CENTRE FOR AUTOMATION AND ROBOTICS

RED DE POSICIONAMIENTO Y NAVEGACIÓN EN INTERIORES.
Red de Excelencia del Ministerio de Economía y Competitividad
del Gobierno de España

Pedestrian Dead-Reckoning (PDR) Tutorial

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CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

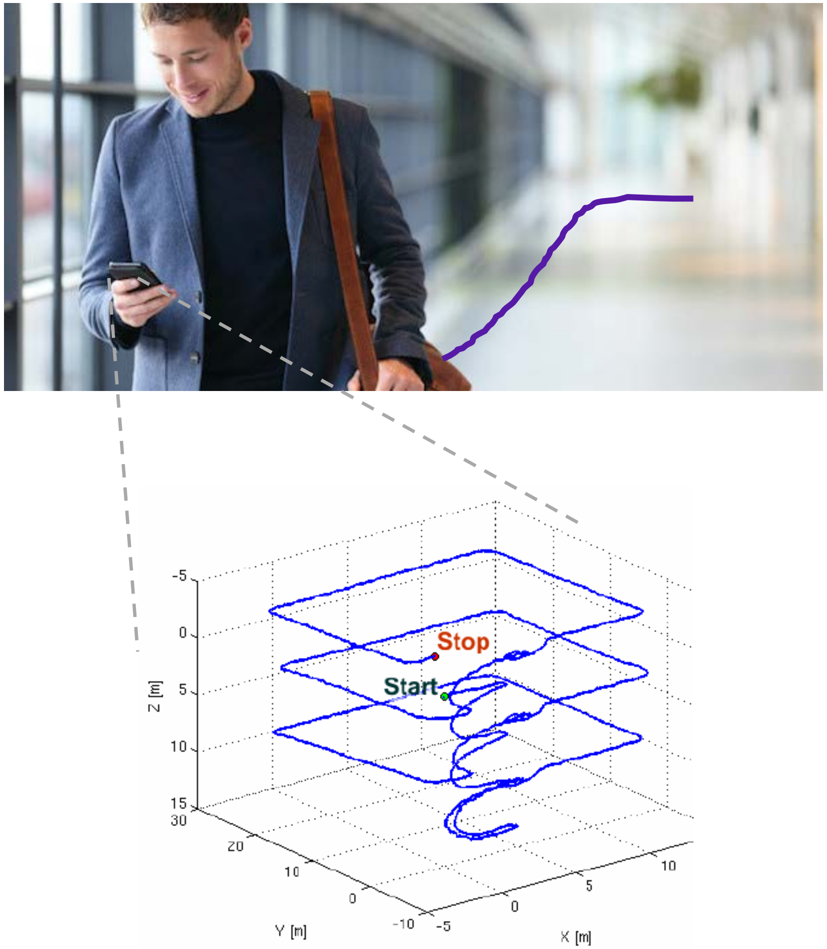
POLITÉCNICA

Outline

- Some theory:
  1. What is PDR?
  2. Inertial Navigation (INS)
  3. Implementation problems
  4. PDR algoritmic solutions
- Practice (Matlab):
  1. Introduction
  2. PDR with pre-recorded logfiles
  3. PDR with your own phone
- Evaluation (Kahoot)

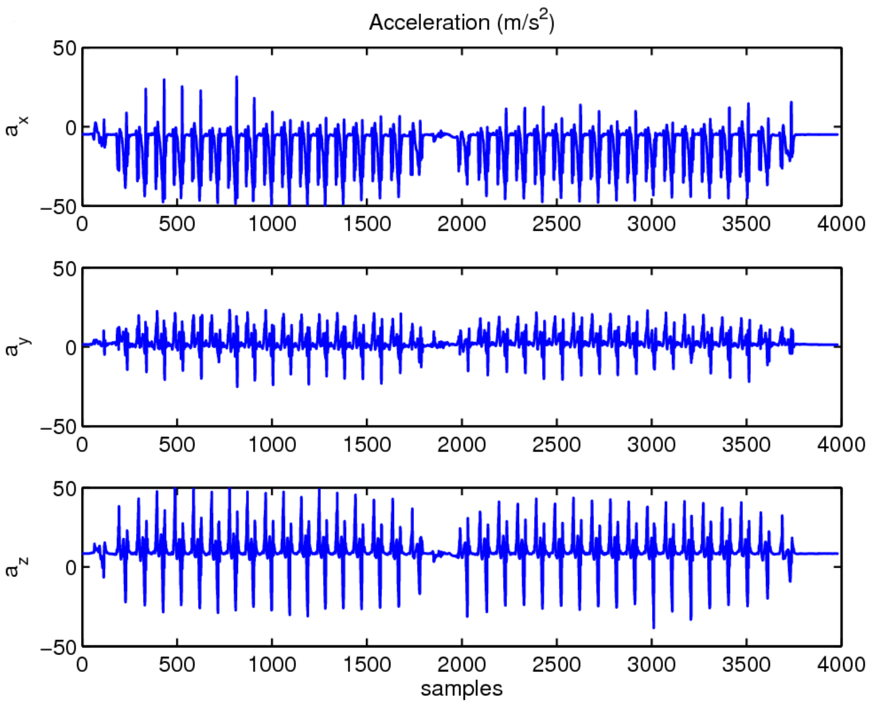
What is PDR?

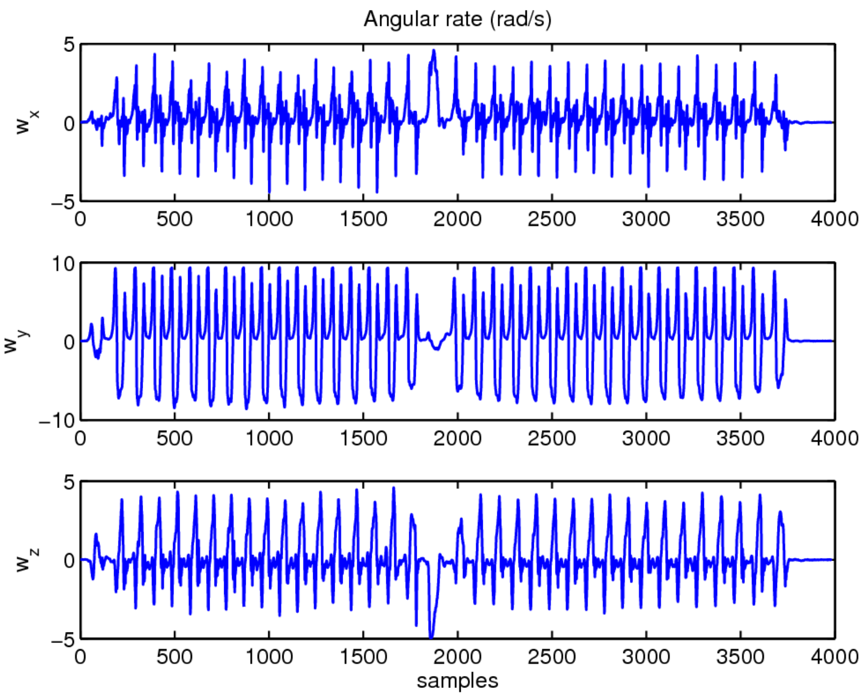
- A method to:
  - **estimate the user's trajectory** (Position & Heading)
  - by **integrating inertial measurements**
- No need of external beacons: GPS, Cell-positioning, LPS (WiFi, BLE, UWB, US, Light,…)
- Assumes known initial conditions:
  - position and orientation
- Uses Inertial data:
  - Acceleration (m/s^2)
  - Angular rate (rad/s)



What is PDR?

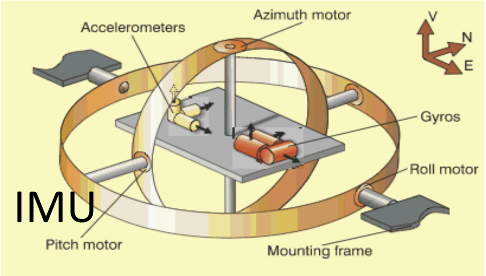
- «Acceleration & Angular rate» signals to integrate
  - Example: 60 meters walk
  - go (18 steps) + 180º turn (1 step) + return walk (18 steps)





What is PDR?

- Acceleration, Angular rate, trajectory integration … it sounds like «Inertial Navigation» or INS…



INS

- Can I use inertial navigation syst. (INS) for PDR?

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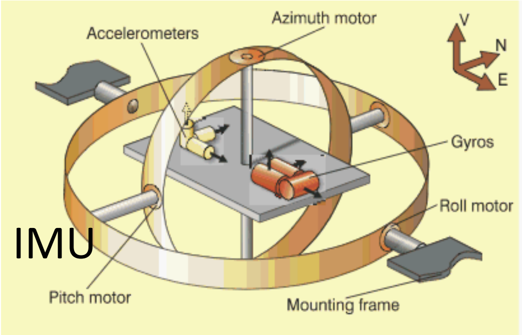
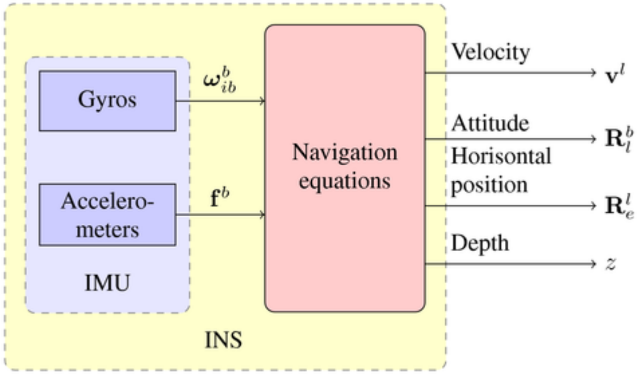
2. Inertial Navigation (INS)

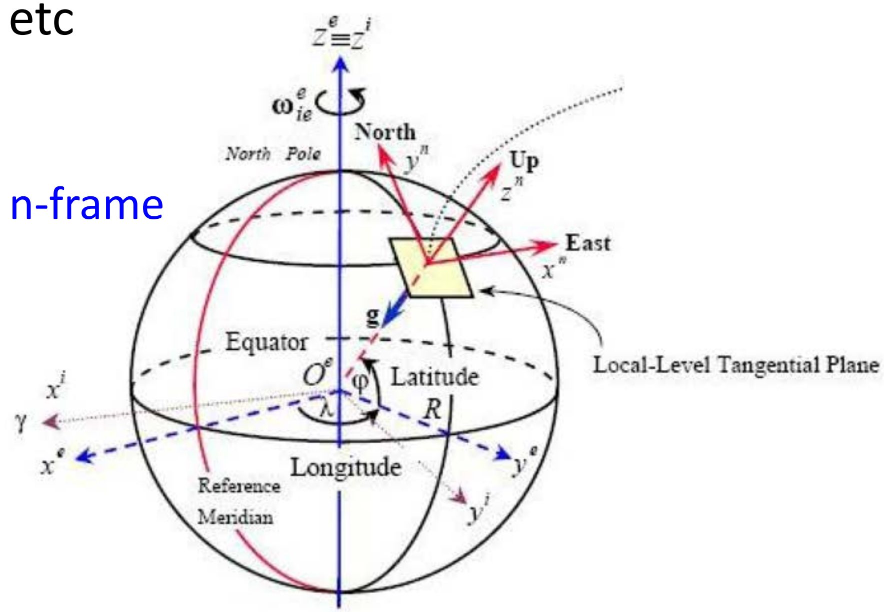
- INS
  - Uses an IMU (Inertial Measurement Unit)
    - 3 accelerometers (measuring “specific force” [m/s^2] caused by **motion** and also **gravity**)
    - 3 giroscopes (measure “angular rate” [rad/s])
  - Applies navigation equations integrating Inertial data
    - Starting from an initial position and pose, estimates the final trajectory of a moving object





