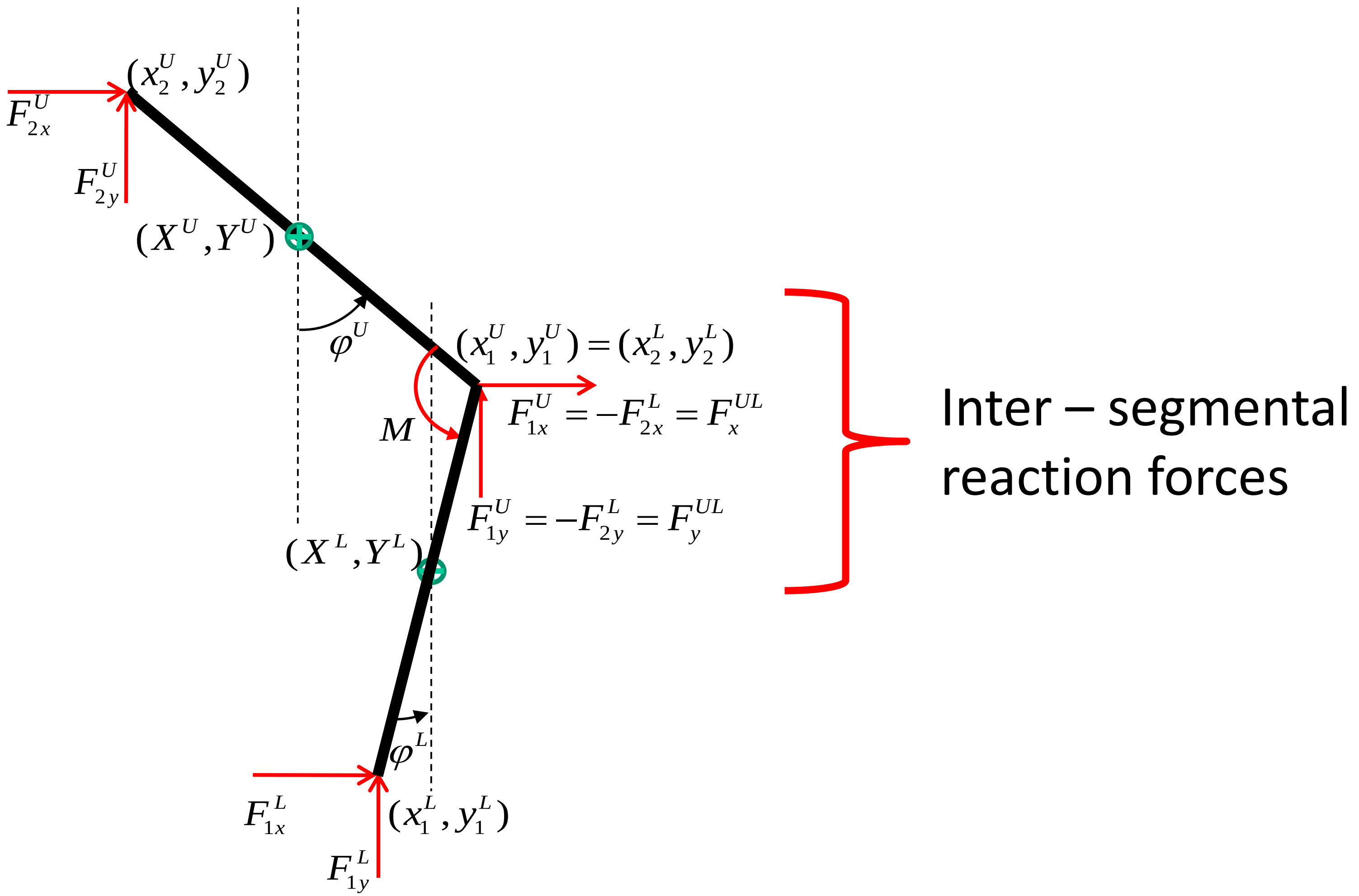
State variables: $X, Y, \varphi, \dot{X}, \dot{Y}, \dot{\varphi}$

One segment



$$
\begin{bmatrix} \ddot{x}_1 \\ \ddot{y}_1 \\ \ddot{x}_2 \\ \ddot{y}_2 \end{bmatrix} =
\begin{bmatrix}
\frac{1}{m} + \frac{l^2 \cos^2\varphi}{4I} & \frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{1}{m} - \frac{l^2 \cos^2\varphi}{4I} & -\frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{l\cos\varphi}{2I} & -\dot{\varphi}^2 \frac{l\sin\varphi}{2} \\
\frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{1}{m} + \frac{l^2 \sin^2\varphi}{4I} & -\frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{1}{m} - \frac{l^2 \sin^2\varphi}{4I} & \frac{l\sin\varphi}{2I} & \dot{\varphi}^2 \frac{l\cos\varphi}{2} - g \\
\frac{1}{m} - \frac{l^2 \cos^2\varphi}{4I} & -\frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{1}{m} + \frac{l^2 \cos^2\varphi}{4I} & \frac{l^2 \sin\varphi\cos\varphi}{4I} & -\frac{l\cos\varphi}{2I} & \dot{\varphi}^2 \frac{l\sin\varphi}{2} \\
-\frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{1}{m} - \frac{l^2 \sin^2\varphi}{4I} & \frac{l^2 \sin\varphi\cos\varphi}{4I} & \frac{1}{m} + \frac{l^2 \sin^2\varphi}{4I} & -\frac{l\sin\varphi}{2I} & -\dot{\varphi}^2 \frac{l\cos\varphi}{2} - g
\end{bmatrix}
\begin{bmatrix} F_{1x} \\ F_{1y} \\ F_{2x} \\ F_{2y} \\ M \\ 1 \end{bmatrix}
$$

Two segments



Dynamics of the biped

Replacement rules:

Torques:

$$M^{LB} = M^{LB\_UL} + M^{LB\_UL},$$
$$M^{UL} = -M^{LB\_UL} + M^{UL\_LL},$$
$$M^{UR} = -M^{LB\_UR} + M^{UR\_LR},$$
$$M^{LL} = -M^{UL\_LL},$$
$$M^{LR} = -M^{UR\_LR}.$$

