Measuring feet trajectories: challenges and applications

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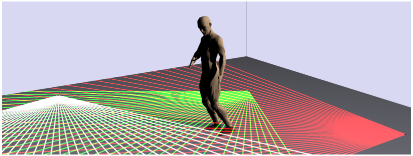

BEMEKO workshop on measurement: challenges & opportunities
Montefiore institute, University of Liège, Belgium — November, 7th 2013

Outline

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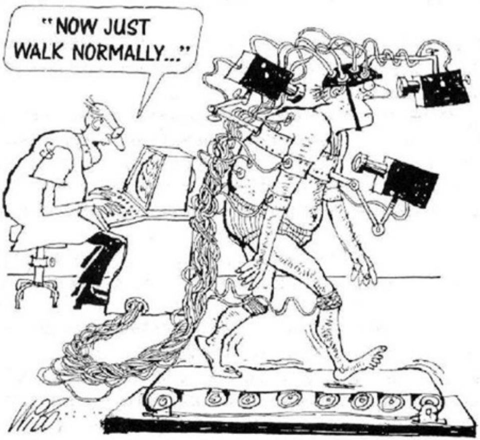
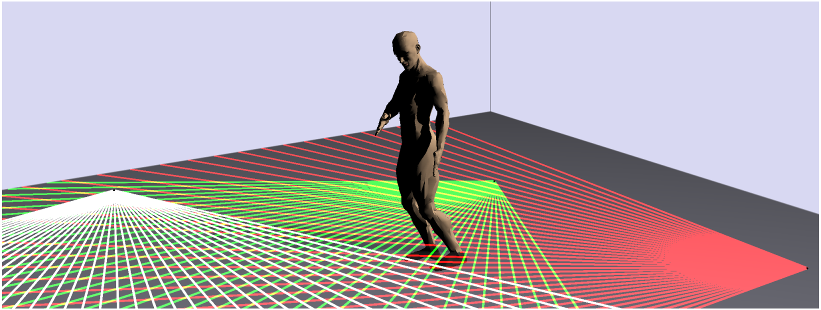
The motivation behind GAIMS



http://www.er.uqam.ca/nobel/r33400/kelvin.gif

GAIMS (*GAIt Measuring System*)

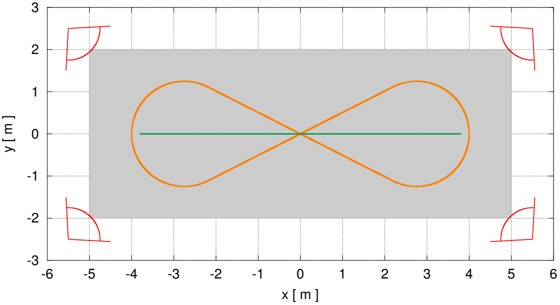
We aim at tracking the feet with a high accuracy and precision, without equipping the person with markers, sensors, *etc*.
A set of unsynchronized range laser scanners are scanning a common horizontal plane (15 *cm* above the floor).



- biometric identification
- follow-up of patients with neurological diseases

Example of application: gait analysis by neurologists

In our target application, 4 sensors (in red) scan a common horizontal plane at 15 Hz. The patients are asked to walk in 3 different modes (comfortable, as fast as possible, tandem) along a straight path (in green) or a ∞-shaped path (in orange).



We aim at estimating reliably the feet trajectories in the gray area. The maximal walking speed is 3.6 m/s ($\simeq 13\, km/h$).

Example of input : walk at preferred pace

(click here to play video)

Example of input : walk in tandem mode

(click here to play video)

Outline

1. Introduction
2. Noise affecting the global point cloud
3. Weaknesses of classical approaches
4. The proposed processing pipeline
5. Conclusion

Limited precision of the distance measurements

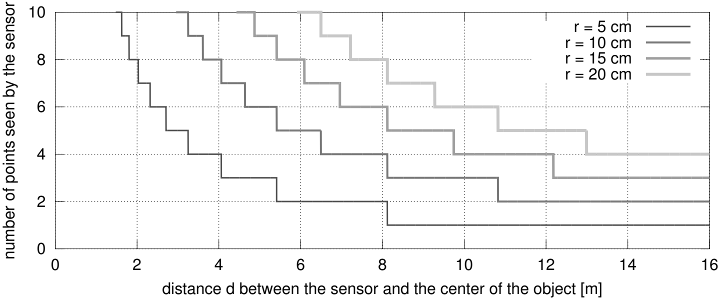
- There is a temporal variation of a few millimeters, and sometimes even a few centimeters, on the acquired distances.
- The sensors are disturbed by highly reflective materials (*e.g.* metal), and by black materials (in the infrared band).
- *Flying pixels* : at discontinuities in the distance profile, the sensors produce a random distance measure between the minimum and the maximum distance around the discontinuity.