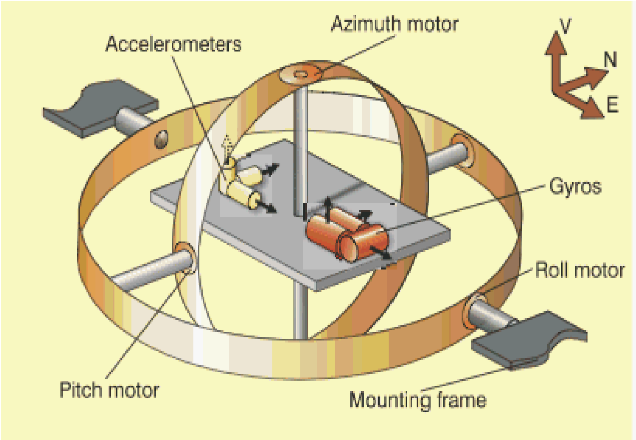
2. Inertial Navigation (INS)

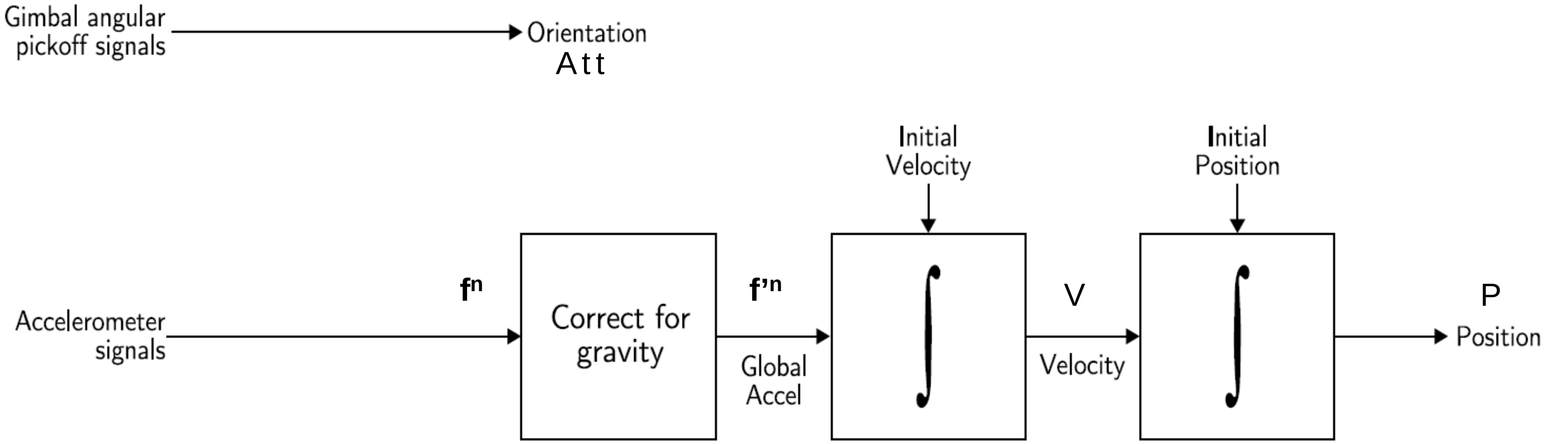
- Global Reference frame (n-frame o navigation) :
  - Inertial (Earth Centered), ECEF, Local (Leveled)
- Attitude:
  - 3D orientation of body IMU reference system (b-frame) respect to the global reference system (n-frame)
    - Euler: Roll, Pitch, Yaw,
    - Direction Cosine Matrix (DCM): $\mathbf{R_b^n}$,
    - Cuatertiones, etc



2. Inertial Navigation (INS)

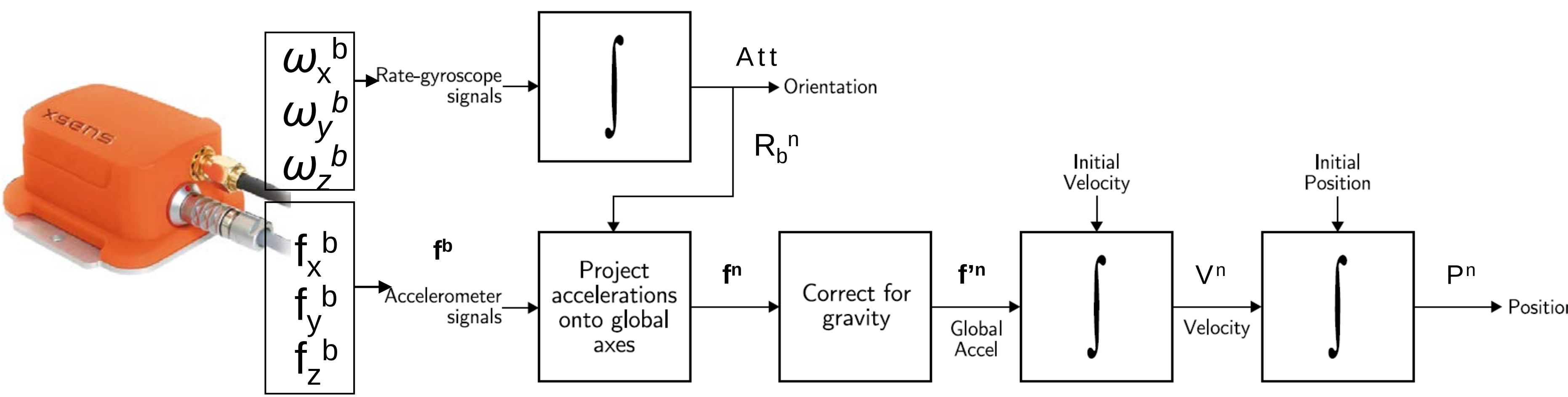
- 2 types of INS:
  - 1) INS with stabilized platform
    - Stabilized with motors to keep gyro signals to zero.
    - Readings of axis: (Roll,Pitch,Yaw) directly gives the Attitude
    - Accelerometer signals are in n-frame => so INS is only substract "gravity", and double integration to get P and V





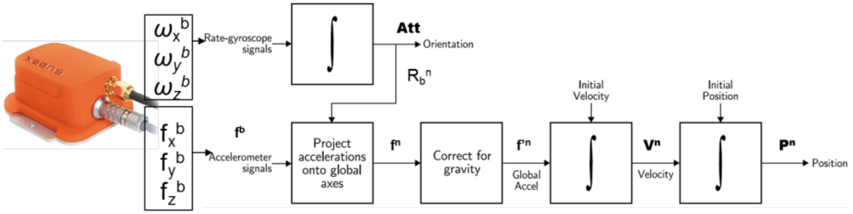
2. Inertial Navigation (INS)

- 2) Strap-down INS:
  - No stabilized platform. 3 Acc y 3Gyr fixed respect the body.
  - Integrate velocity (Gyro) to keep track of Attitude (R_b^n)
  - Transform especific force (f^b) measureed by acelerometers in b-frame to n-frame (f^n) using Attitude.
  - Eliminate gravity (g) to that acceleration (f^n), obtaing: f'^n
  - Integrate f'^n to obtain velocity (V^n), and again to get position (P^n)



2. Inertial Navigation (INS)

- Strap-down INS: Implementation in Matlab




```
%----------------------------------------------------------------------------
%  INS
%  Acc: IMU Acelerometer signal (3 axis) [m/s^2]
%  Gyr: IMU Angular Rate signal (3 axis) [rad/s]
%  fs:  Frecuencia muestreo [Hz]

% Actualizar matriz de orientación con valores de los "Gyros"
SkewGyros=[0 -Gyr(i,3)  Gyr(i,2);...
        Gyr(i,3)  0  -Gyr(i,1);...
        -Gyr(i,2) Gyr(i,1) 0]*pi/180; % rad/s
Rot_nb(:,:,i)=Rot_nb(:,:,i-1)*(2*eye(3)+SkewGyros/fs)*inv(2*eye(3)-SkewGyros/fs); % Pade(1,1)
```

2. Inertial Navigation (INS)

- INS concept is easy and we have the code

- So, PDR problem is solved:
  - Let’s take an IMU and
  - implement PDR as INS !!!

- Any problem with that?
  - Yes, several….

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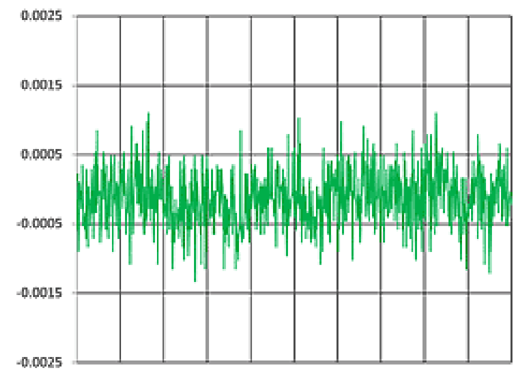
3. Implementation problems

- The size and weight of IMU:
  - Pure INS solutions require bulky sensors
  - Not good to be carried by a person in PDR

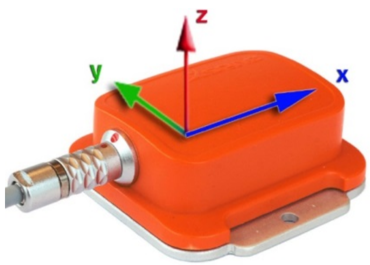
MEMS

3. Implementation problems

- The noise in the MEMS IMU:
  - Additive noise in Acc & Gyr readings
  - Bias (systematic, unstability, turn on)
  - Ortogonality, scaling, thermal .....



