Sensor Fusion Adaptive Filtering for Position Monitoring in Intense Activities

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1. Origins of the project: Motivation & Goals

- Motivation:
  - A system to monitor and measure body movement.
- Goals:
  - Developing a wireless Inertial Measurement Unit:
    - **Accelerometer.**
    - **Gyroscope.**
    - **802.15.4 Communication.**
  - Developing calibration algorithms:
    - **Conversion of raw data:** A. Olivares, G. Olivares, J. M. Górriz, J. Ramírez. High-efficiency low-cost accelerometer-aided gyroscope calibration. *International Conference on Test and Measurement*, Hong Kong, pp. 354-360, (2009).
    - **Compensation of undesired effects at the output of the sensors:** cross axis and misalignment errors, dynamic bias, etc.
  - Developing data preprocessing algorithms:
    - **Angle computation:** Sensor fusion approaches (Kalman, LMS and RLS adaptive filtering). **Robust system under intense activities conditions.**
  - Developing data processing algorithms:
    - **Recognition of the performed exercise.**

2. Body position monitoring

- Human body position monitoring is employed in entertainment industry, military, movement science, medical applications, etc.
- Systems based on cameras are usually very accurate, however, their cost is very high and they are not suitable to be carried by the person under test.
- IMU based systems offer much more flexibility since they can be easily carried by the subject due to their low size.
- IMUs are composed by accelerometers, gyroscopes and sometimes magnetometers.
- For this study we used WAGYRO a wireless IMU developed by the Dept. of Computer Architecture and Computer Technology of the University of Granada.

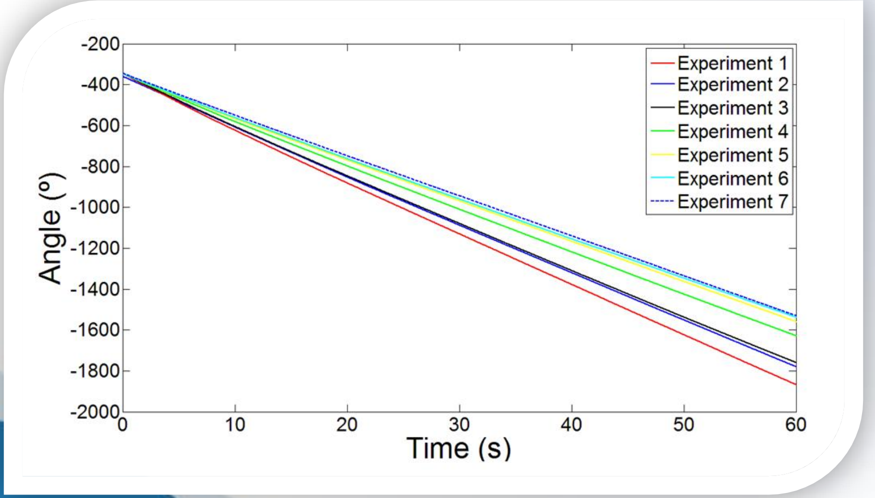
2. Body position monitoring

- Wagyro:

3. Issues with Instrumentation:

Problems of MEMS inertial sensors.

- The use of microelectromechanic system (MEMS) sensors has been popularized due to their low size and cost and their reasonable precision.
- However, MEMS devices present a set of negative factors that need to be taken care of to avoid a loss of precision in the measurements.
  - **Angle wander produced when the gyroscope signal is integrated. Caused by:**
    - Angle Random Walk
    - Dynamic variation of the bias in the gyroscope output. Mainly due to self-heating effects.
    - Depends on sensor quality.
  - **Electronic noise at the output of the accelerometer.**
  - **Bias, cross-axis and misalignment errors at the output of the accelerometer.**

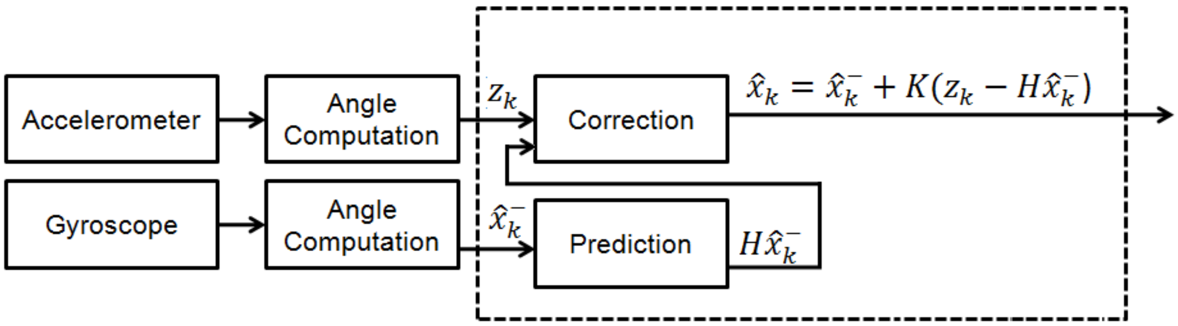


4. Sensor Fusion Approaches

- Most authors tend to use Kalman filtering approaches.
- We aim to develop other approaches using LMS and RLS filtering variations to perform a comparative study.
- Sensor fusion: The use of different sensors information to achieve a robust and accurate measurement under all situations.
- General adaptive filtering approach:
  - **Angle computed using the accelerometer:** Gravity components decomposition. Trigonometric transformations.
  - **Accelerometer angle signal is pretty accurate when movements are smooth and there is not much dynamic acceleration, but it can be very inaccurate under intense activities that generate bursts of measured dynamic acceleration.**
  - **Angle compute using the gyroscope:** Numeric integration.
  - **Gyroscope angle signal is immune to distortions caused by dynamic acceleration, but is distorted by the angle wander.**
  - **We use the two signals as the inputs of an adaptive filter so the angle wander and the electronic noise and distortions due to the dynamic acceleration are almost removed.**