Ground reaction forces:

For the phase LL-stance and LR-swing:

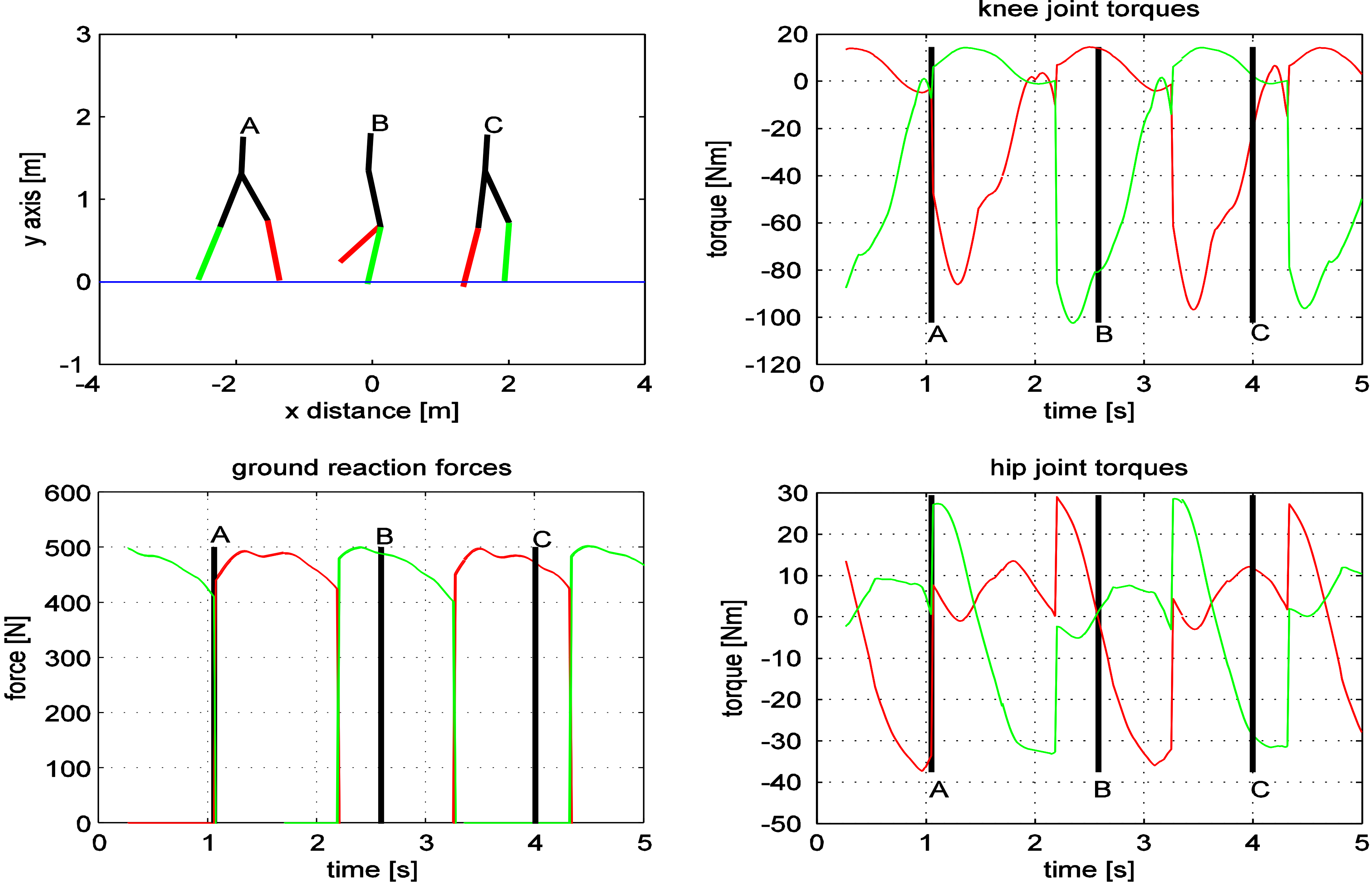
$$F_{1x}^{LL} = F_x^{G\_LL},$$
$$F_{1y}^{LL} = F_y^{G\_LL},$$
$$F_{1x}^{LR} = 0,$$
$$F_{1y}^{LR} = 0,$$

For the phase LL-swing and LR-stance:

$$F_{1x}^{LL} = 0,$$
$$F_{1y}^{LL} = 0,$$
$$F_{1x}^{LR} = F_x^{G\_LR},$$
$$F_{1y}^{LR} = F_x^{G\_LR}.$$

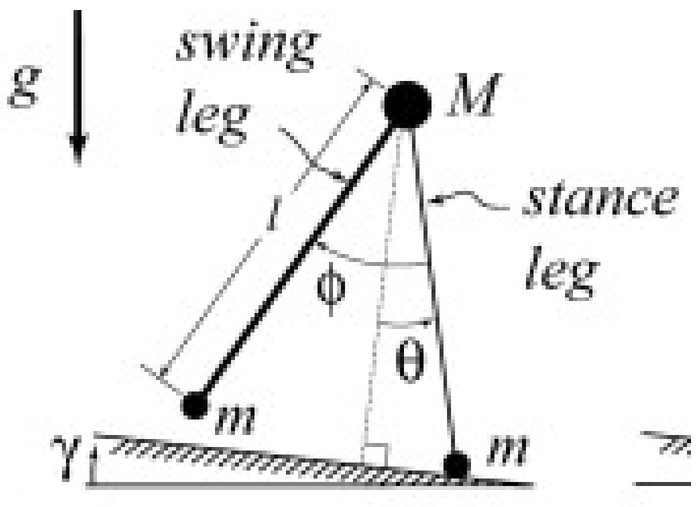
Inter-segmental reaction forces:

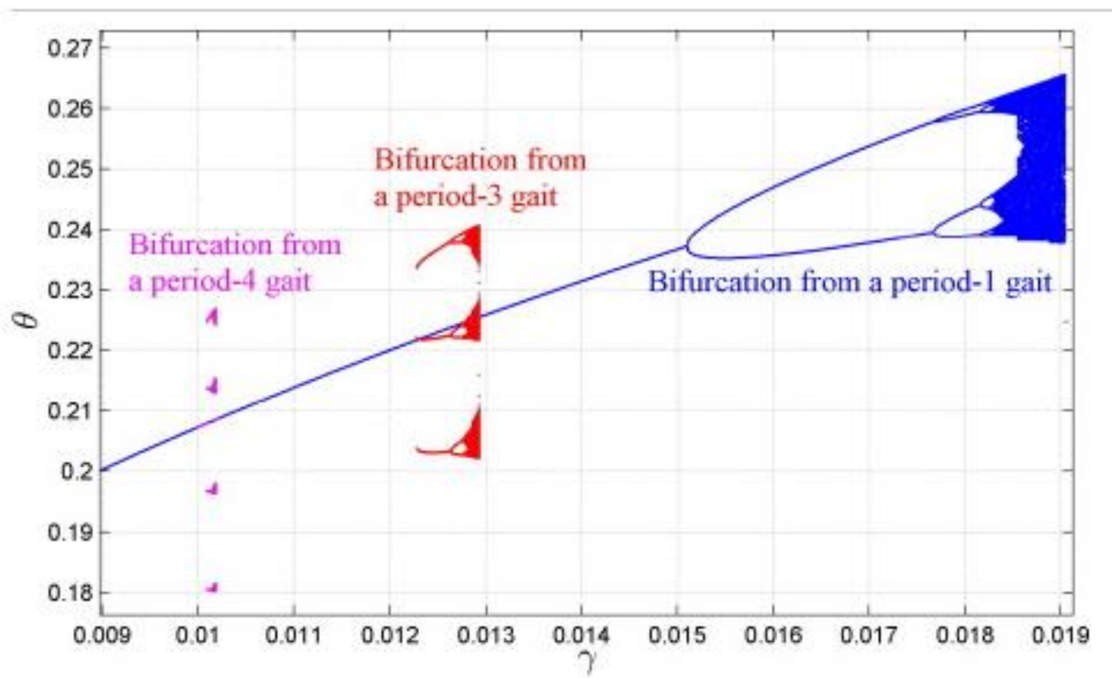
$$F_{2x}^{LB} = 0,$$
$$F_{2y}^{LB} = 0,$$
$$F_{1x}^{LB} = F_x^{LB\_UL} + F_x^{LB\_UR},$$
$$F_{1y}^{LB} = F_y^{LB\_UL} + F_y^{LB\_UR},$$
$$F_{1x}^{UL} = F_x^{UL\_LL},$$
$$F_{1y}^{UL} = F_y^{UL\_LL},$$
$$F_{2x}^{UL} = -F_x^{LB\_UL},$$
$$F_{2y}^{UL} = -F_y^{LB\_UL},$$
$$F_{1x}^{UR} = F_x^{UR\_LR},$$
$$F_{1y}^{UR} = F_y^{UR\_LR},$$
$$F_{2x}^{UR} = -F_x^{LB\_UR},$$
$$F_{2y}^{UR} = -F_y^{LB\_UR},$$
$$F_{2x}^{LL} = -F_x^{UL\_LL},$$
$$F_{2y}^{LL} = -F_y^{UL\_LL},$$
$$F_{2x}^{LR} = -F_x^{UR\_LR},$$
$$F_{2y}^{LR} = -F_y^{UL\_LR}.$$



Andrzej Polański, Adam Świtoński, Henryk Josiński, Karol Jędrasiak, Konrad Wojciechowski, Estimation system for forces and torques in a biped motion, Computer Vision and Graphics International Conference on Computer Vision and Graphics,ICCVG 2010: Computer Vision and Graphics, pp. 185-192.

Chaotic properties of gait dynamics





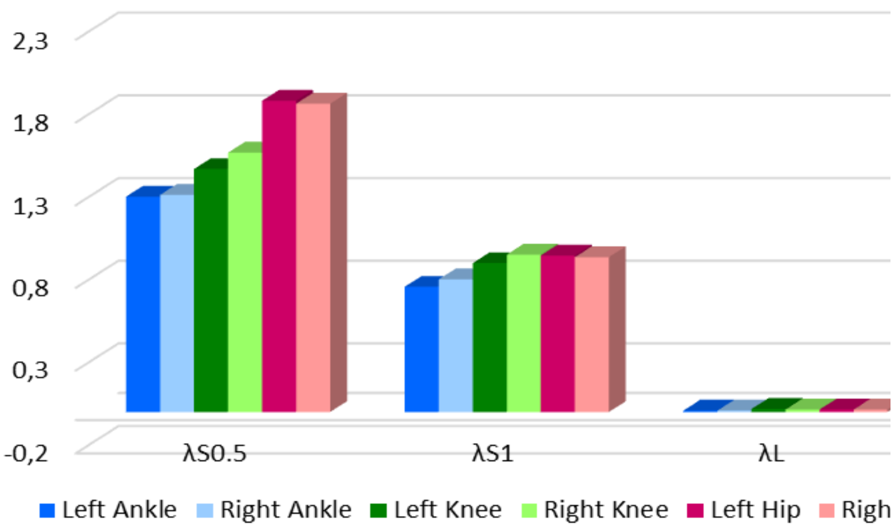
Sajid Iqbal, Xizhe Zang, Yanhe Zhu, Jie Zhao, (2014), Bifurcations and chaos in passive dynamic walking: A review, Robotics and Autonomous Systems 62 (2014) 889–909.