- Noise generates:
  - Integration errors
  - Errors in Attitude



Xsens Mti:

Acc

Acceleration Range (g)	VRW ($\mu g/\sqrt{\text{Hz}}$)	BRW (mg)
$\pm 5/18$	122	0.05

Gyr

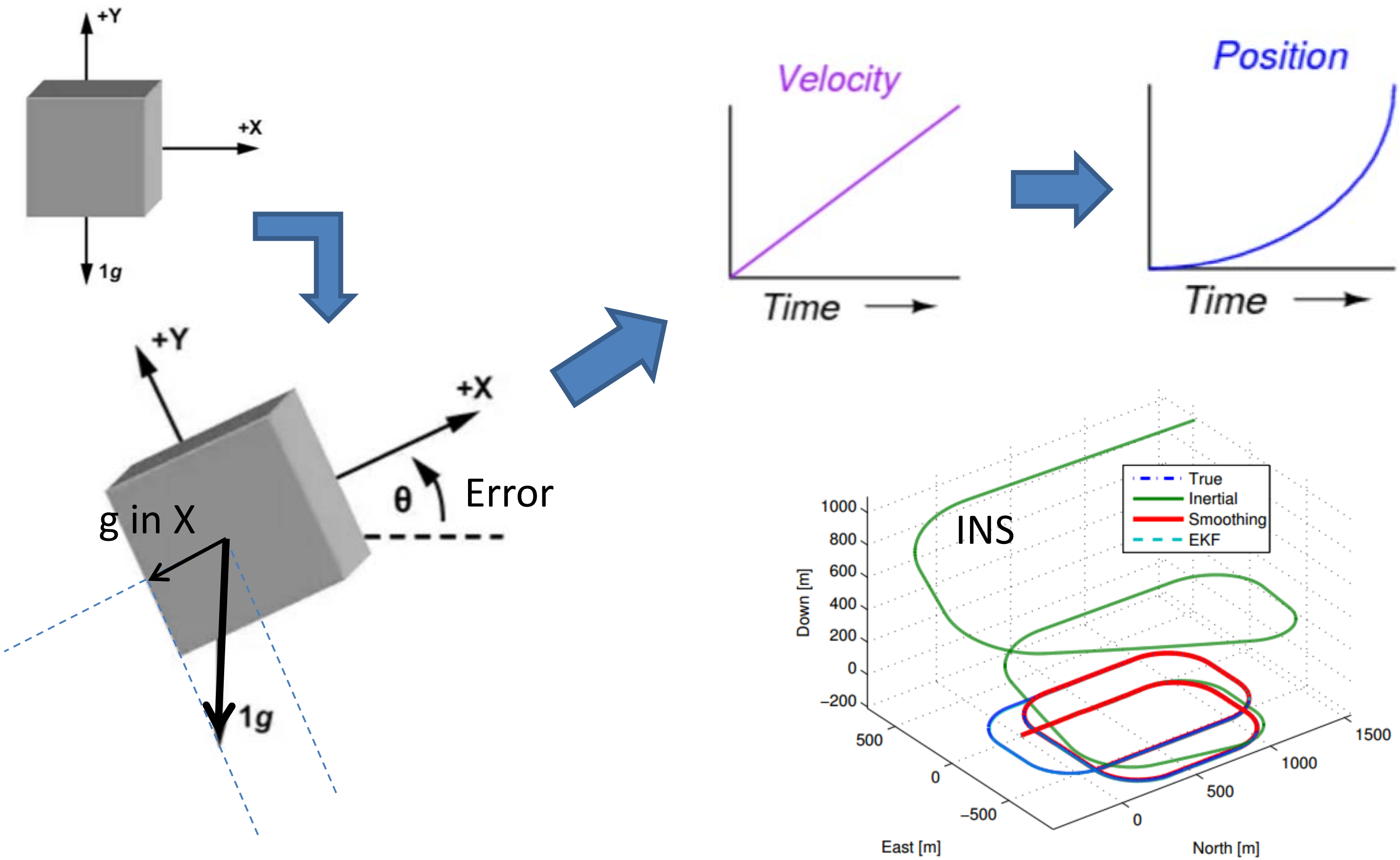
Angular Rate Range ($^\circ$/s)	ARW ($^\circ/\sqrt{\text{hr}}$)	BRW ($^\circ$/hr)
± 300	3	50

Static accuracy (roll/pitch)	<0.5 deg
Static accuracy (heading)[1]	<1 deg
Dynamic accuracy	2 deg RMS
Angular resolution	0.05 deg

[1] in homogeneous magnetic environment

3. Implementation problems

- Attitude error => gravity to leak as acceleration



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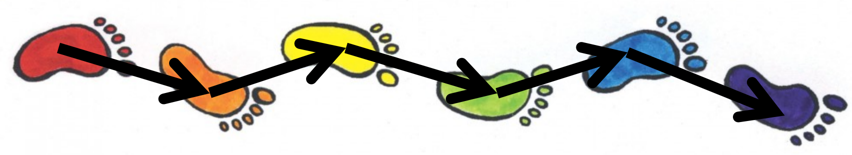
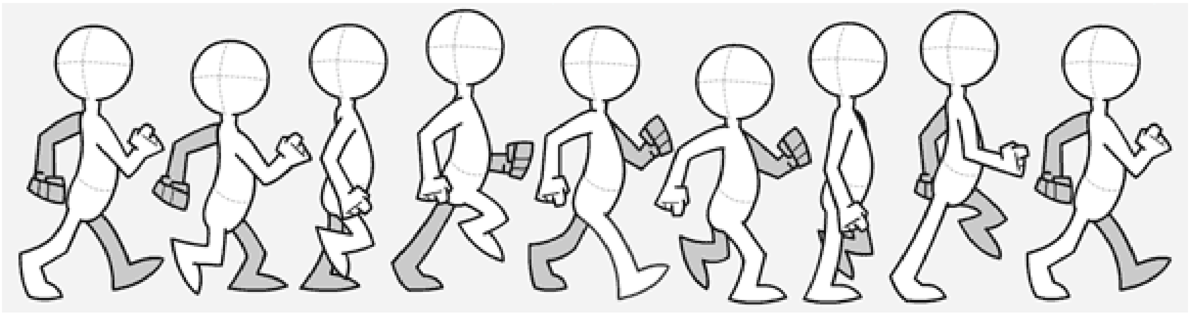
4. PDR algorithmic solutions

- Ways to improve INS for Pedestrians:
  - 1) Split the INS problem into pieces: Step by step

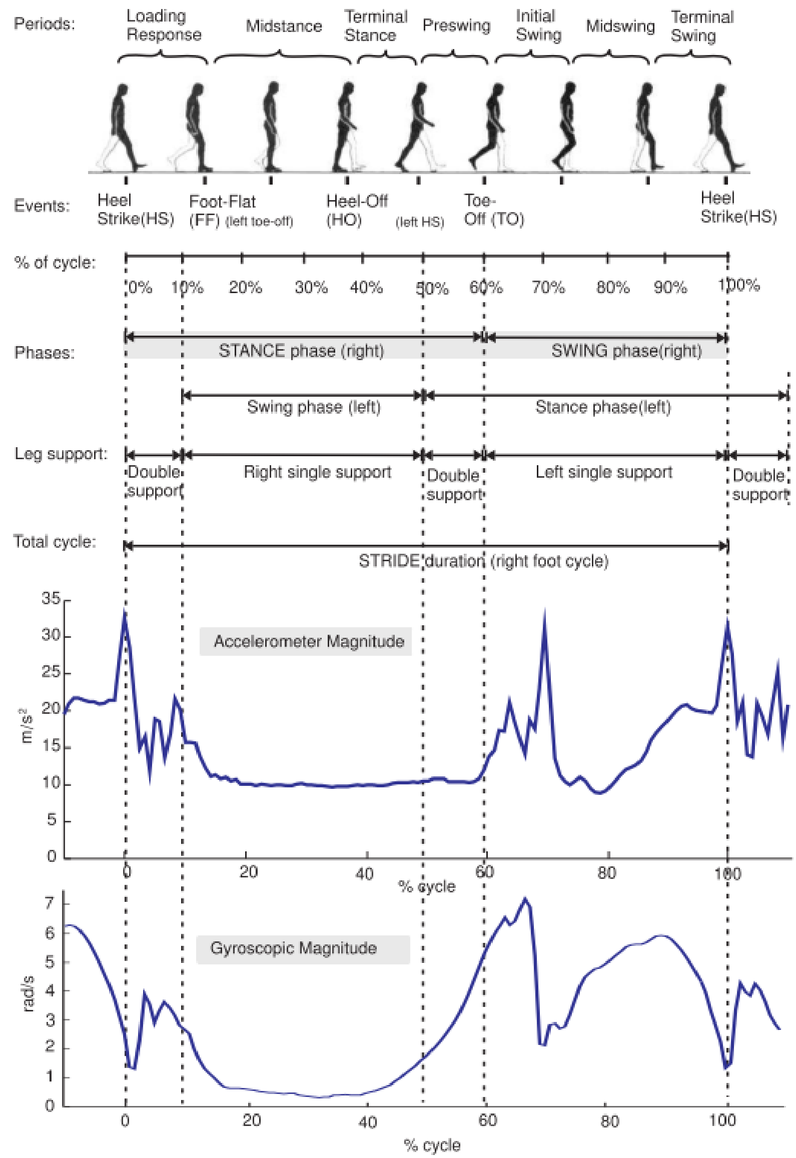


  - 2) Apply human motion models:
    - Step frequency: 1Hz (useful for signal filtering and stance length estimation),
    - Foot on floor (if IMU at foot => Velocity=0 at stance; ZUPT)



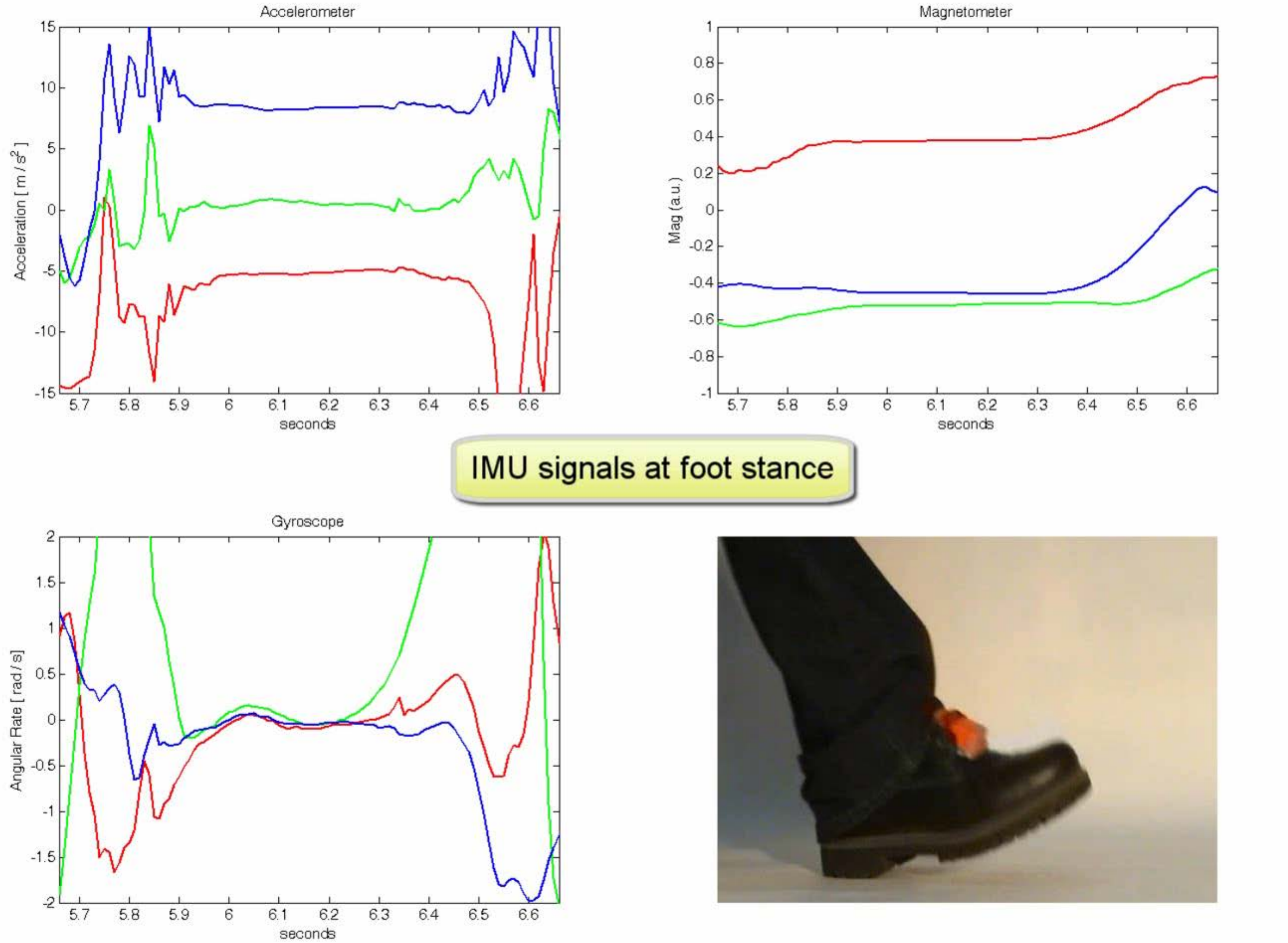
4. PDR algorithmic solutions

- Walking Phases:
  - 2 states (stance and swing) and 7 different phases
  - The stance (60%) and swing (40%) phases
  - For a foot-mounted IMU: Magnitude of Acc & Gyr are stable during Midstance (central stance phase)