Low angular resolution

The sensors measure distances in 274 directions spanning $\Theta \simeq 96°$.

The number of points seen on an object rapidly decreases when the object moves away from the sensor.

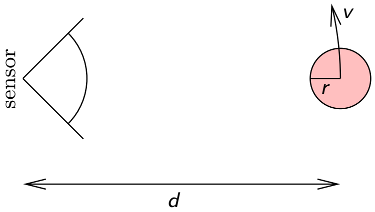
Let us consider a circular object of radius r, whose center is located at a distance d from the sensor. The sensor sees this object in an angle $\theta = 2 \arcsin\left(\frac{r}{d}\right)$, and a minimum of $\left\lfloor \theta \, \frac{274-1}{\Theta} \right\rfloor$ points.



Scanning duration

- The acquisition rate is 15 Hz.
- An internal mirror turns at $360 \times 15 = 5400\,°/s$.
- The infrared beam turns at $\Omega = 10800\,°/s$.
- A complete distance profile is acquired in $\frac{\Theta}{\Omega} \simeq 9\,ms$.

Let us consider an object of radius r, located at a distance $d \gg r$, and turning around the sensor with a small angular velocity ω. It can be showed that, due to its motion, the object is seen with an apparent radius $r' \simeq r\left(1 + \frac{\omega}{\Omega}\right)$.



v	d	error
$16km/h$	$1m$	2.36%

Asynchronism

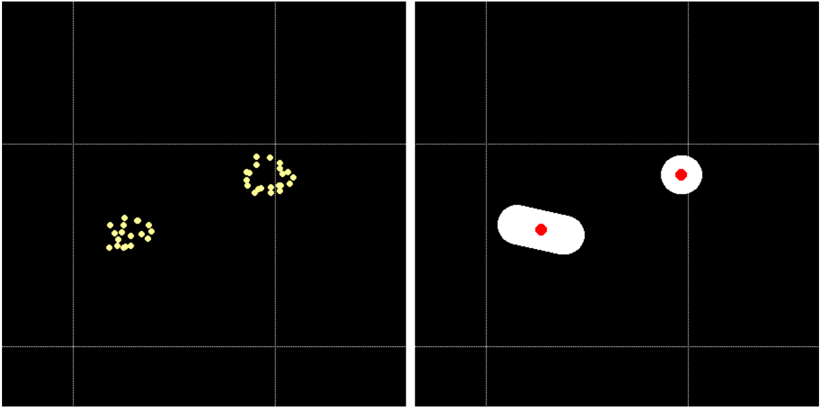
There may be a difference of $\frac{1}{15}\,s$ between the acquisition time of the points in the global point cloud. The displacement of the objects during $\frac{1}{15}\,s$ should be negligible in comparison to their size. Otherwise, the perceived shape of the objects would be highly altered.

Example

For a walking speed of $5\,km/h$, the maximal speed of the feet is approximately $16\,km/h$. Therefore, during $\frac{1}{15}\,s$, a feet can move by $29.6\,cm$. As this is larger than the size of the element, highly deformed global point clouds are expected, and advanced processing strategies are necessary.

An easy case (*e.g.* by clustering)

- Left: a cloud obtained by simulation with 4 sensors at 15 Hz. The grid size is 1 m.
- Right: ground truth. Red: the positions of the feet at the reference instant. White: the trace of the two feet during $\frac{1}{15}$ s.