Chaotic properties of gait

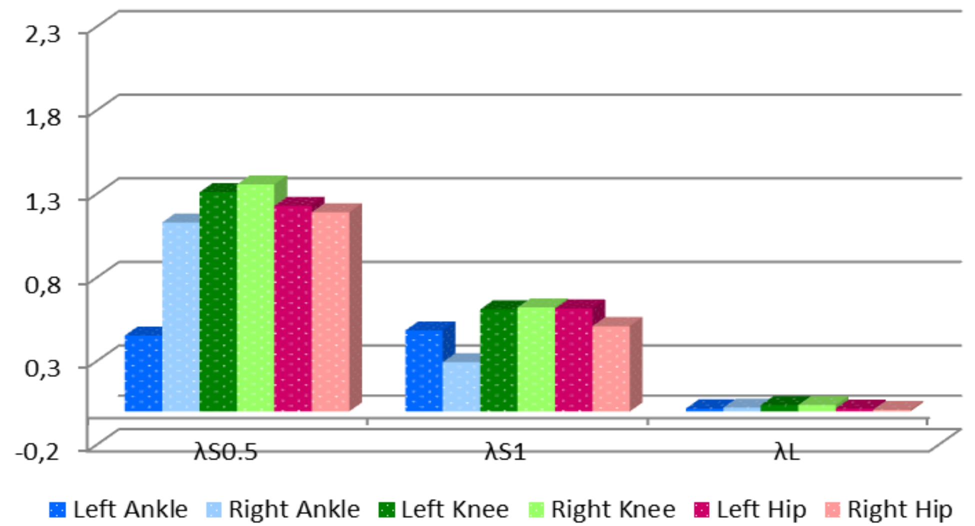
Piórek M., Josiński H., Michalczuk A., Świtoński A., Szczęsna A., (2017), Quaternions and Joint Angles in an Analysis of Local Stability of Gait for Different Variants of Walking Speed and Treadmill Slope. Information Sciences 384, pp. 263-280 (2017)

Chaotic properties of gait

Healthy



PD



λ_{S05}, λ_{S1}, λ_{L} - Lyapunov exponents

Features for gait classification

Features for gait classification

- Geometric features from image processing
- Geometric features of the estimated skeleton model
- Gait features
- Euler angles
- Quaternion coordinates
- Rotation / quaternion distances
- Velocities, accelerations
- Integral indexes

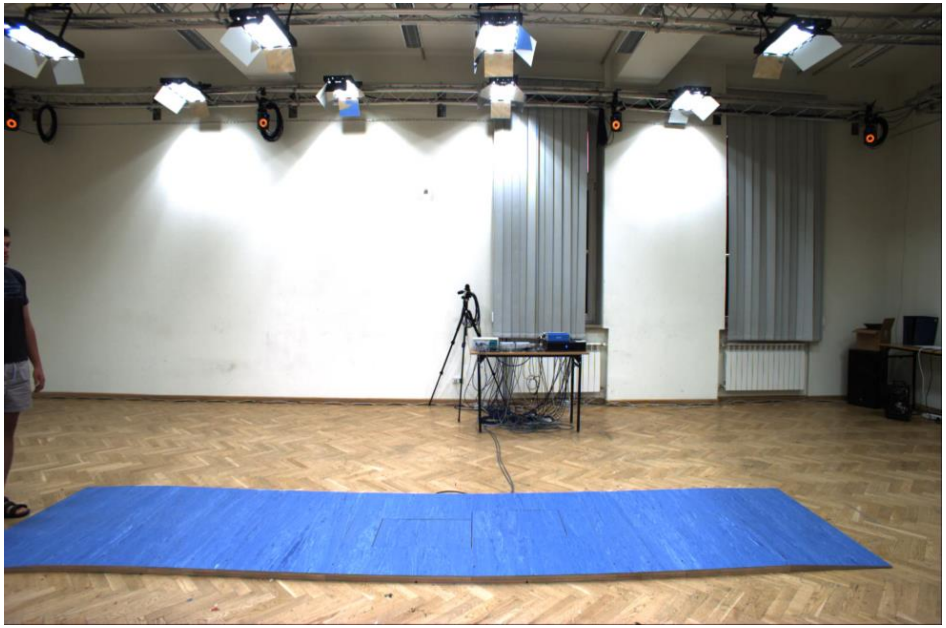
Features for gait classification

- Estimated forces, torques in dynamic gait models
- Lyapunov exponent, entropies computed on the basis of chaotic gait models
- Tremor parameters in Parkinson disease patients
- Measurements coming from multimodal systems (EMG, EEG)