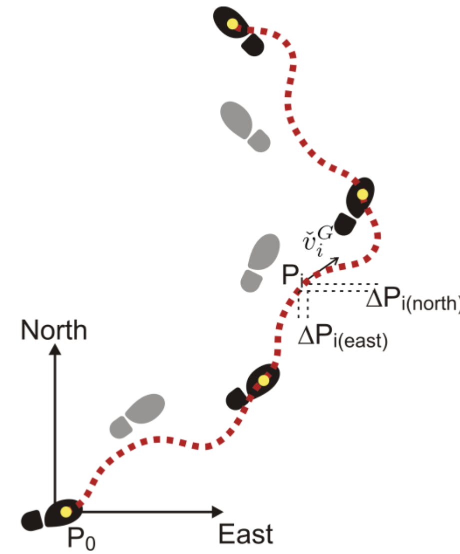
4. PDR algorithmic solutions

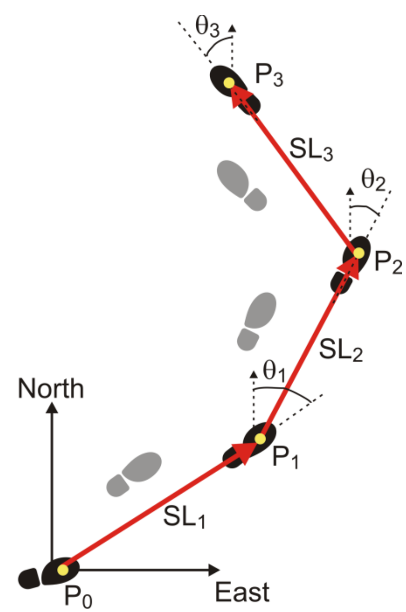
- Foot-attached IMU signals at stance:



4. PDR algorithmic solutions

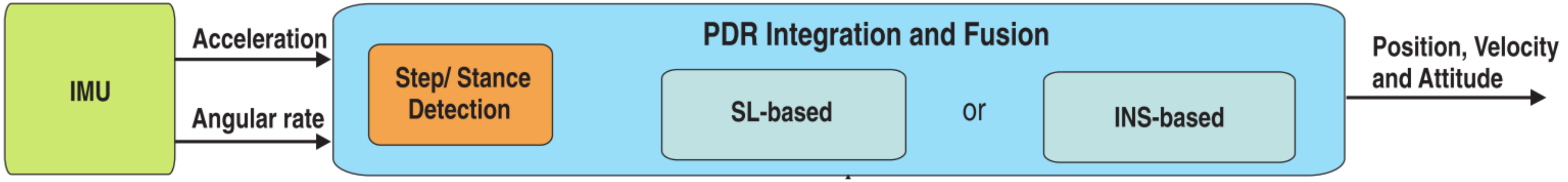
- There are 2 main types of PDR algorithms:
  - "**INS-ZUPT**": Integrates accelerations (INS) and correct velocities with zero velocity updates (ZUPT) at stance. IMU must be on foot.
  - "**SL+θ**": Accumulates Stride Length (SL) estimations, along the Orientation angle (θ) at foot stance. General purpose (IMU anywhere)





4. PDR algorithmic solutions

- General block diagram for an IMU-based Pedestrian Navigation System:



4. PDR algorithmic solutions

- Step detection

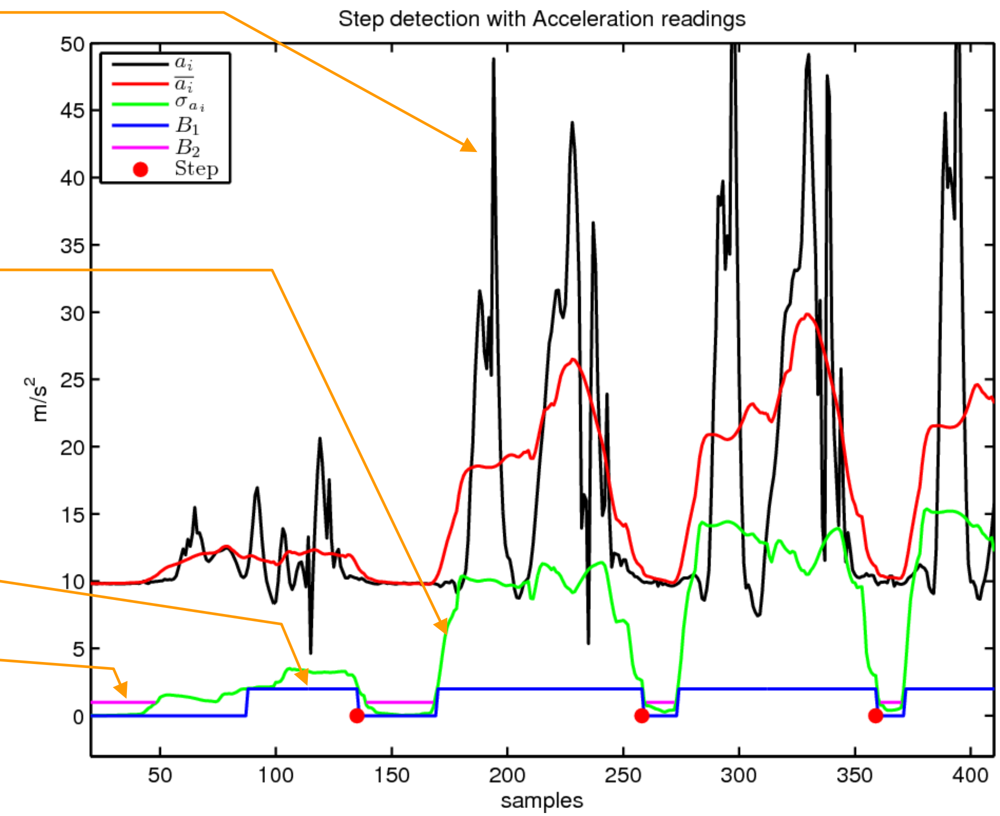
- Step Detection Methods
  - Ad-hoc
    - Signal Thresholds
    - Multicondition Thresholds
    - Zero-crossing
    - Peak detectors
  - Advanced Processing
    - Wavelet Transform
    - Gait Phase Classification
  - Additional Sensors
    - Pedometer
    - Contact foot-switches
    - Foot radar

4. PDR algorithmic solutions

- **Step detection** using Accelerometers:

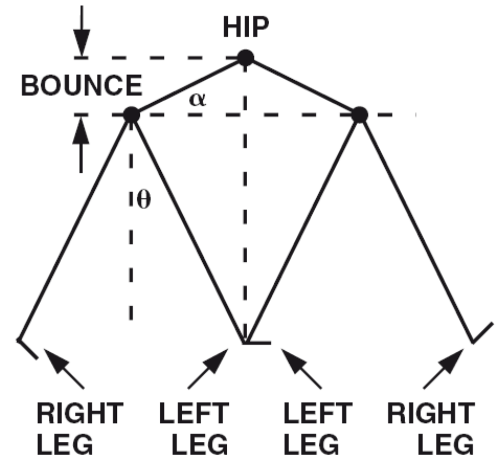
Magnitude of acceleration

1 $$a_i = \sqrt{a_{x_i}^2 + a_{y_i}^2 + a_{z_i}^2}$$



4. PDR algorithmic solutions

- **Step Length** (SL) Weinberg Algorith.
  - Assumes SL is prop. to BOUNCE (vertical movement of hip)
  - Bounce estimated from largest Acc.



1 Magnitude of acceleration

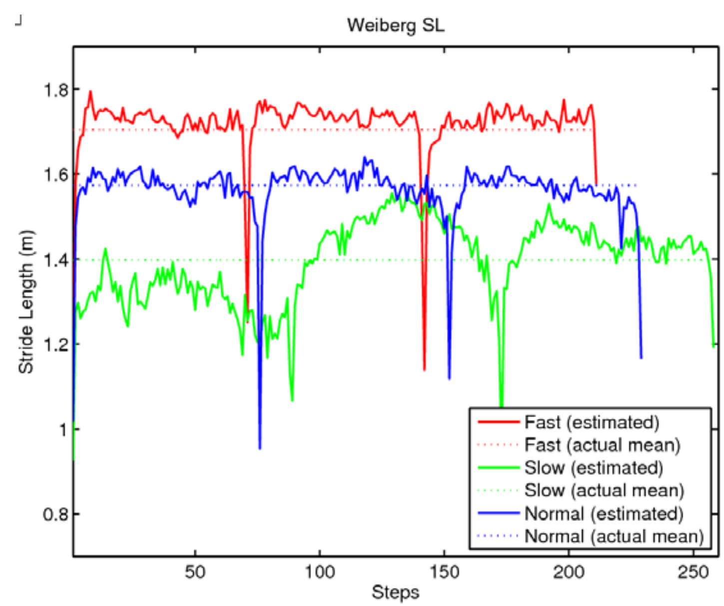
$$a_i = \sqrt{a_{x_i}^2 + a_{y_i}^2 + a_{z_i}^2}$$

2 Low-Pass Filter

$$\tilde{a}_i = LP(a_i)$$

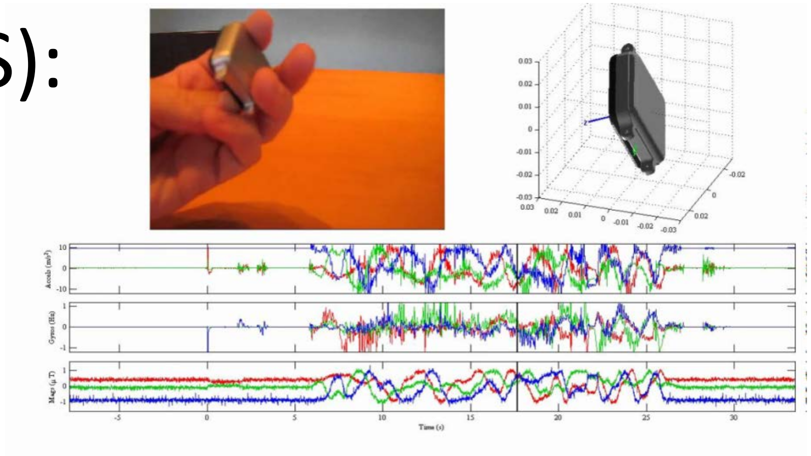
3 Weiberg hip bounce model

$$SL_{Weiberg_k} = K \cdot \{\max_{j=[i_{(k)} \pm w]}^{\tilde{a}_j} - \min_{j=[i_{(k)} \pm w]}^{\tilde{a}_j}\}^{1/4}$$