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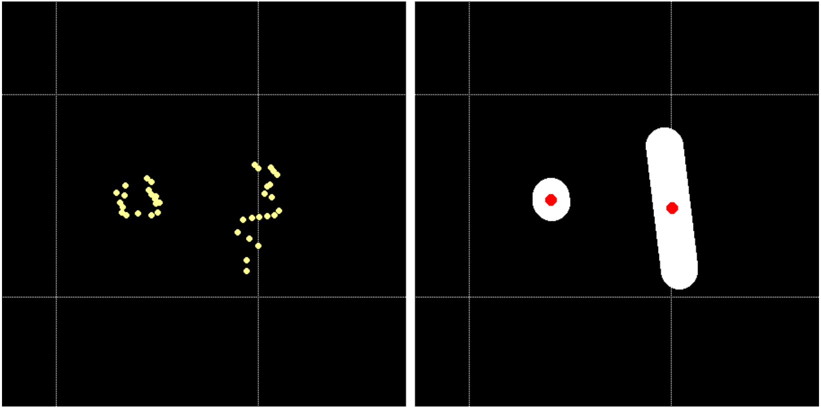

An easy case (only one foot moves)

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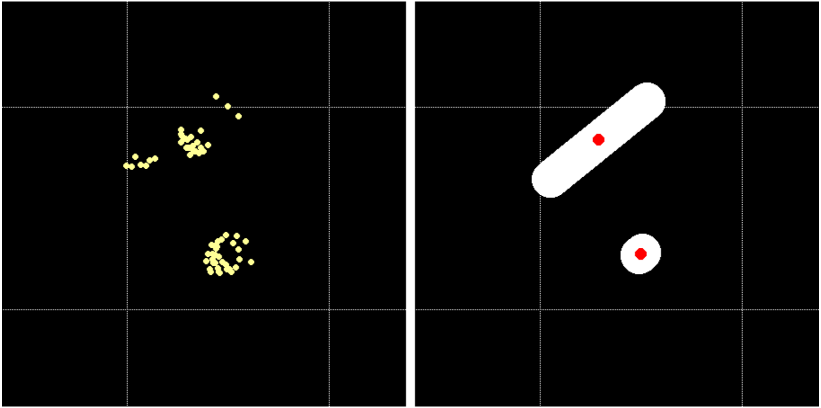

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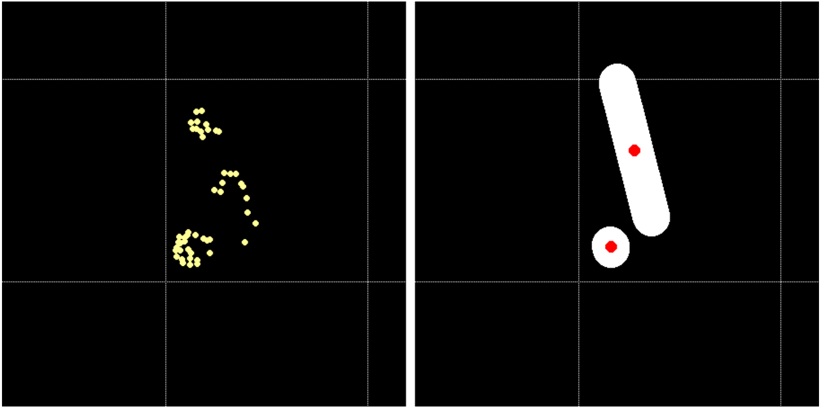

A difficult case (no separation)

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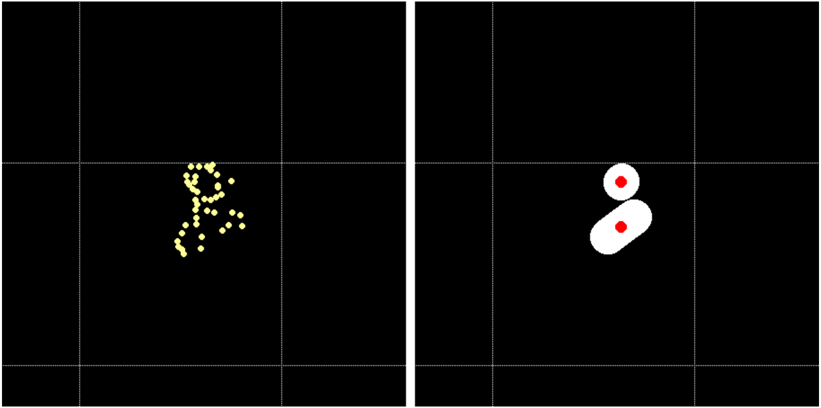