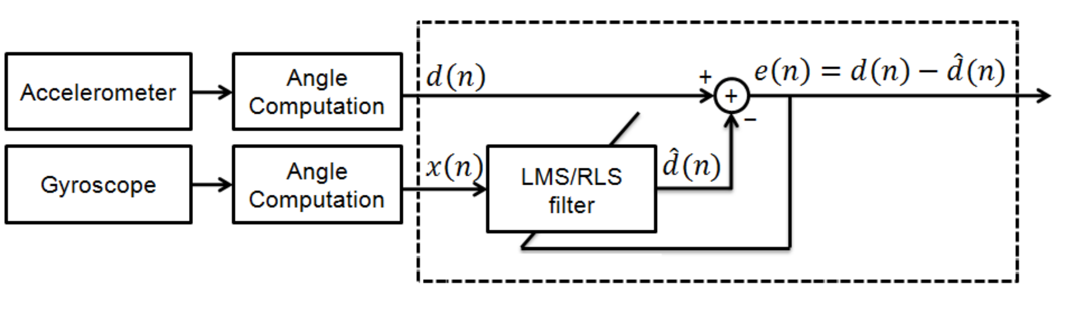
4. Sensor Fusion Approaches

- Kalman filter approach:
- The Kalman filter estimates a process based on an observation.
- The gyroscope signal is filtered based on the acceleration signal observations.
- We can tell the filter which signal to trust more by modifying the values of the filter parameters.



4. Sensor Fusion Approaches

- LMS / RLS approach.
- LMS and RLS filters are widely used to cancel undesired components in signals, such as noise and echo.
- We will use the gyroscope signal as the input to be filtered and the accelerometer signal as the desired signal.
- This configuration will remove the gyroscope's dynamic bias while it will filter the accelerometer's electronic noise and the dynamic acceleration peaks due to their LPF nature.



5. Experiments

A. First part:
 – Theoretical simulations. Computation of MSE over synthesized signals.

B. Second part:
 – Application on real signals: Data gathered from a series of vertical jumps.

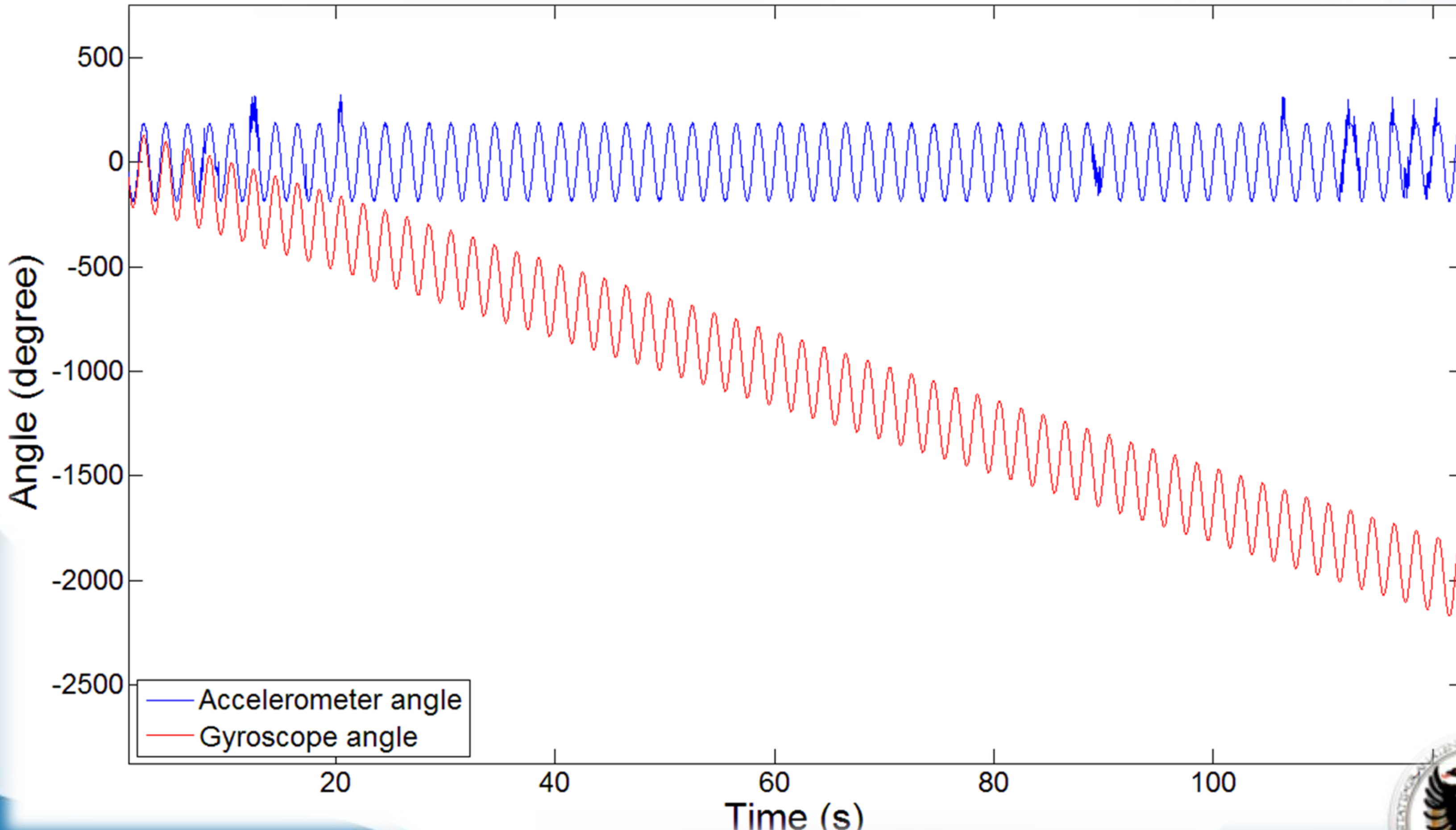
I. Three signals are synthesized:
 – Unbiased angle signal: sinusoidal signal (amplitude = ±180º ,sampling frequency = 50 Hz, period = 2 seconds).
 – Accelerometer angle signal: Unbiased angle signal + random noise (amplitude = ±10º) + random bursts simulating dynamic acceleration (max. amplitude= ±150º, duration =1s).
 – Gyroscope angle signal: Unbiased angle signal + linear bias (value taken from experiments).
 – All signals have a duration of 8 minutes.