4. PDR algorithmic solutions

- **Attitude** estimation (AHRS):



  - Orientation from gyroscopes :

$$\omega^s = (\omega_x^s, \omega_y^s, \omega_z^s)$$ Gyro signals

$$C(t) = C(0) \cdot exp\left(\int_0^t \Omega(\tau) d\tau\right)$$

C (rotation matrix) computed integrating the skew simetric matrix from an initial orientation

  - Orientation from accelerometers / magnetometer (absolute reference):

$$m^s = (m_x^s, m_y^s, m_z^s)$$ magnetometer signals

$$a^s = (a_x^s, a_y^s, a_z^s)$$ acceleration signals

$$\phi = \tan\left(\frac{a_y^s}{a_z^s}\right)^{-1}$$ Pitch

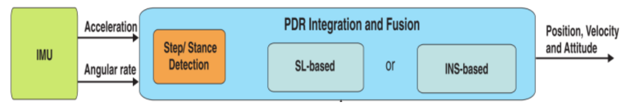
$$\theta = \tan\left(\frac{-a_x^s}{\sqrt{(a_y^s)^2 + (a_z^s)^2}}\right)^{-1}$$ Roll

$$\psi = \tan\left(\frac{-m_x^h}{m_y^h}\right)^{-1} \pm D$$ Yaw

  - Some Integrated AHRS algorithms (optimal weighting):
    - Madwick AHRS algorithm (Gradient descent optimization gyro vs. accel/magne).
    - Mahony AHRS algorithm (complementary filter)

$$q_{fused}(k) = \gamma \cdot q_g(k) + (1 - \gamma) \cdot q_{a/m}(k)$$

4. PDR algorithmic solutions

- **PDR Algorithm: "SL+θ":** 

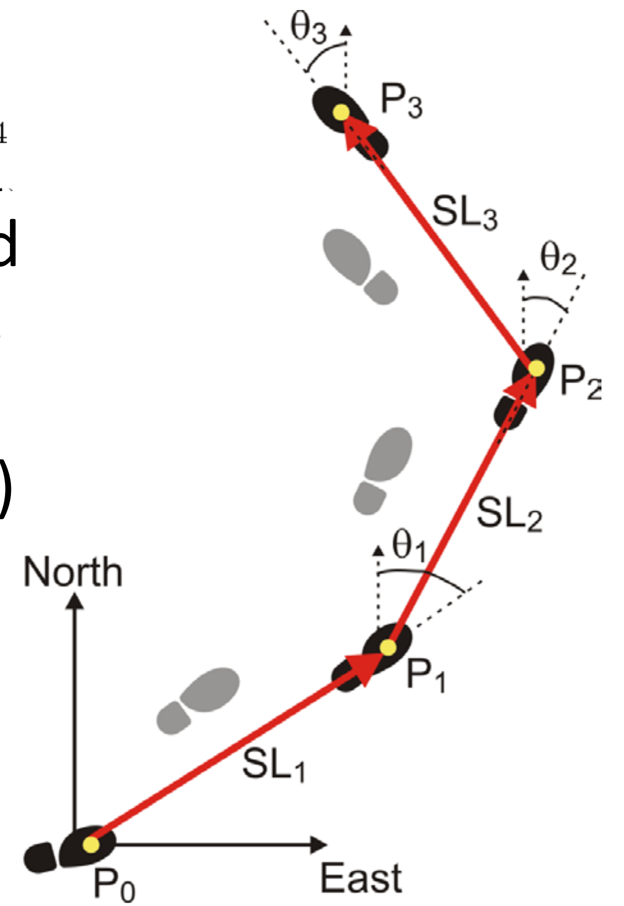
  - The SL can be computed, e.g.:

$$\mathrm{SL}_{\mathrm{Weiberg}_k} = K \cdot \{\max_{j=[i_{(k)} \pm w]}^{\tilde{a}_j} - \min_{j=[i_{(k)} \pm w]}^{\tilde{a}_j}\}^{1/4}$$

  - The θ angle at foot stance, computed using gyros (& opt. magnetometers).
  - Accumulates Stride Length (SL) estimations along the Orientation (θ)

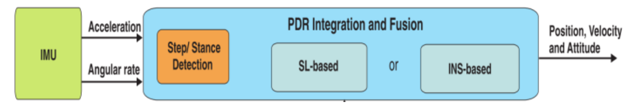
$$\begin{cases} P_k(\mathrm{north}) = P_{k-1}(\mathrm{north}) + \mathrm{SL}_k \cdot cos(\theta_{\mathrm{stance}_k}) \\ P_k(\mathrm{east}) = P_{k-1}(\mathrm{east}) + \mathrm{SL}_k \cdot sin(\theta_{\mathrm{stance}_k}), \end{cases}$$

  - "K" number of steps
  - Method valid con "normal" walking (only forward walk).

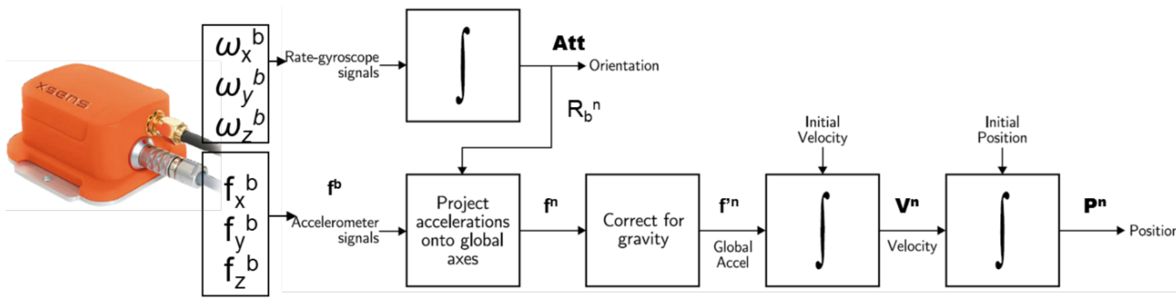


4. PDR algorithmic solutions

- **PDR Algorithm: "INS-ZUPT" :**



  - Integrate accelerations to obtain velocity (INS).



  - Correct velocity at foot stance (ZUPT).

3

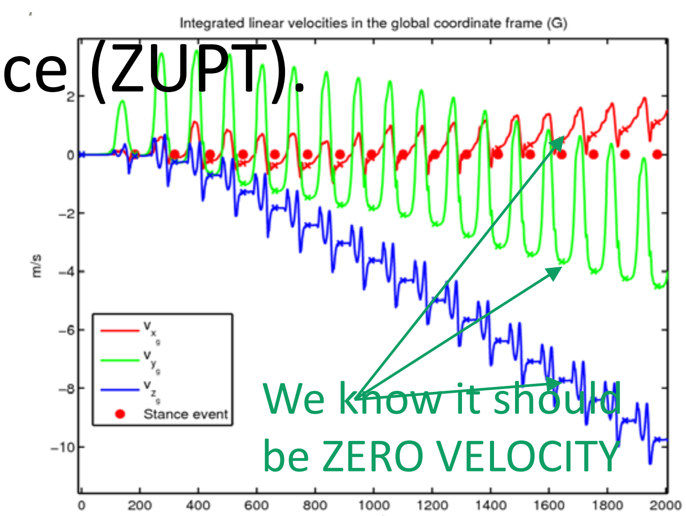
Correct v_i^G

3a Mean velocity stance k

$$\mu_k = \sum_{j=i_{(k)}-w}^{s_{(k)}+w} v_j^G/(2w+1)$$

3b Correct all samples in step by interpolation

$$\check{v}_i^G = v_i^G - [\mu_k(i - i_{(k-1)}) + \mu_{k-1}(i_{(k)} - i)]/m_k$$



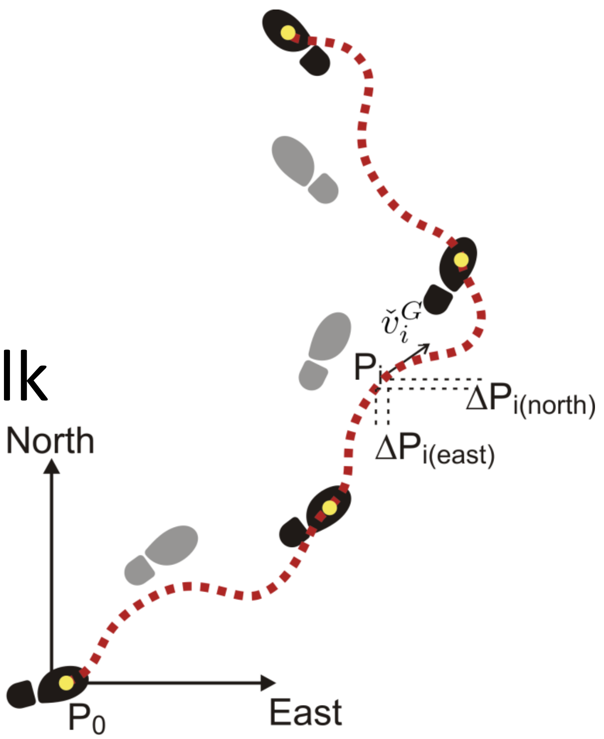
4. PDR algorithmic solutions

- **PDR Algorithm: “INS-ZUPT”** (cont):
  - Accumulates position increments:

$$\Delta P_i = \check{v}_i^G \cdot \Delta T$$

$$\begin{cases} P_i(\text{north}) = P_{i-1}(\text{north}) + \Delta P_i(\text{north}) \\ P_i(\text{east}) = P_{i-1}(\text{east}) + \Delta P_i(\text{east}). \end{cases}$$

  - Method valid for “any” type of walk (forward/lateral/backwards walk, running, crawling, etc).
  - ...but IMU must be on foot



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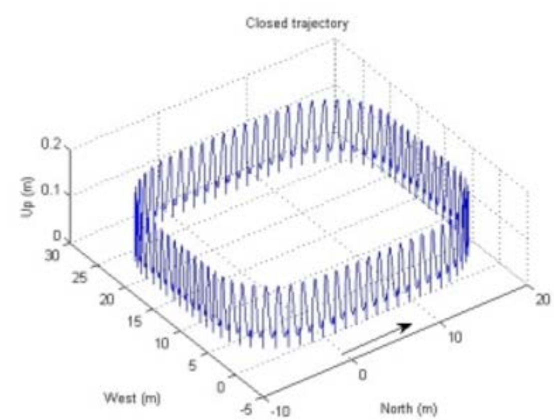
Practice: Introduction