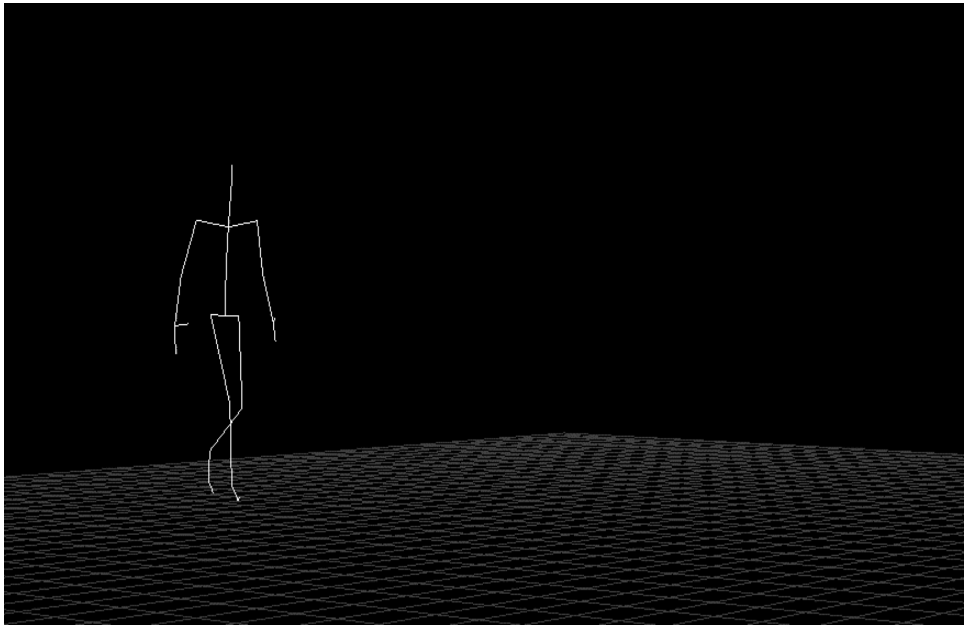
Results of gait classification

Person identification

Video recordings



Marker systems



Video recordings, CASIA Algorithm 1

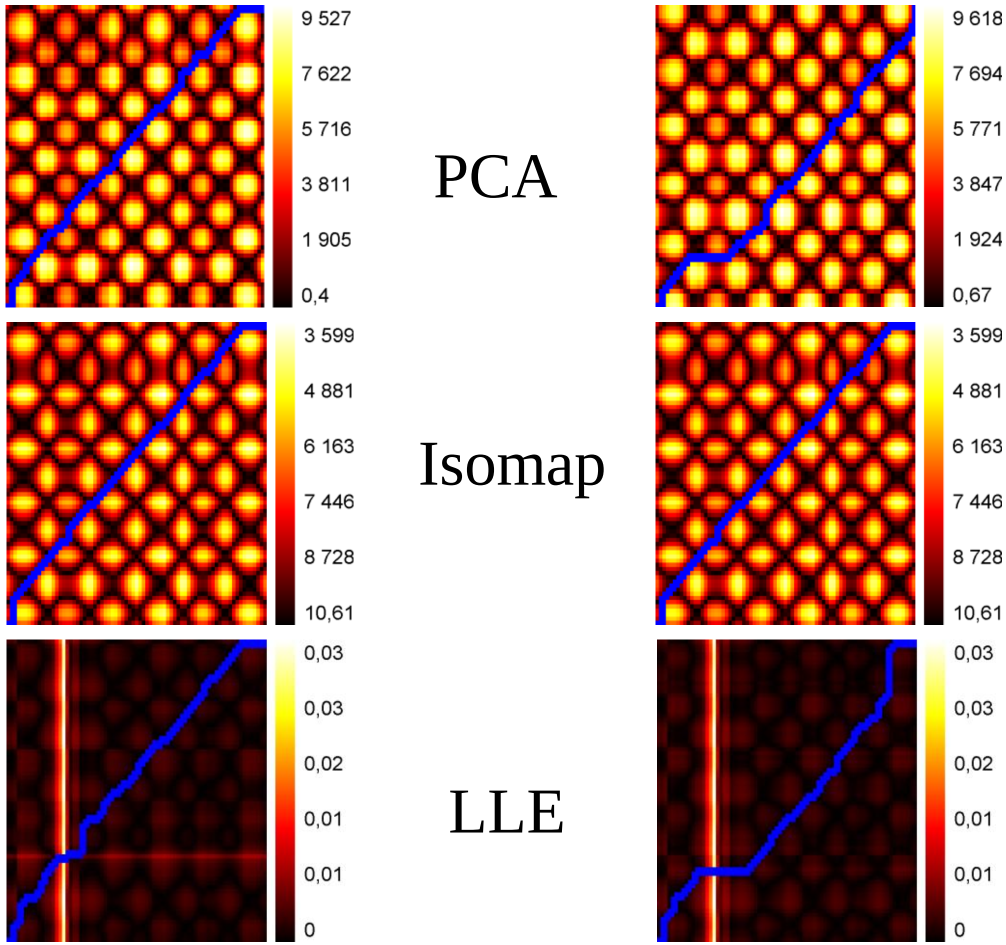
- Step 1: Dimensionality reduction

  - PCA

  - Isamap

  - LLE
- Step 2: DTW
- Step 3: Nearest neighbor (multiclass) classification

CASIA (A), step 1,2



fyc-fyc fyc-hy

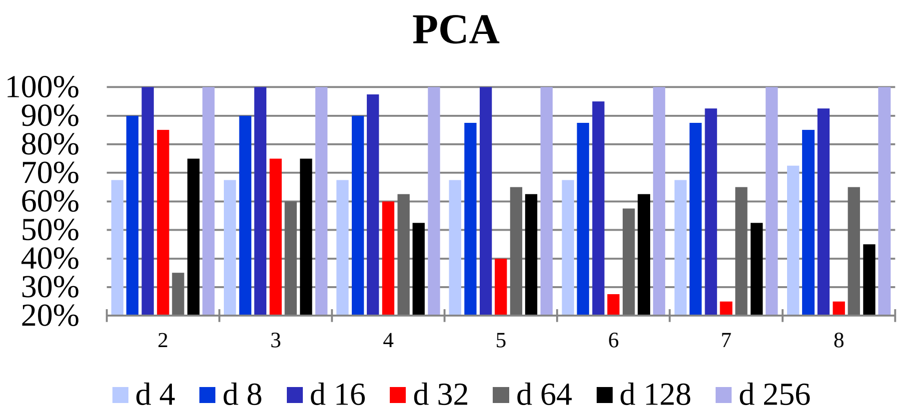
CASIA (A) step 3

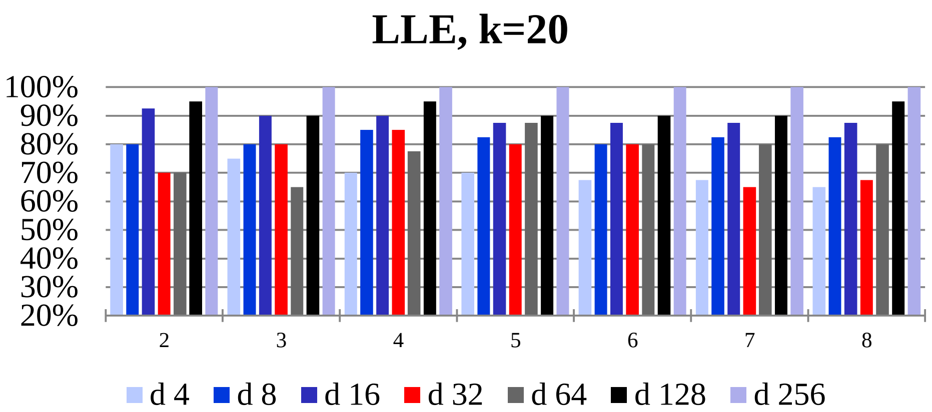
Wym.	PCA	Isomap	LLE
1	50,00%	60,00%	52,50%
2	57,50%	70,00%	70,00%
4	67,50%	77,50%	75,00%
8	70,00%	80,00%	77,50%
16	90,00%	82,50%	82,50%
32	95,00%	82,50%	92,50%
64	90,00%	80,00%	97,50%
128	87,50%	82,50%	97,50%
256	87,50%	82,50%	97,50%
512	85,00%	80,00%	87,50%