5. Experiments

II. Then the gyroscope and the acceleration angle signals are used as the inputs of the filters.
III. The MSE is calculated by averaging the MSE of 50 executions of all filter algorithms.
IV. New signals are synthesized for each one of the executions so they will be slightly different as the accelerometer noise has a random nature.
V. The MSE signals are divided in 3 equal parts for which the average MSE is calculated. These values will give us information about the filter performance at the beginning, the middle and the end of the time period.
VI. Kalman filter is compared versus Normalized LMS, Momentum Normalized LMS (MN-LMS), standard RLS, Householder RLS (H-RLS) and QR-decomposition-based RLS (QRD-RLS).

5. Experiments

- Synthesized signals:



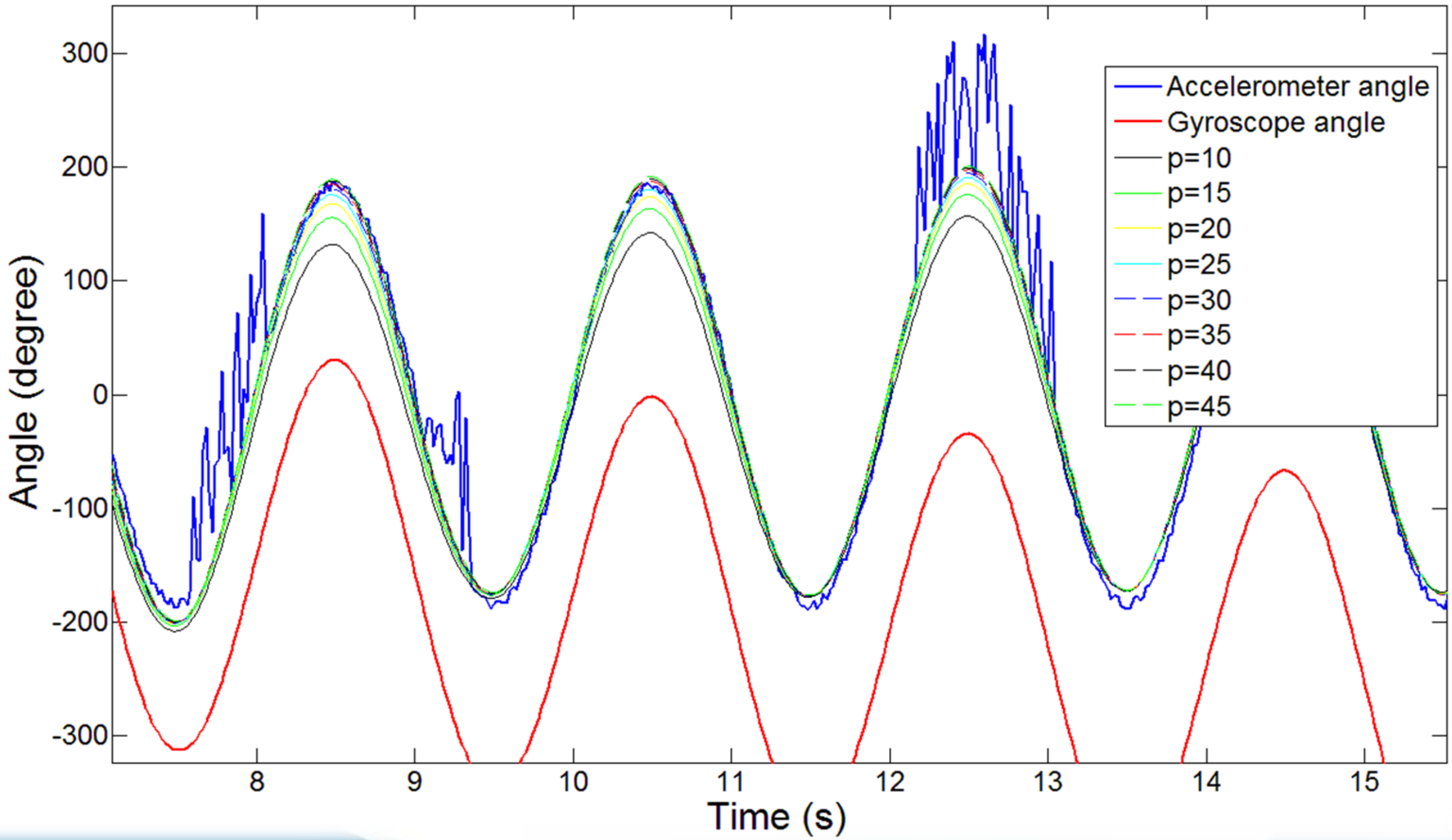
6. Results

- Results of theoretical simulations:

Filter	Parameters	Mean MSE (dB)		
		Period 1	Period 2	Period 3
Kalman	Sz=0.03 Var_a=0.3 Var_g=0.05	63.15	77.30	84.89
NLMS	Filter size=600 Step size=1.5	82.18	75.07	63.03
MNLMS	Filter size=400 Step size=1E-6	53.13	55.52	51.02
RLS	Filter size=45	42.34	41.97	40.16
HRLS	Filter size=15	51.58	48.30	43.09
QRDRLS	Filter size=40	53.46	55.32	50.85

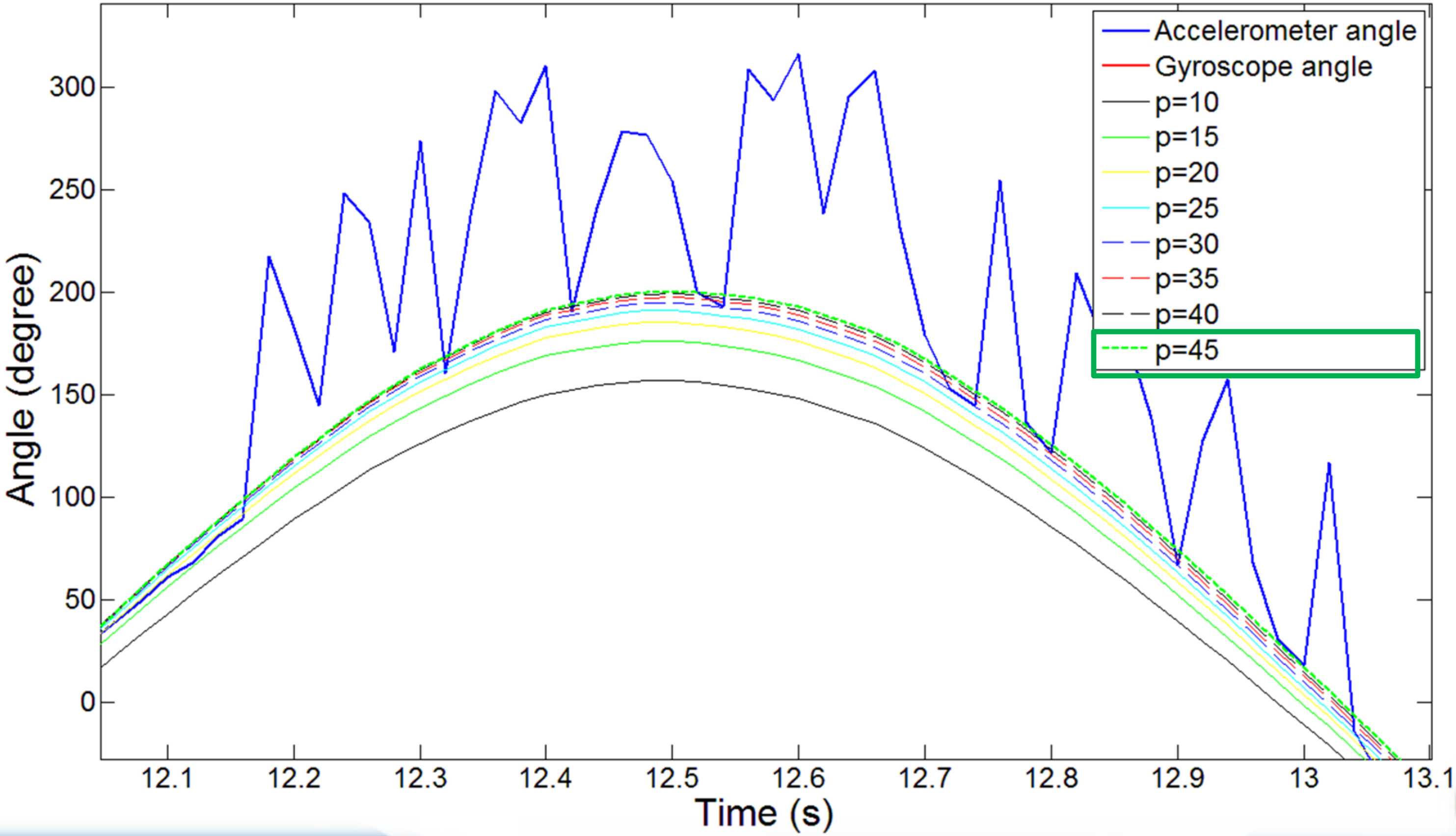
6. Results

- Results of theoretical simulations:
  - RLS filtering



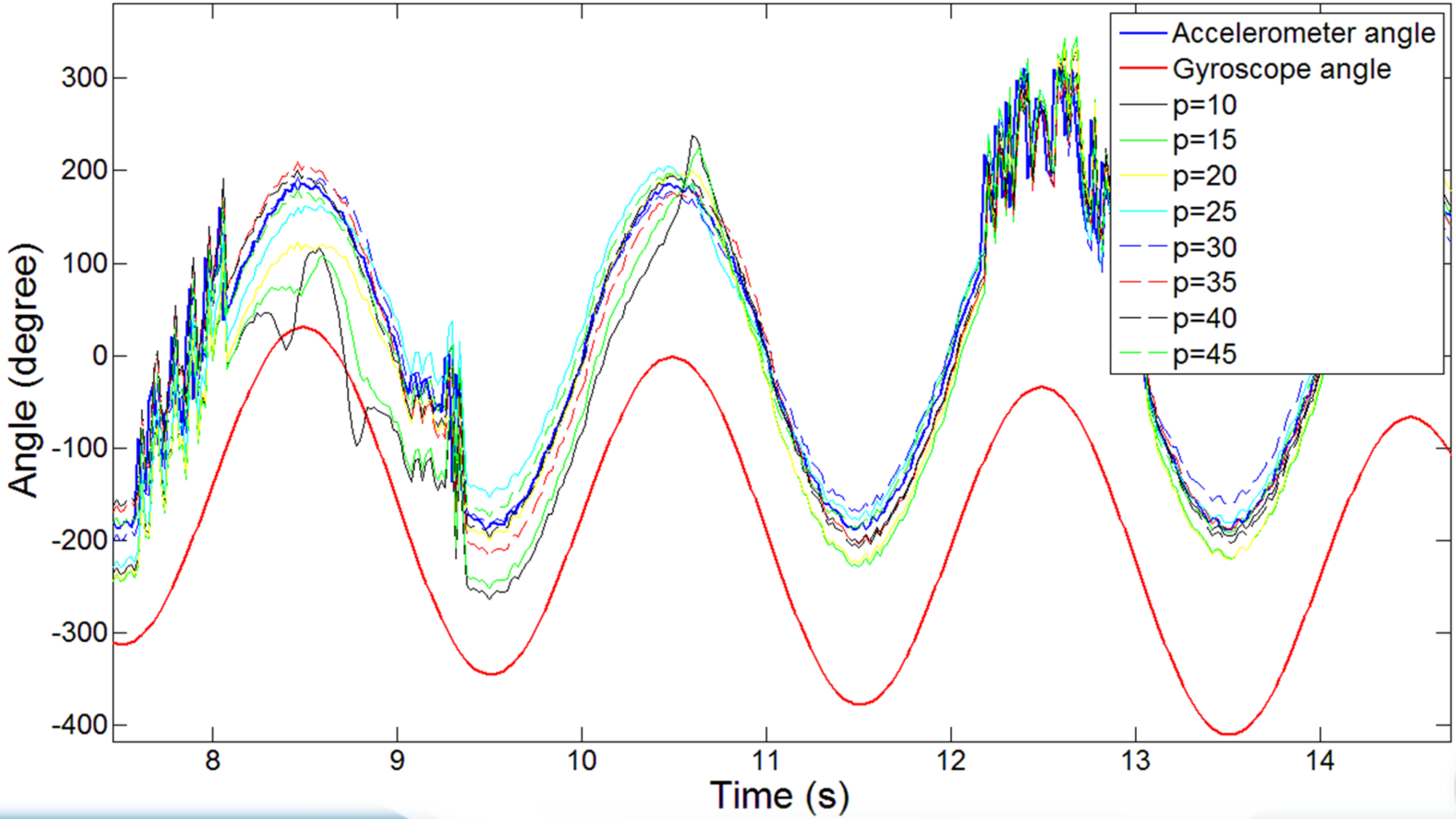
6. Results

- Results of theoretical simulations:
  - RLS filtering (zoomed)