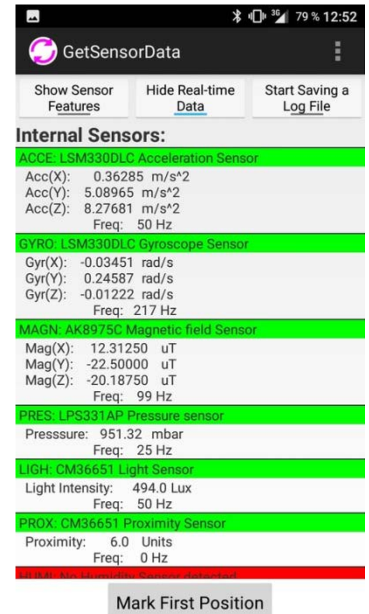
- **Dataset #1: IDEAL Noise-less**
  - Simulated IMU:
    - acceleration (Acc), turn rates (Gyr) and magnetic field (Mag)
  - Ground-truth included (4 loops):
    - position (Pos), velocity (Vel) and orientation (Euler and DCM)
  - Units are in:
    - meters, seconds and radians.
  - Sampling frequency: 100 Hz
  - IMU rotated on foot as in picture.
  - All trajectories starts at point (0,0,0)
  - Gravity is 9.8 m/s2

1.2) Closed trajectory in a square loop of 30 x 30 m.
Download dataset



Practice: Introduction

- **Dataset #2: REAL**
  - 2 IMUs:
    - Foot-mounted Xsens IMU and Internal IMU at Smartphone
  - Using "GetSensorData" App:
    - Records logfile with:
      - WiFi RSS, Inertial data (Accelerometer & Gyroscope), Magnetic, GPS, the orientation of the phone, Pressure, Temperature, Humidity, Sound intensity and Light intensity




```
GYRO;4.410;-0.03726;-0.16860;-0.17318;3
AHRS;4.410;28.7201;0.4508;177.5888;0.00141;0.24804;0.96855;-106
LIGH;4.410;4767.0;0
ACCE;4.411;-0.67995;4.85544;8.30309;3
MAGN;4.411;1.26000;-39.48000;-17.76000;3
PRES;4.419;948.5206;0
GYRO;4.420;-0.04948;-0.13347;-0.16463;3
AHRS;4.420;28.7140;0.5296;177.4918;0.00095;0.24800;0.96855;122
LIGH;4.420;4748.0;0
ACCE;4.421;-0.69911;4.90333;8.35098;3
MAGN;4.421;1.26000;-39.36000;-17.76000;3
GYRO;4.430;-0.06017;-0.09407;-0.13347;3
AHRS;4.430;28.6960;0.6096;177.4190;0.00043;0.24786;0.96858;-3
ACCE;4.432;-0.70868;4.88417;8.34140;3
MAGN;4.432;1.38000;-39.42000;-17.64000;3
```

Practice: Introduction

- **Matlab algorithms and logfiles**:
  – Three main files, for 3 practices
  – PDR algorithms:
    - INS for position & Attitude
    - Step detection
    - Step length estimation
    - Two PDR types:
      – INS-ZUPT,
      – SL+theta
  – Tools:
    - Visualization and
    - Log_file interpretation
  – Log_files:
    - #1 ideal (4 loops),
    - #2 rectangular (3 loops)
    - You will create your own log_files

Download from http://lopsi.weebly.com/

MATLAB

Name	Size	Date Modified	Type
main_P3.m	2 KB	31/01/17 12:32	MATLAB Scrip
main_P2.m	3 KB	31/01/17 12:58	MATLAB Scrip
main_P1.m	2 KB	31/01/17 15:34	MATLAB Scrip
ZUPT_StrideLength_Heading_Position.m	9 KB	30/01/17 16:37	MATLAB Fun...
Weiberg_StrideLength_Heading_Position.m	5 KB	30/01/17 16:30	MATLAB Fun...
visualizar_INS_results.m	3 KB	26/01/17 12:27	MATLAB Fun...
StepDetection_Gyro.m	3 KB	2/11/09 13:36	MATLAB Fun...
StepDetection_Acel_smartphone.m	3 KB	30/01/17 16:00	MATLAB Fun...
StepDetection_Acel.m	4 KB	27/01/17 17:40	MATLAB Fun...
ReadLogFile.m	25 KB	30/01/17 15:51	MATLAB Fun...
INS.m	6 KB	31/01/17 15:34	MATLAB Fun...
log_files		31/01/17 15:50	File Folder
logfile_3loops_forward.txt	8 MB	25/01/17 13:26	Documento ...
logfile_3loops_1lateralbackwards.txt	8 MB	25/01/17 13:31	Documento ...
ideal_footIMU_rectangulo.txt	4 MB	24/01/17 12:12	Documento ...
logfile_3loops_1lateralbackwards.mat	3 MB	31/01/17 13:08	MAT File
ideal_footIMU_rectangulo_GT.mat	892 KB	24/01/17 12:12	MAT File
ideal_footIMU_rectangulo.mat	474 KB	31/01/17 15:34	MAT File

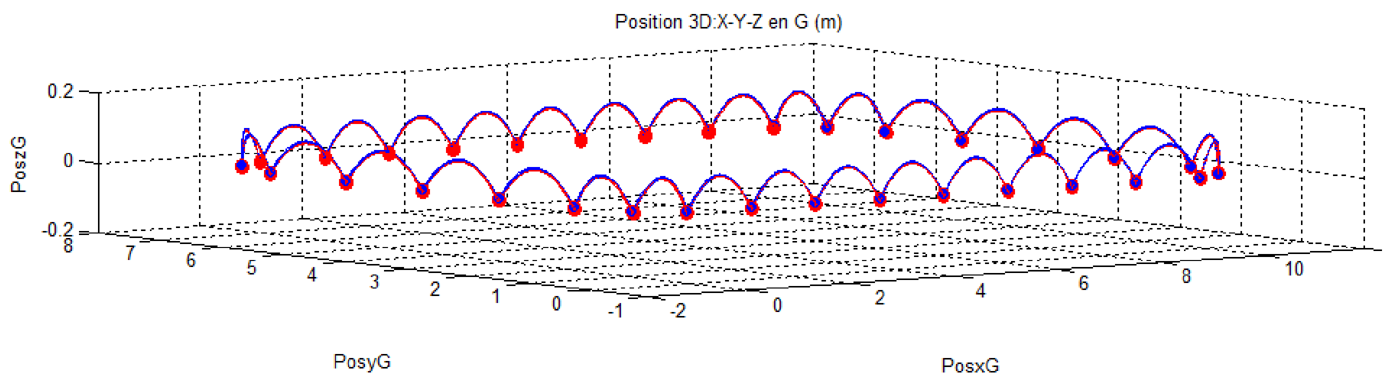
Outline

- Some theory:
  1. What is PDR?
  2. Inertial Navigation (INS)
  3. Implementation problems
  4. PDR algoritmic solutions
- Practice (Matlab):
  1. Introduction
  2. PDR with pre-recorded logfiles
  3. PDR with your own phone
- Evaluation (Kahoot)

PDR with pre-recorded logfiles

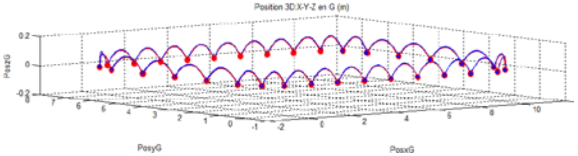
- PRACTICE 1: **Effects of noise on INS**

```
% ----------------------------------------
%        PDR Tutorial: PRACTICE 1 (main_P1.m)
%       Lopsi Group. CAR-CSIC/UPM
%                  2017
%-----------------------------------------
clc; clear all; close all; disp('PRACTICE 1: Effects of noise on INS');
%                PRACTICE 1: Effects of noise on INS
% 1) Load ideal noise-free data (ideal_footIMU_rectangulo.txt) and inspect
% 2) Apply INS algorithm (INS.m) to ideal IMU signals and check correct integration
% 3) Add noise (rand or bias) to IMU signals and inspect drift in velocity and position generated
```



PDR with pre-recorded logfiles

- PRACTICE 1: **Effects of noise on INS**

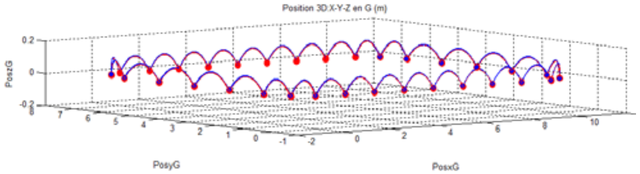



```
%......................................................................
% 1) Load ideal noise-free data (ideal_footIMU_rectangulo.txt) and inspect

% Read log_file
disp('1) Load ideal noise-free data (ideal_footIMU_rectangulo.txt) and inspect');
disp('Reading Logfile...');
[~,~,Acc,Gyr]=ReadLogFile('.\log_files\ideal_footIMU_rectangulo.txt','Xsens');  % load IMU simulated data: A
load('.\log_files\ideal_footIMU_rectangulo_GT.mat'); % load Ground_truth data: 'Pos_G','Vel_G','Att_G','Rot_
disp('Logfile Read...');
disp('-> TO DO: Inspect IMU signals  (press enter to continue)');
pause;

%......................................................................................
% 2) Apply INS algorithm (INS.m) to ideal IMU signals and check correct integration
disp(sprintf('\n2) Apply INS algorithm (INS.m) to ideal IMU signals and check correct integration'));
% Apply INS to obtain Pos,Vel y Att:
disp('Applying INS...');
[Pos_G_rec,Vel_G_rec,Att_G_rec]=INS(Acc,Gyr);
disp('INS ended. Showing results...');
visualizar_INS_results(Pos_G_rec,Vel_G_rec,Att_G_rec,Pos_G,Vel_G,Att_G,Rot_GS,Stance,StepDectSample,10);
disp('-> TO DO: Check correct integration (press enter to continue)');
pause;
```

PDR with pre-recorded logfiles

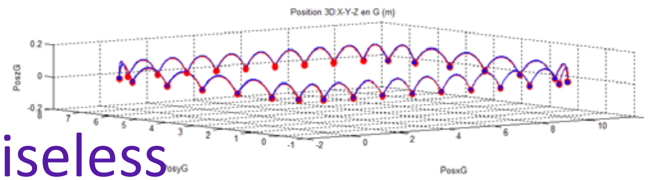
- **PRACTICE 1: Effects of noise on INS**

```
%.............................................................................................
% 3) Add noise (rand or bias) to IMU signals and inspect drift
disp(sprintf('\n3) Add noise (rand or bias) to IMU signals and inspect drift'));
Amplitud=0.0;  % m/s^2
Bias=0.0;        % m/s^2
samples=length(Acc);
Acc(:,1:3)=Acc(:,1:3)+Amplitud*randn(samples,3);
Acc(:,3)=Acc(:,3)+Bias*ones(samples,1);

Amplitud=0.0;  % rad/s
Bias=0.001;         % rad/s
samples=length(Gyr);
Gyr(:,1:3)=Gyr(:,1:3)+Amplitud*randn(samples,3);
Gyr(:,3)=Gyr(:,3)+Bias*ones(samples,1);

% Apply INS to obtain Pos,Vel y Att:
disp('Applying INS with noise...');
[Pos_G_rec,Vel_G_rec,Att_G_rec]=INS(Acc,Gyr);
disp('INS with noise ended. Showing results...');
visualizar_INS_results(Pos_G_rec,Vel_G_rec,Att_G_rec,Pos_G,Vel_G,Att_G,Rot_GS,Stance,StepDectSample,20);
disp('-> TO DO: Check correct integration (press enter to continue)');
```