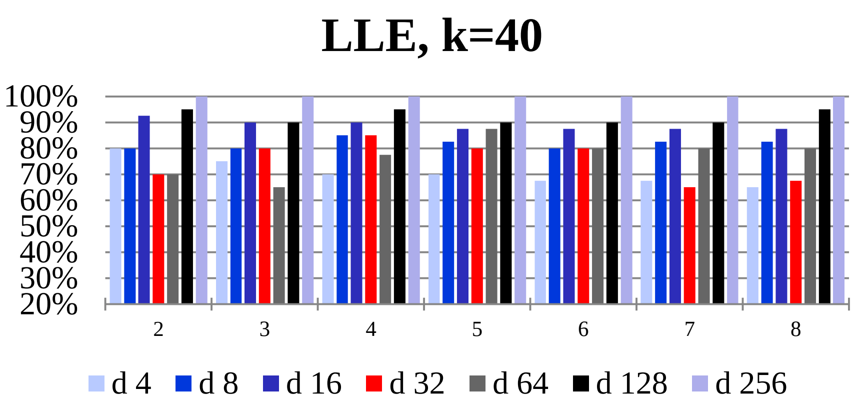
Video recordings, CASIA Algorithm 2

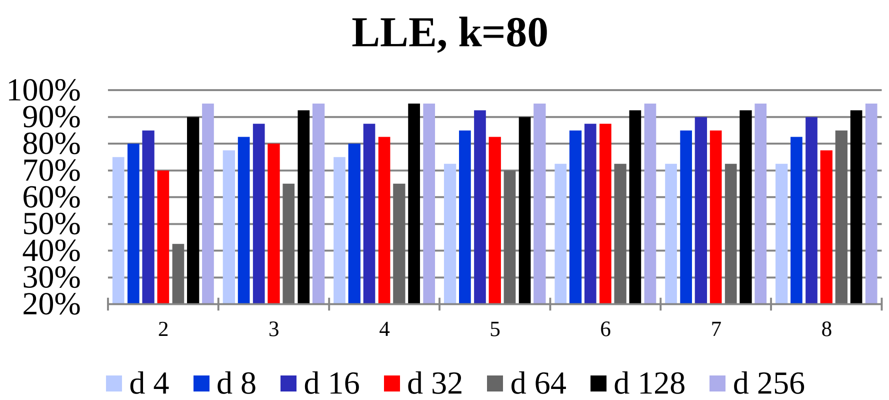
- Step 1: Dimensionality reduction
  - PCA
  - Isamap
  - LLE
- Step 2: HMM (Hidden Markov Model, Baum Welsch, Viiterbi algorithms)
- Step 3: Nearest neighbor (multiclass) classification

CASIA (A) HMM, step 3









Feature extraction and HMM-based classification of gait video sequences for the purpose of human identification, H Josiński, D Kostrzewa, A Michalczuk, A Świtoński, K Wojciechowski, Vision Based Systems for UAV Applications, 233-245