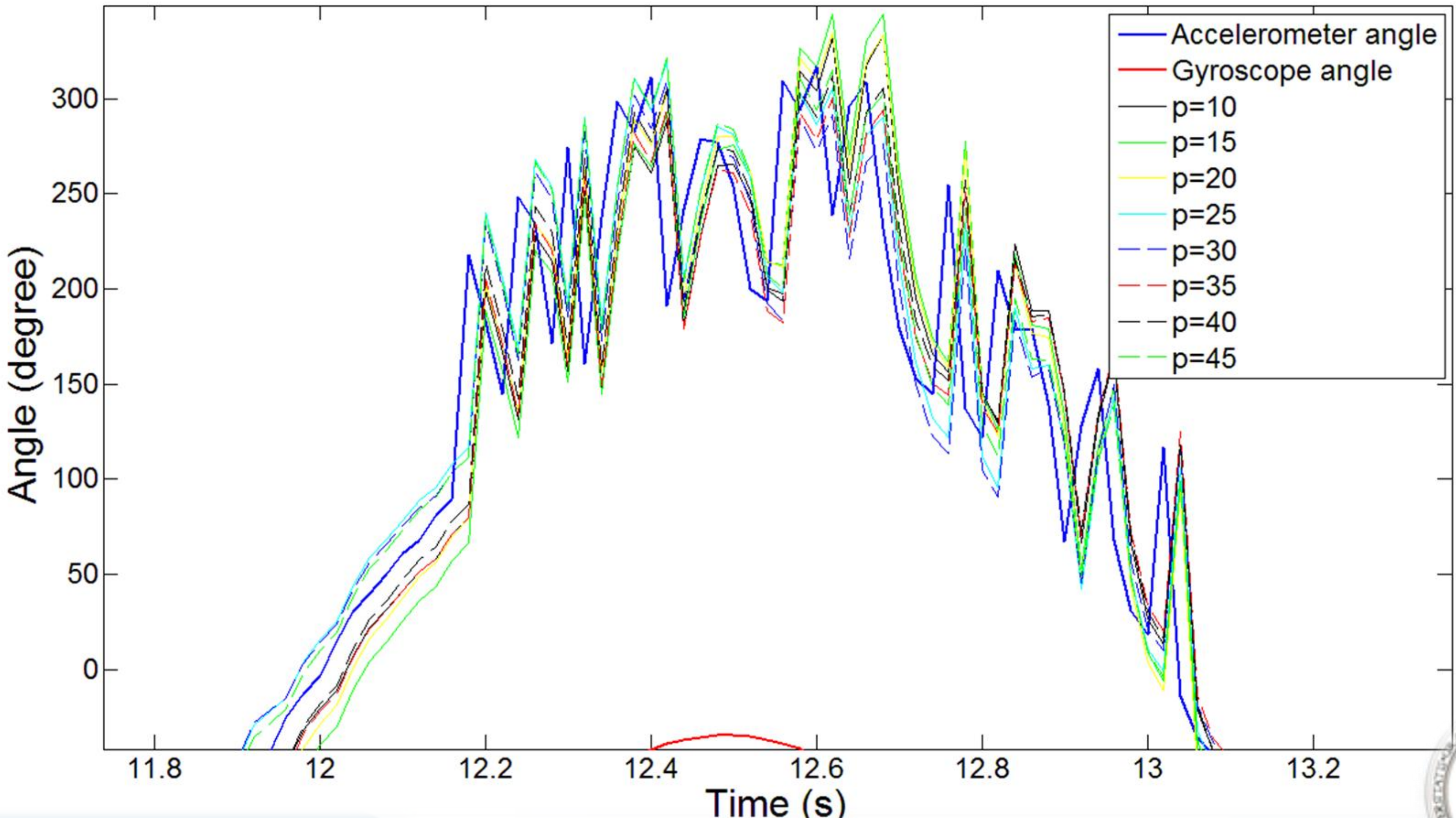
6. Results

- Results of theoretical simulations:
  - QRD-RLS filtering



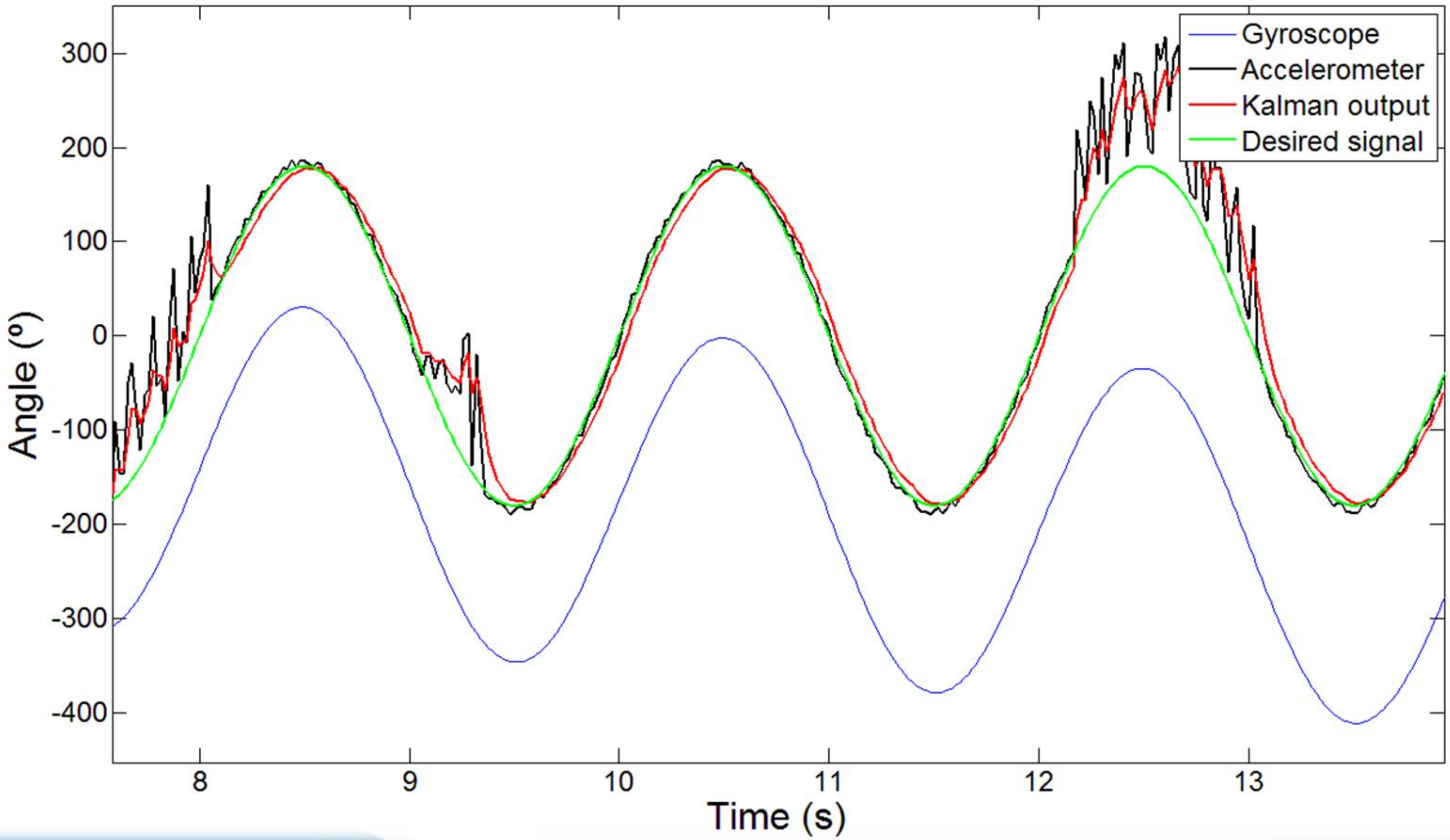
6. Results

- Results of theoretical simulations:
  - QRD-RLS filtering (zoomed)