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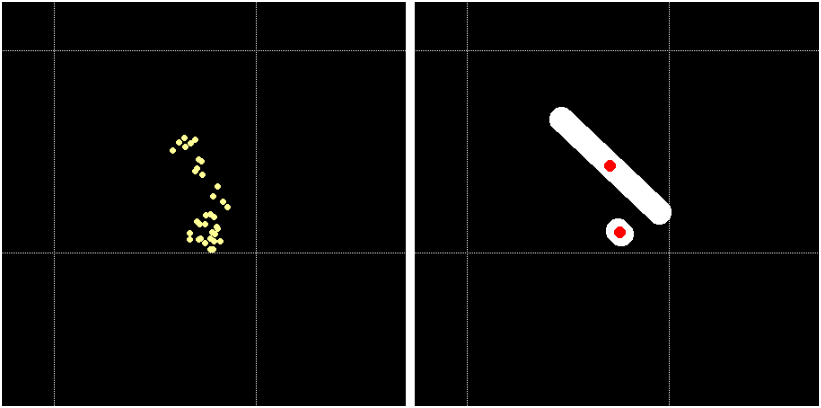

A difficult case (two possible movements)

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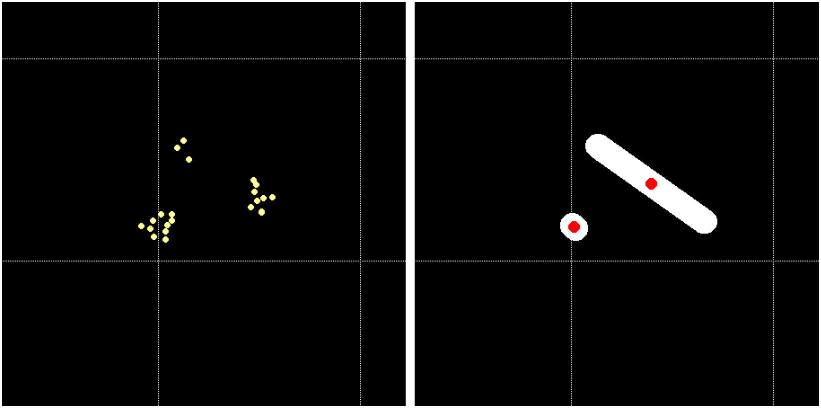

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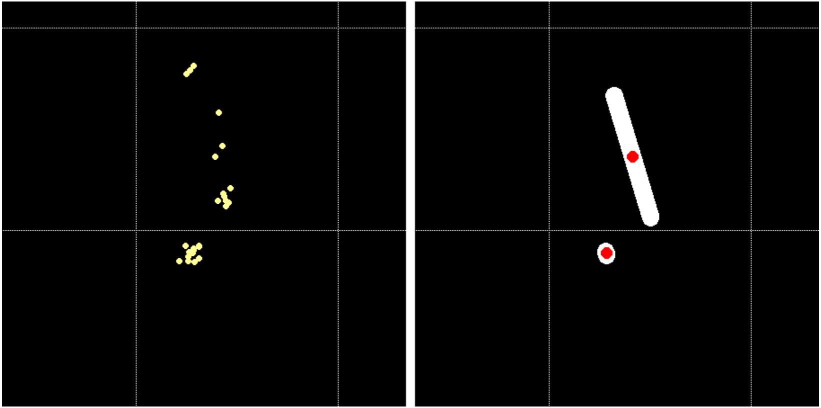

A difficult case (almost aligned points)

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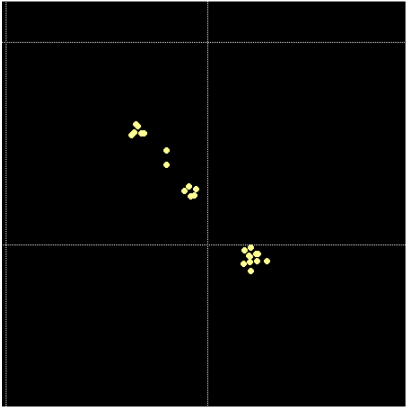
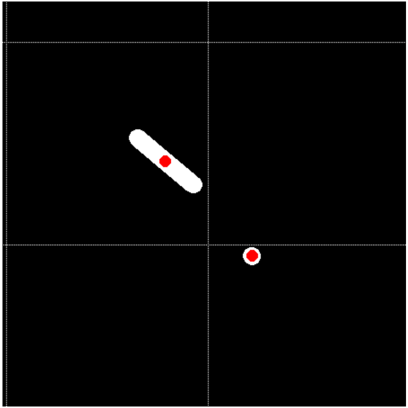




Outline

A classical processing approach

1. segmentation of the scene into its components (the walls, the objects, the legs, *etc*)
2. the location of each component is defined (usually by its centroid)
3. tracking coupled to data association techniques are used to estimate the trajectory of each component

Even if this processing flow is often encountered in the literature, it is inappropriate to measure the feet trajectories.