Video recording ⇨ skeleton model Algorithm 3,

Step 1 – estimation of skeleton joints

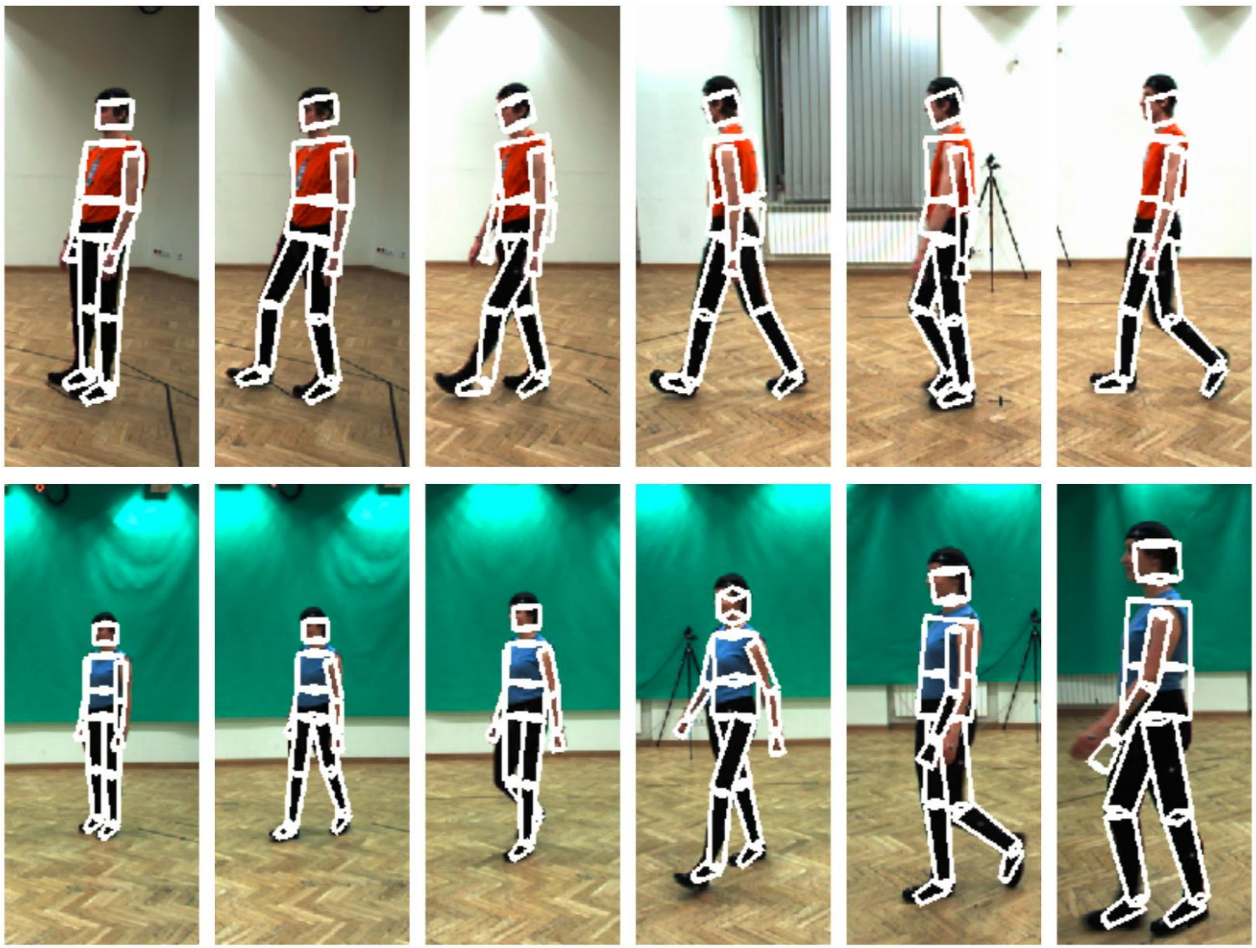
Step 2 – DTW

Step 3 – NN classifier

Adam Switonski, Tomasz Krzeszowski, Henryk Josinski, Bogdan Kwolek, Konrad Wojciechowski, (2018), Gait recognition on the basis of markerless motion tracking and DTW transform, **IET Biometrics, 2018, DOI: 10.1049/iet-bmt.2017.0134**

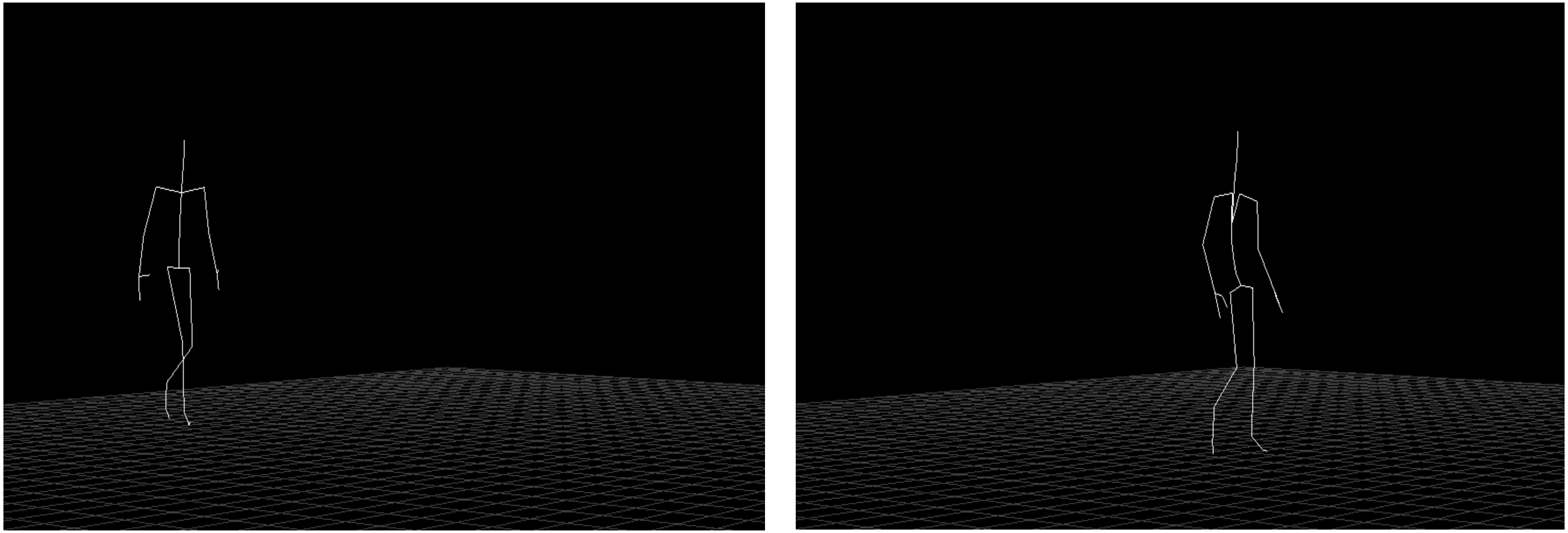
Balazia, M., Sojka, P.: 'Gait recognition from motion capture data'. ACM Trans. Multimedia Comput. Commun. Appl., special issue on representation,Anal. Recognit. 3D Hum., 2018, 14, (1)

Video recordings → skeleton model



OURS	**90.52**
1NN/PCALDA	69.83
1NN/MMC	81.03
1NN/raw DTW	64.66
1NN/PCALDA	47.41
1NN/MMC	67.24
1NN/raw DTW	48.28

Skeleton models, HML



Adam Switonski, Henryk Josinski, KonradWojciechowski, (2018), Dynamic TimeWarping in classification and selection of motion capture data, (under review).

Skeleton models, HML

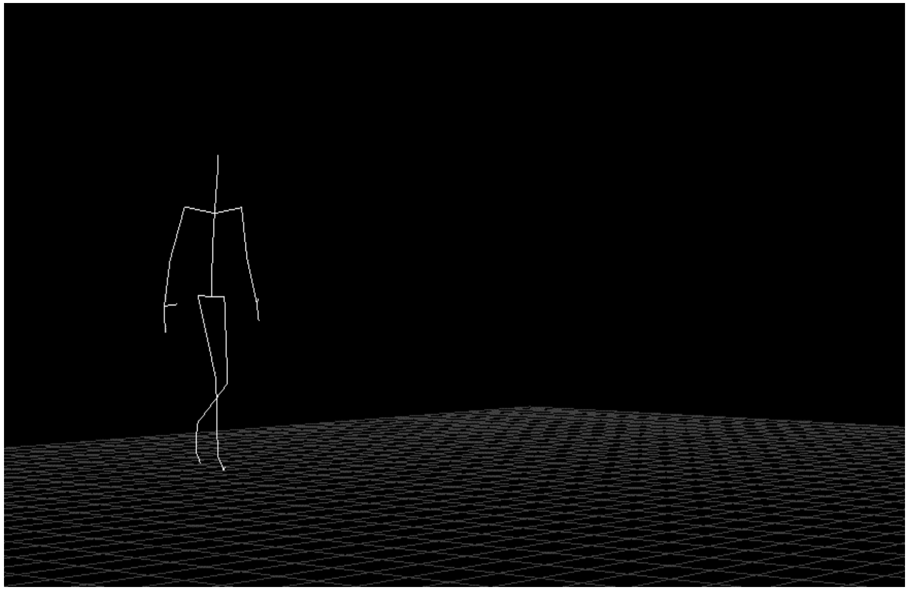
Combination of the DTW technique with distances between poses (skeletons) computed by using quaternion geodesic distances gives best results