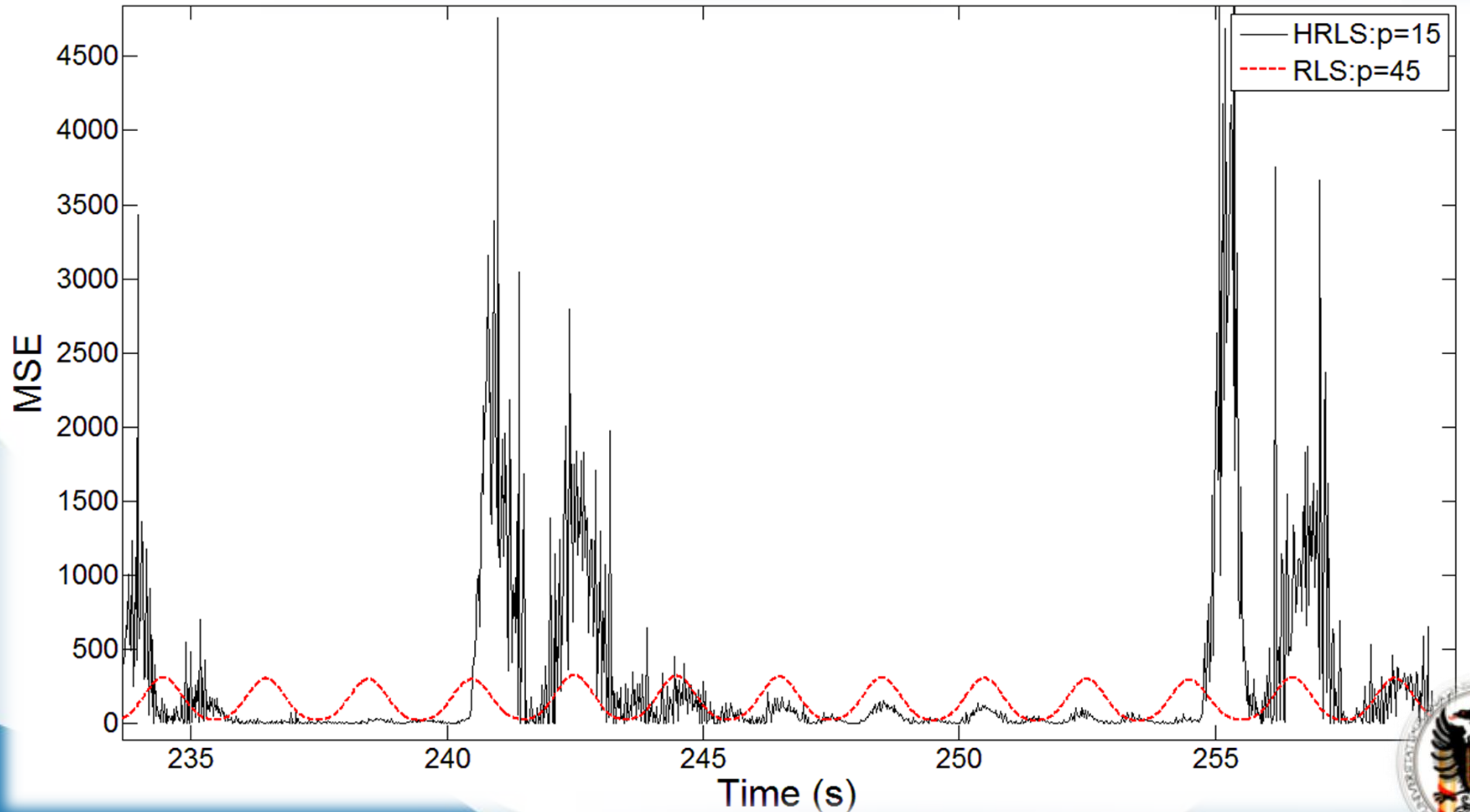
6. Results

- Results of theoretical simulations:
  - Kalman filtering



6. Results

- Results of theoretical simulations:
  - MSE (HRLS & RLS)