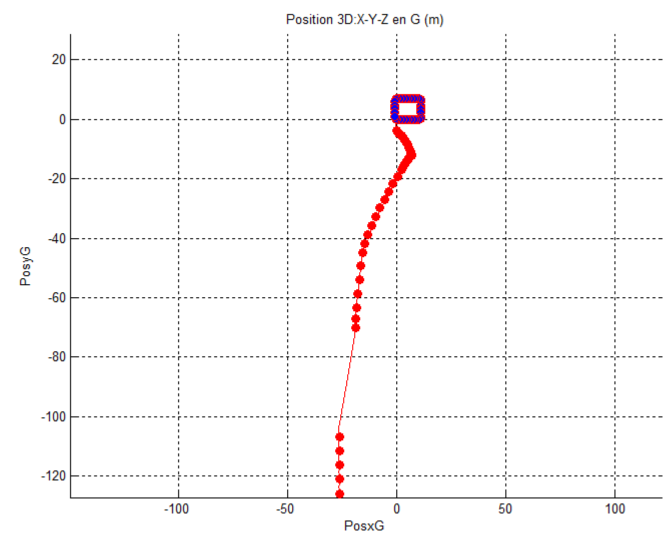


PDR with pre-recorded logfiles

- <u>PRACTICE 1: **Effects of noise on INS**</u>
  - **Conclusions:**



    - INS works perfectly on ideal or noiseless IMU data
    - INS does not work if sensor data has:
      - Bias, Noise,
      - Low sampling frequency
      - Quantization, saturated
      - Axis misalignements



PDR with pre-recorded logfiles

- PRACTICE 2: **PDR with foot-mounted real Xsens-MEMS IMU**
  - One square 3 times (76 steps: 22+23+31, forward walk, but last 3 sides lateral/backwards walk)

PDR with pre-recorded logfiles

- PRACTICE 2: **PDR with foot-mounted real Xsens-MEMS IMU**

```
% -----------------------------------------
%         PDR Tutorial: PRACTICE 2 (main_P2.m)
%       Lopsi Group. CAR-CSIC/UPM
%                  2017
%------------------------------------------

clc; clear all; close all; disp('PRACTICE 2: PDR with FOOT-MOUNTED real XSENS-MEMS IMU');
%
%        PRACTICE 2: PDR with FOOT-MOUNTED real XSENS-MEMS IMU
% 1) Load real data with foot-mounted IMU (logfile_3loops_1lateralbackwards.txt)
%       -One square 3 times (76: 22+23+31 steps, forward walk, but last 3 sides lateral/backwards walk)
% 2) Apply INS PDR algorithm and analyse drifts in position
% 3) Apply INS-ZUPT and analyse processing:
%       -Detection of steps and stance
%       -Correction of Velocities to zero (ZUPT)
%       -Walking direction
```

PDR with pre-recorded logfiles

- **PRACTICE 2: PDR with foot-mounted real Xsens-MEMS IMU**

```
%.........................................................................
% 1) Load real data with foot-mounted IMU (logfile_3loops_1lateralbackwards.txt)
%       -One square 3 times (76: 22+23+31 steps, forward walk, but last 3 sides lateral/backwards walk)

% Read log_file
disp('1) Load real data with foot-mounted test and inspect');
disp('Reading Logfile...');
% load IMU read data: Acc,Gyr de Xsens (3 loops)
[~,~,Acc,Gyr]=ReadLogFile('.\log_files\logfile_3loops_1lateralbackwards.txt','Xsens',1);  % 76 steps (2 loops
%[~,~,Acc,Gyr]=ReadLogFile('.\log_files\logfile_3loops_forward.txt','Xsens',1);  % 66 steps (3 loops)
disp('Logfile Read...');
disp('-> TO DO: Inspect IMU signals and bias (press enter to continue)');
pause;
```

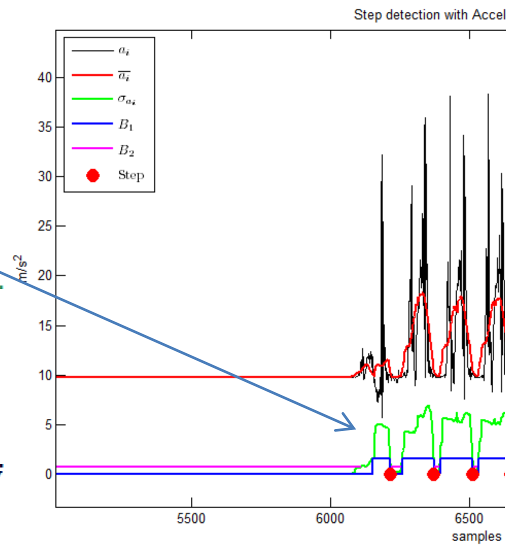
PDR with pre-recorded logfiles

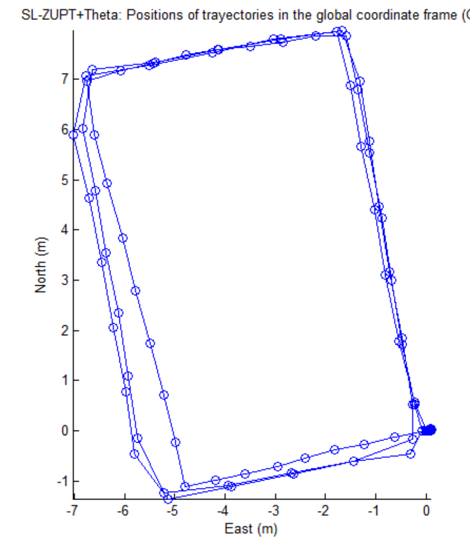
- PRACTICE 2: **PDR with foot-mounted real Xsens-MEMS IMU**

```
%.............................................................................................
% 2) Apply INS PDR algorithm and analyse drifts in position (remove bias)
disp(sprintf('\n2) Apply INS PDR algorithm and analyse drifts in position (remove bias)'));
% Remove bias Gyro
samples=5000;  % asumo 50 segundos parado (y fs=100 Hz)
bias_Gyr=[mean(Gyr(1:samples,1)), mean(Gyr(1:samples,2)), mean(Gyr(1:samples,3))];
Gyr_unbiased=Gyr;  %[nx4]
Gyr_unbiased(:,1:3)=[Gyr(:,1)-bias_Gyr(1), Gyr(:,2)-bias_Gyr(2), Gyr(:,3)-bias_Gyr(3)];

% Apply INS to obtain Pos,Vel y Att:
disp('Applying INS...');
[Pos_G_rec,Vel_G_rec,Att_G_rec]=INS(Acc,Gyr);
%[Pos_G_rec,Vel_G_rec,Att_G_rec]=INS(Acc,Gyr_unbiased);
disp('INS ended. Showing results...');
idx_fig=10;
visualizar_INS_results(Pos_G_rec,Vel_G_rec,Att_G_rec,idx_fig);
disp('-> TO DO: Check uncorrect INS integration/ remove bias (press enter to continue)');
pause;
```

PDR with pre-recorded logfiles

- **PRACTICE 2: PDR with foot-mounted real Xsens-MEMS IMU**





76 steps should be detected

```
%.............................................................
% 3) Apply INS-ZUPT and analyse processing:
%        -Detection of steps and stance
%        -Correction of Velocities to zero (ZUPT)
%        -Walking direction

disp(sprintf('\n3) Apply INS-ZUPT and analyse processing'));
disp('Applying INS-ZUPT...');
%-----Step detection------
idx_fig=20;
[Num_steps,Step_events,StancePhase,idx_fig]=StepDetection_Acel(Acc,1,idx_fig);
%-----INS-ZUPT-----------
[StrideLengths, Thetas, Positions,idx_fig]=ZUPT_StrideLength_Heading_Position(Acc,Gyr,Step_events,StancePhase,1,idx_fig);
%[StrideLengths, Thetas, Positions,idx_fig]=ZUPT_StrideLength_Heading_Position(Acc,Gyr_unbiased,Step_events,StancePhase,1,idx_fig);

disp('INS-ZUPT ended. Showing results...');
disp('-> TO DO: Check correct integration INS-ZUPT');
```

Check: Step detection thresholds

PDR with pre-recorded logfiles

- PRACTICE 2: **PDR with foot-mounted real Xsen-MEMS IMU**
  - **Conclusions:**
    - Bias&noise in Gyros cause attitude errors growing linear with time => big problems
    - INS does not work with MEMS IMUs, even with bias removed
    - INS-ZUPT makes PDR, with bias removed, to work pretty well (for foot-mounted IMU)

PDR with pre-recorded logfiles

- PRACTICE 3: **PDR with hand-held real smartphone IMU (Samsung S4)**


```
% ----------------------------------------
%        PDR Tutorial: PRACTICE 3 (mai_P3.m)
%       Lopsi Group. CAR-CSIC/UPM
%                  2017
%-----------------------------------------

clc; clear all; close all; disp('PRACTICE 3: PDR with hand-held real smartphone IMU (Samsung S4) ');
%
%        PRACTICE 3: PDR with hand-held real smartphone IMU (Samsung S4)
%  1) Load real data with smart-phone IMU (logfile_3loops_1lateralbackwards.txt)
%          -One square 3x (76 steps, forward walk, but last 3 sides lateral/backwards walk)
%  2) Apply SL+theta PDR algorithm and analyse results:
%        -Check bias remove effect
%        -Step detection & Stride Length estimation
%        -Position estimation while walking lateral/backwards

%.........................................................................................
% 1) Load real data with smart-phone IMU (logfile_3loops_1lateralbackwards.txt)
%       -One square 3 times (76 steps, forward walk, but last 3 sides lateral/backwards walk)

% Read log_file
disp('1) Load real data with smart-phone IMU and inspect');
disp('Reading Logfile...');
% load IMU read data: Acc,Gyr de Xsens (3 loops)
%[~,~,Acc,Gyr]=ReadLogFile('.\log_files\logfile_3loops_1lateralbackwards.txt','Xsens',1); %ON FOOT %(2 loops + 1 l
[Acc,Gyr,~,~]=ReadLogFile('.\log_files\logfile_3loops_1lateralbackwards.txt','smartphone',1); %ON HAND %(2 loops +
disp('Logfile Read...');
```