	kNN	d_{Euc}		d_{Man}		$d^H_{geodesic}$		d^H_{cosine}		d^H_{TS}		d^H_C	
		TT	CV10	TT	CV10	TT	CV10	TT	CV10	TT	CV10	TT	CV10
Angles	1NN	87,64	99,77	85,96	99,54	90,45	99,77	84,27	98,85	90,45	99,77	84,27	98,85
	3NN	84,27	98,62	82,58	97,94	87,08	98,39	82,02	95,87	87,08	98,62	82,02	97,48
	5NN	82,58	97,71	83,15	94,50	86,52	97,94	82,58	94,50	85,39	97,48	82,58	94,50
Velocities	1NN	87,08	91,28	87,08	91,74	88,20	91,97	88,76	90,60	88,20	91,97	88,76	90,60
	3NN	88,76	89,45	88,76	90,37	89,89	89,45	86,52	88,99	89,89	89,45	86,52	88,99
	5NN	85,39	89,91	87,08	90,60	87,08	90,14	84,83	88,53	87,08	90,14	84,83	88,53
Acceler..	1NN	49,44	62,39	49,44	60,55	46,63	61,70	50,00	60,78	46,63	61,70	50,00	60,78
	3NN	41,57	52,98	38,76	50,92	43,26	51,83	43,82	49,08	43,26	51,83	43,82	49,08
	5NN	38,20	48,85	34,27	46,10	38,76	48,85	41,57	49,31	38,76	50,00	41,57	49,31

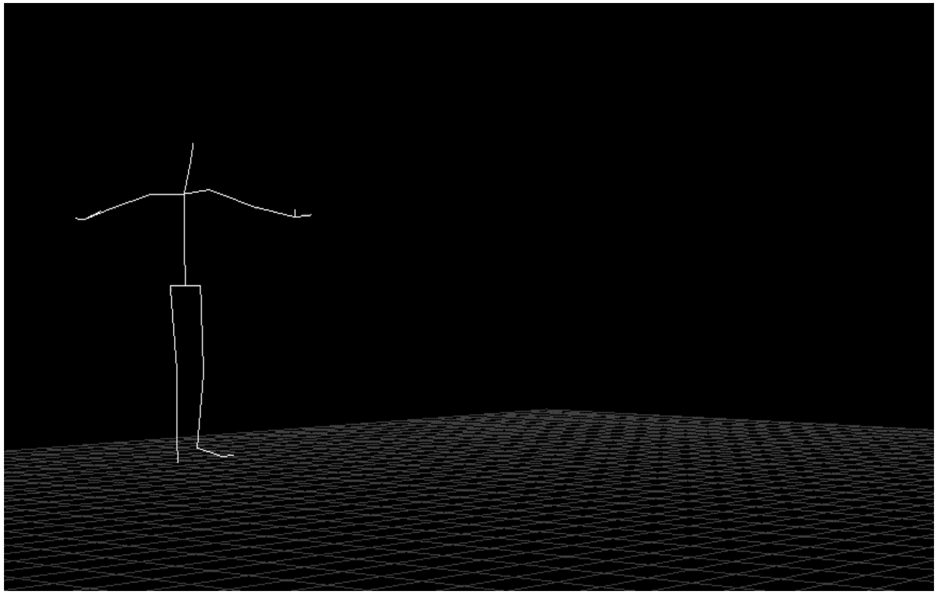
Table 1: DTW classification based on complete set of joints in respect to different number k of nearest neighbors and rotation distance functions.

Orthopedic diagnosis

Normal gait



Coxarthrosis patient



Świtoński, A. Mucha, R. Danowski, D. Mucha, M. Polański, A. Cieślar, G. Wojciechowski, K. Sieroń, A., (2011), Diagnosis of the motion pathologies based on a reduced kinematical data of a gait, Electrotechnical Review, R. 87, nr 12b, pp. 173--176

Summary, Conclusions

Summary, Conclusions

Forensic gait analysis

A PRIMER FOR COURTS

Forensic gait analysis: a primer for courts

Issued: November 2017 DES4929

THE ROYAL SOCIETY

The production of this primer on forensic gait analysis has been led by His Honour Judge Mark Wall QC and Professor Dame Sue Black DBE FRSE. We are most grateful to them, to the Executive Director of the Royal Society, Dr Julie Maxton CBE, the former Chief Executive of the Royal Society of Edinburgh, Dr William Duncan, and the members of the Primers Steering Group, the Editorial Board and the Writing Group. Please see the back page for a full list of acknowledgments.

Sir Venki Ramakrishnan
President of the Royal Society

Professor Dame Jocelyn Bell Burnell
President of the Royal Society of Edinburgh

Summary, Conclusions

- Forensic gait analysis, potentially very useful, is in its infancy
- Gait data as court evidence – extremely rare
- Gait Analyst is not a legally protected title
- No evidence to support the assertion that gait is unique within current or foreseeable limitations of measurements used in forensic gait analysis
- No credible database that permits assessment of the frequency of either normal or abnormal gait characteristics
- No published and verified error rates associated with the current methodology
- No published black-box studies of analyst reliability and repeatability
- no standardised methodology for analysis, comparison and reporting of gait characteristics

Summary, Conclusions

- Classification – most often – multiclass
- Must be considered together with gait modeling
- Closely related to many regression tasks
- Feature engineering (identification, construction, selection) is the main issue in gait classification
- Importance of gait cycle modeling (DTW)

Thank you for your attention