The classical pipeline: segmentation

1. Detecting the discontinuities in a distance profile
   - for a single sensor
2. Clustering a point cloud
   - it is difficult to separate the legs at the swing phase middle since they are very close
   - the deformation of the point cloud may also cause difficulties

The classical pipeline: localization

The blob's centroid is a biased estimation of its real location, which implies some bias in the resulting feet trajectories.

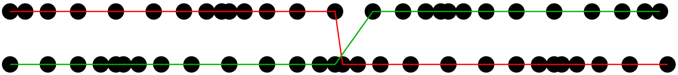
- the point clouds may be deformed :
  - motion of the feet
  - sensors asynchronism
- the points are not sampled regularly along the leg's contour :
  - a sensor sees only one side of the foot
  - (self-)occlusions

The classical pipeline: tracking with Kálmán

- Requires to specify a model of motion.
- Most models described in the literature are unrealistic:
  - constant velocity
  - constant acceleration in each phase of the gait cycle
  - only a few degrees of freedom
  - *etc*
- A model represents the average gait of the healthy population
- The role is to filter out the component of the signal which does not correspond to the predicted movement
- It is delicate to preserve the part of the gait which is specific to the observed person

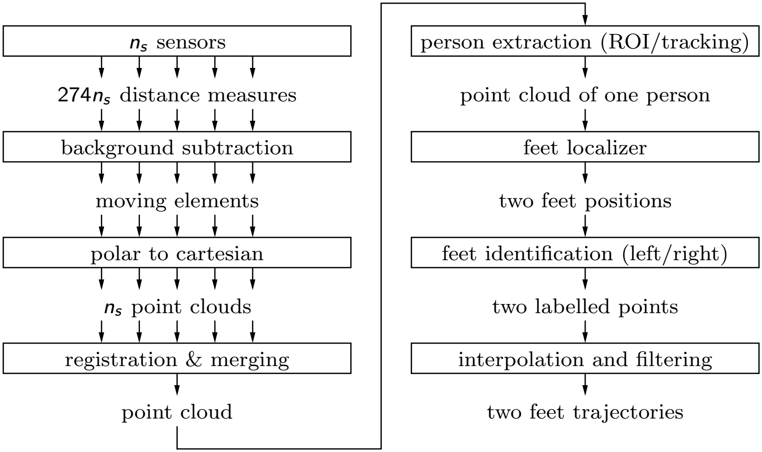
The classical pipeline: data association

- There is no information to distinguish between the left and the right feet
- The data association is thus typically performed thanks to the tracker
- A crossing between the two feet trajectories may occur, due to the proximity
- A crossing may have severe consequences for medical applications



Outline

The whole analysis stream



The feet trajectories measured and labeled by GAIMS can be used to derive many significant gait descriptors.

Results

GAIMS and our processing pipeline have been used successfully for the analysis of the gait of patients with multiple sclerosis

- We have found significant differences between healthy persons and patients with multiple sclerosis *[Phan-Ba et al.]*

  $\Longrightarrow$ a new tool to detect multiple sclerosis *[Azrour et al.]*

- We are able to detect subtle intra-subject gait modifications (*ataxia*) *[Piérard et al.]*

  $\Longrightarrow$ a new tool to estimate the state of the disease *[Azrour et al.]*

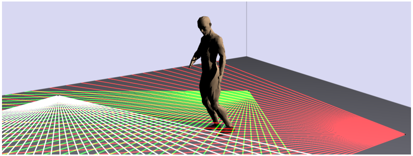
- We have found correlations with the quantity and quality of physical therapy and physical activity *[Giet]*

These findings show that our processing pipeline preserves the interesting (abnormal) components of the gait.

Outline

Conclusion

- GAIMS is a non-intrusive system measuring reliable feet trajectories (precise, accurate, insensitive to the appearance of clothes and to the lighting conditions, *etc*)
- The observed person does not need to be equipped with any active or passive marker, sensor, *etc*
- We proposed a new processing pipeline that is more effective than the traditional tracking paradigm
- It has proven to be useful for medical applications and could also be used for other applications



How to cite this work

S. Piérard, S. Azrour, R. Phan-Ba, and M. Van Droogenbroeck.
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GAIMS: a powerful gait analysis system satisfying the constraints of clinical routine.
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