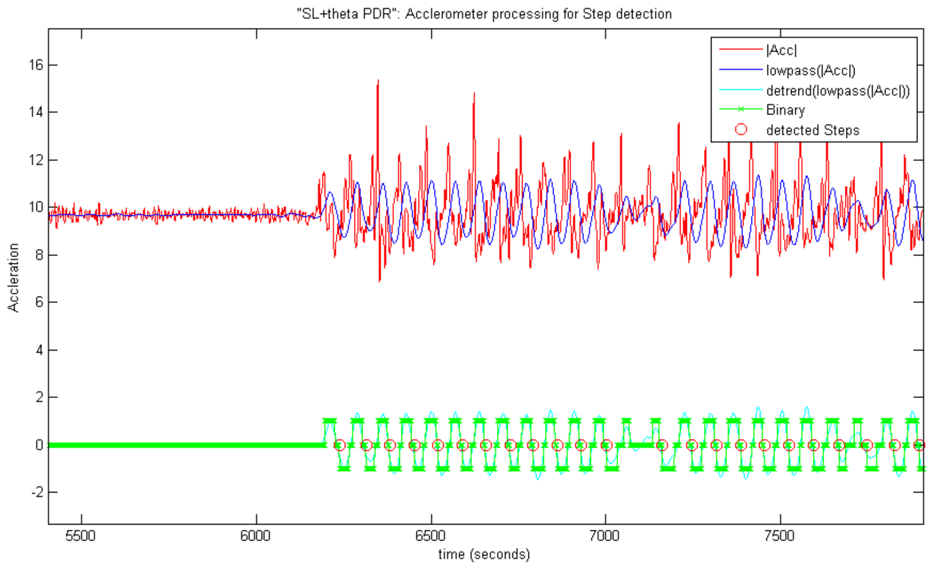
PDR with pre-recorded logfiles

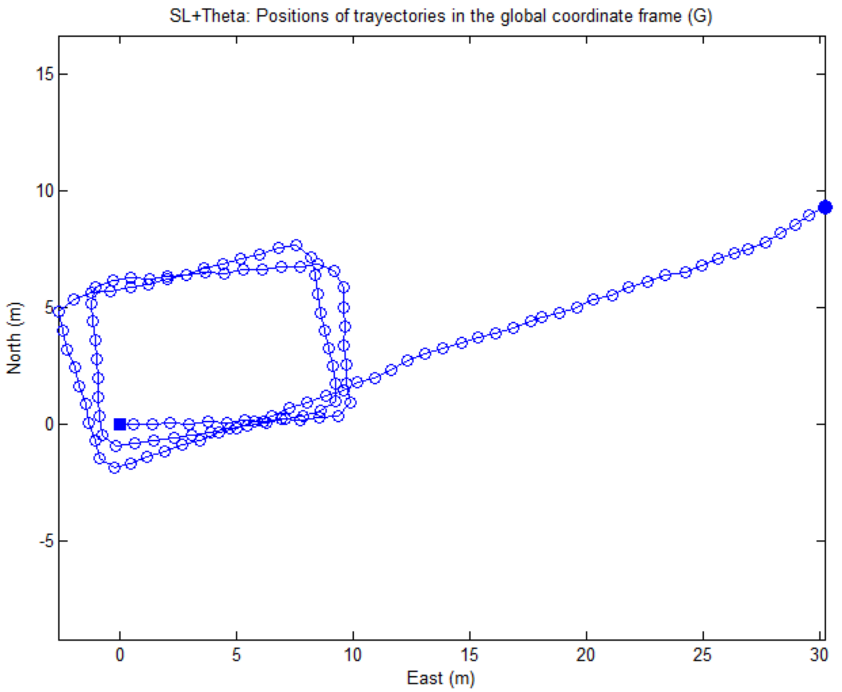
- PRACTICE 3: **PDR with hand-held real smartphone IMU (Samsung S4)**

```
%.............................................................................................
% 2) Apply SL+theta PDR algorithm and analyse results
%        -Check bias remove effect
%        -Step detection & Stride Length estimation
%        -Position estimation while walking lateral/backwards
disp(sprintf('\n2) Apply SL+theta PDR algorithm and analyse rsults'));
% Remove bias Gyro
samples=5000;  % asumo 50 segundos parado (y fs=100 Hz)
bias_Gyr=[mean(Gyr(1:samples,1)), mean(Gyr(1:samples,2)), mean(Gyr(1:samples,3))];
Gyr_unbiased=Gyr;  %[nx4]
Gyr_unbiased(:,1:3)=[Gyr(:,1)-bias_Gyr(1), Gyr(:,2)-bias_Gyr(2), Gyr(:,3)-bias_Gyr(3)];

% Apply INS to obtain Pos,Vel y Att:
disp('Apply SL+theta PDR...');
%-----Step detection------
idx_fig=20;
%[Num_steps,Step_events,StancePhase,idx_fig]=StepDetection_Acel(Acc,1,idx_fig);
[Num_steps,Step_events,StancePhase,idx_fig]=StepDetection_Acel_smartphone(Acc,1,idx_fig);
%-----SL-theta-----------
%[StrideLengths, Thetas, Positions,idx_fig]=Weiberg_StrideLength_Heading_Position(Acc,Gyr,Step_events,StancePhase,
[StrideLengths, Thetas, Positions,idx_fig]=Weiberg_StrideLength_Heading_Position(Acc,Gyr_unbiased,Step_events,Stan
```

PDR with pre-recorded logfiles

- PRACTICE 3: **PDR with hand-held real smartphone IMU (Samsung S4)**





PDR with pre-recorded logfiles

- PRACTICE 3: **PDR with hand-held real smartphone IMU (Samsung S4)**
  - Conclusions:
    - Step detection is more challenging
    - SL+theta PDR is good for forward walking, but can be cheated if direction of motion and direction of IMU/phone is not the same
    - Still to be done: create a robust PDR method for free phone position vs person’s motion

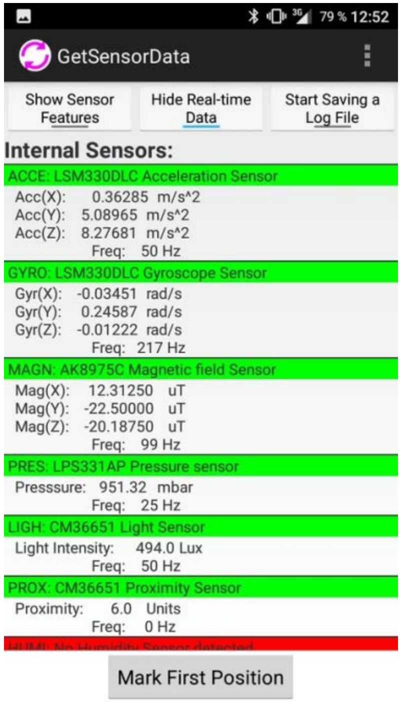
WORK IN PROGRESS

Outline

- Some theory:
  1. What is PDR?
  2. Inertial Navigation (INS)
  3. Implementation problems
  4. PDR algoritmic solutions
- Practice (Matlab):
  1. Introduction
  2. PDR with pre-recorded logfiles
  3. PDR with your own phone
- Evaluation (Kahoot)

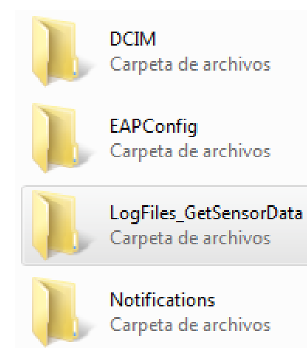
PDR with your own phone

- [PRACTICE 4: **SL+θ PDR with your phone**]
  1. Get your phone (Android)
  2. Install the App «**GetSensorData**». Download App from http://lopsi.weebly.com/downloads.html



PDR with your own phone

- PRACTICE 4: **SL+θ PDR with your phone**
  - **Design a trajectory** of your wish (control number of steps, turns, ending position,..)
  - Remember to keep **phone in front of you**
  - **Start recording** with the App (Start button)
  - Transfer recorded logfile to your PC
  - Apply the **SL+theta PDR** algorithm (main_P3.m)
  - Analize results, repeat test if necessary.



Outline

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  3. PDR with your own phone
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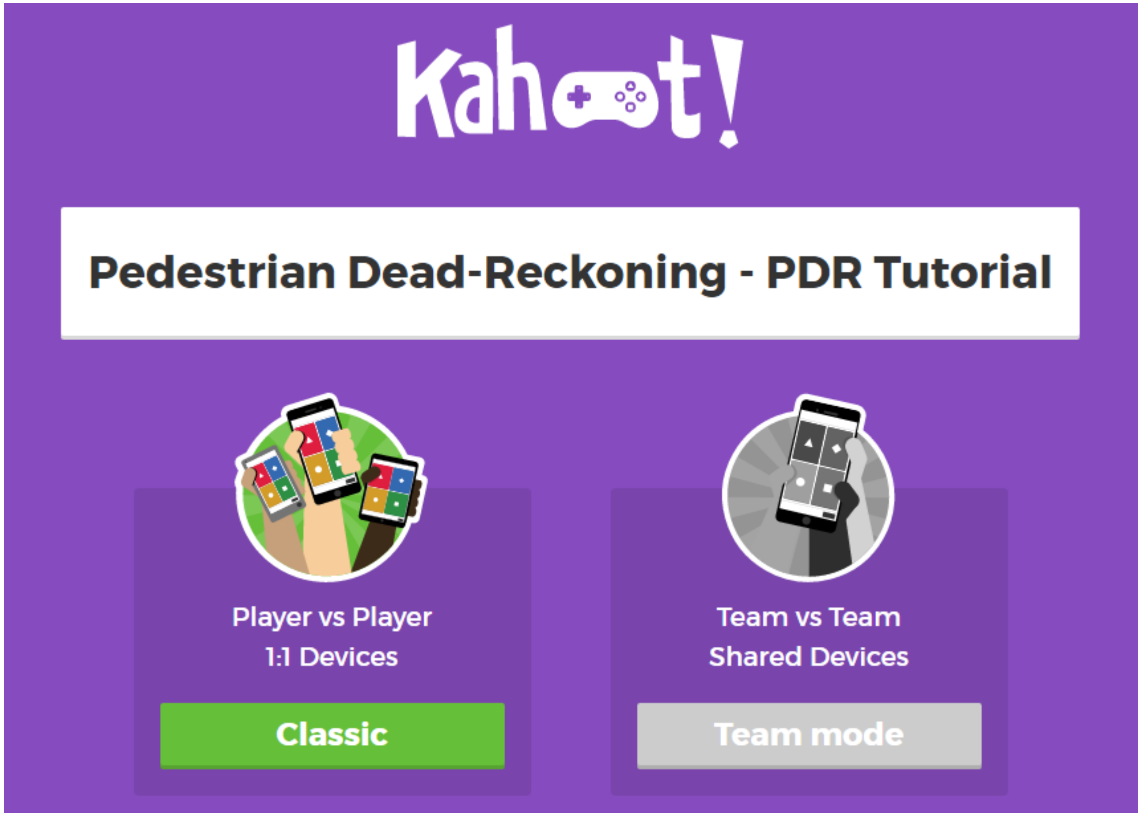
Testing PDR with Kahoot

- [Play PDR evaluation game:]



Some PDR references

- Oliver J. Woodman, “**An introduction to inertial navigation**”, UCAM-CL-TR-696, 2007.
- R. Harle. “**A survey of indoor inertial positioning systems for pedestrians**”. IEEE Communications Surveys & Tutorials, 15(3), pp. 1281-1293, 2013.
- Skog et al, “**Zero-velocity detection in pedestrian navigation systems - an algorithm evaluation**,” Biomedical Engineering, vol. 57, no. 11, pp. 2657–2666, 2010.
- A.R. Jiménez et al., «**A Comparison of Pedestrian Dead-Reckoning Algorithms using a Low-Cost MEMS IMU**», WISP, pp. 37-42, 2009.

Competición PDR (REPNIN)

- Demuestra tu aprendizaje en PDR y llévate un **premio 300€**
- Patrocinado por la red:
  - Red de Posicionamiento y Navegación en Interiores (REPNIN). TEC2015-71426-REDT
- Información disponible en la web:
  - http://introarte.net/pruebas/geintra/
  - Procedimiento:
    1. Indicar **deseo de participar** (ahora o por email: antonio.jimenez@csic.es) => Te envío los **log_files**.
    2. **Procesa los datos** con tus algoritmos mejorados de PDR
    3. Guarda **tus estimaciones de posición XY cada 0.5 segundos** en un fichero texto => y envíalo por correo.
    4. Fecha tope de envío resultados: **1 de Junio**