6. Results

- Results of theoretical simulations:
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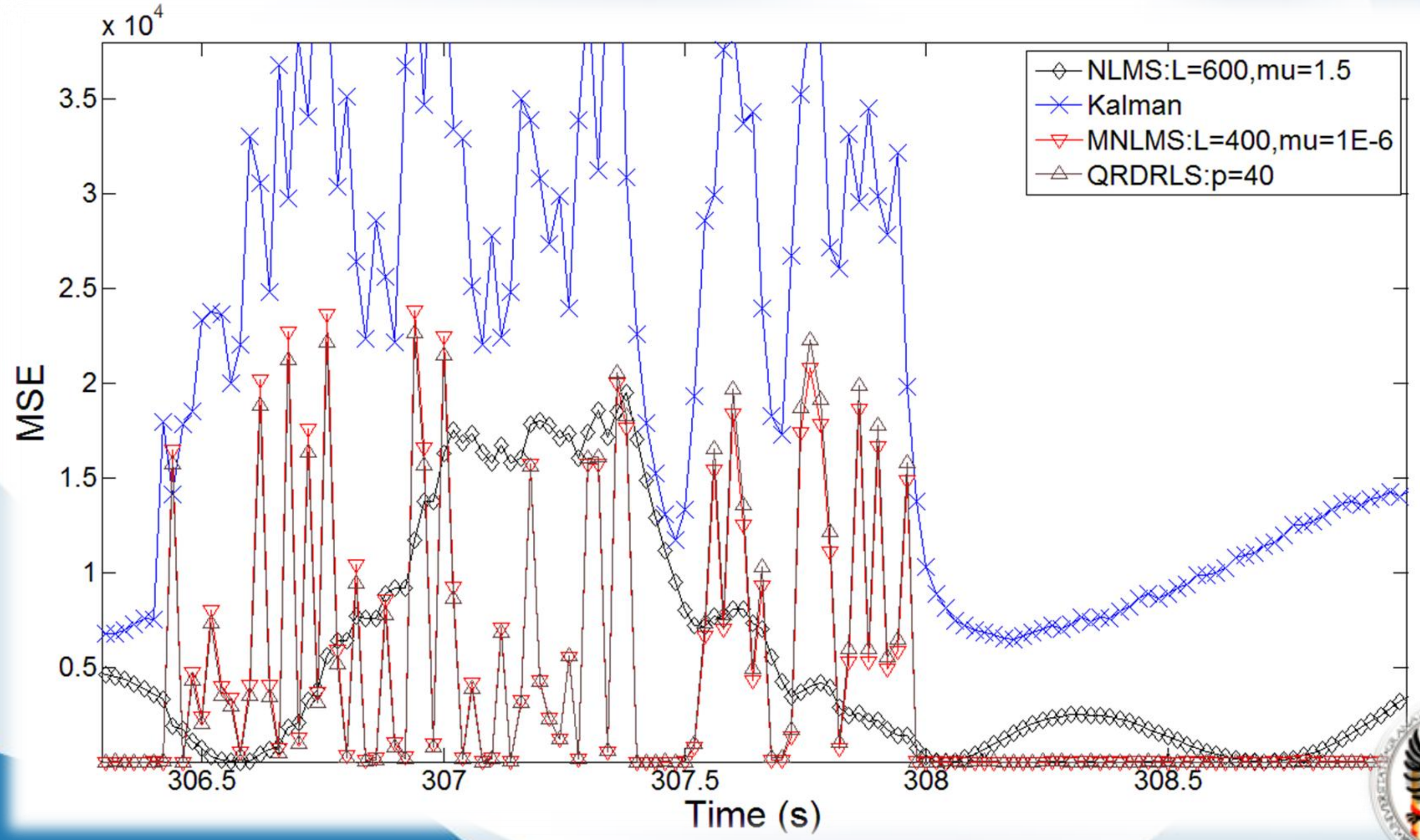
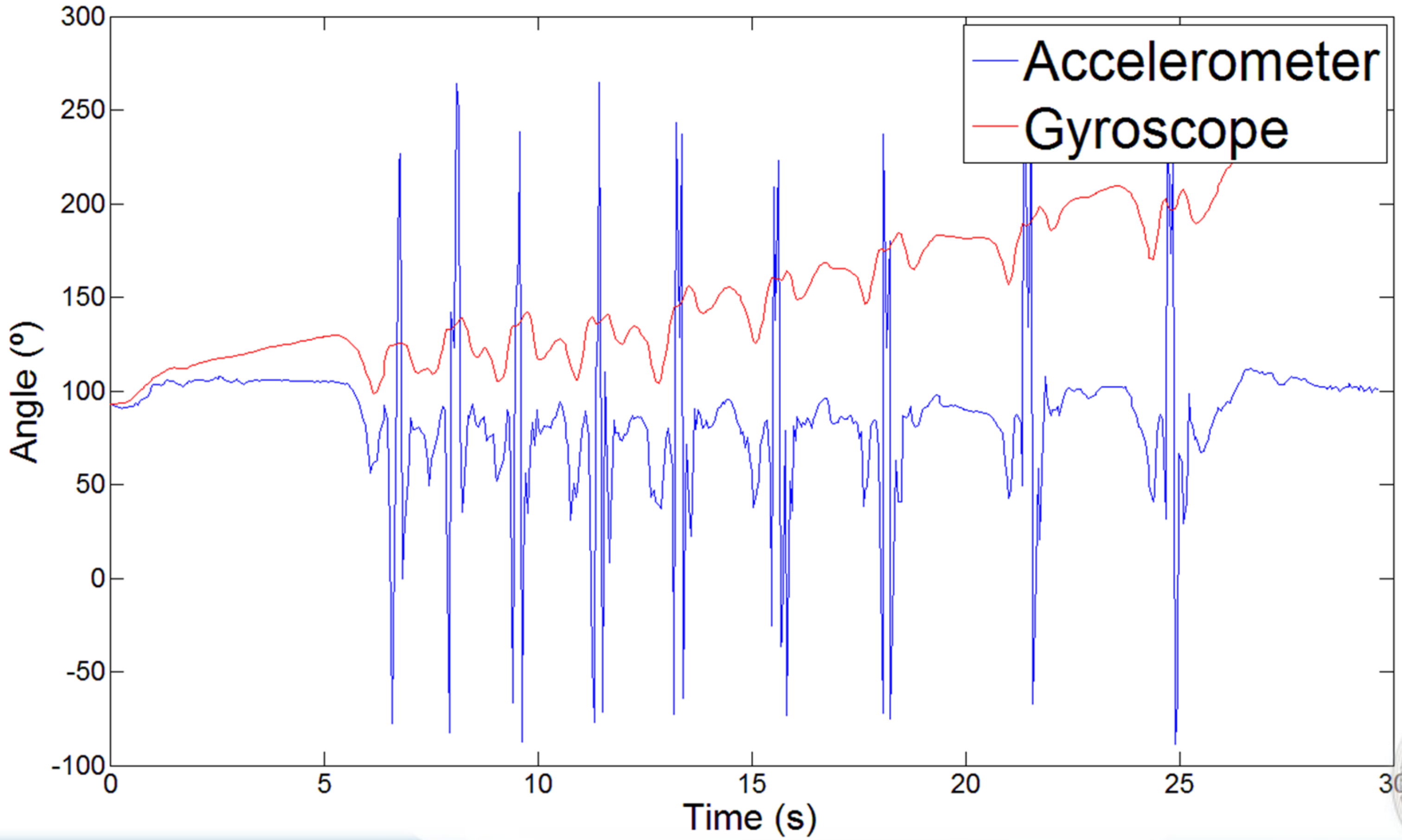


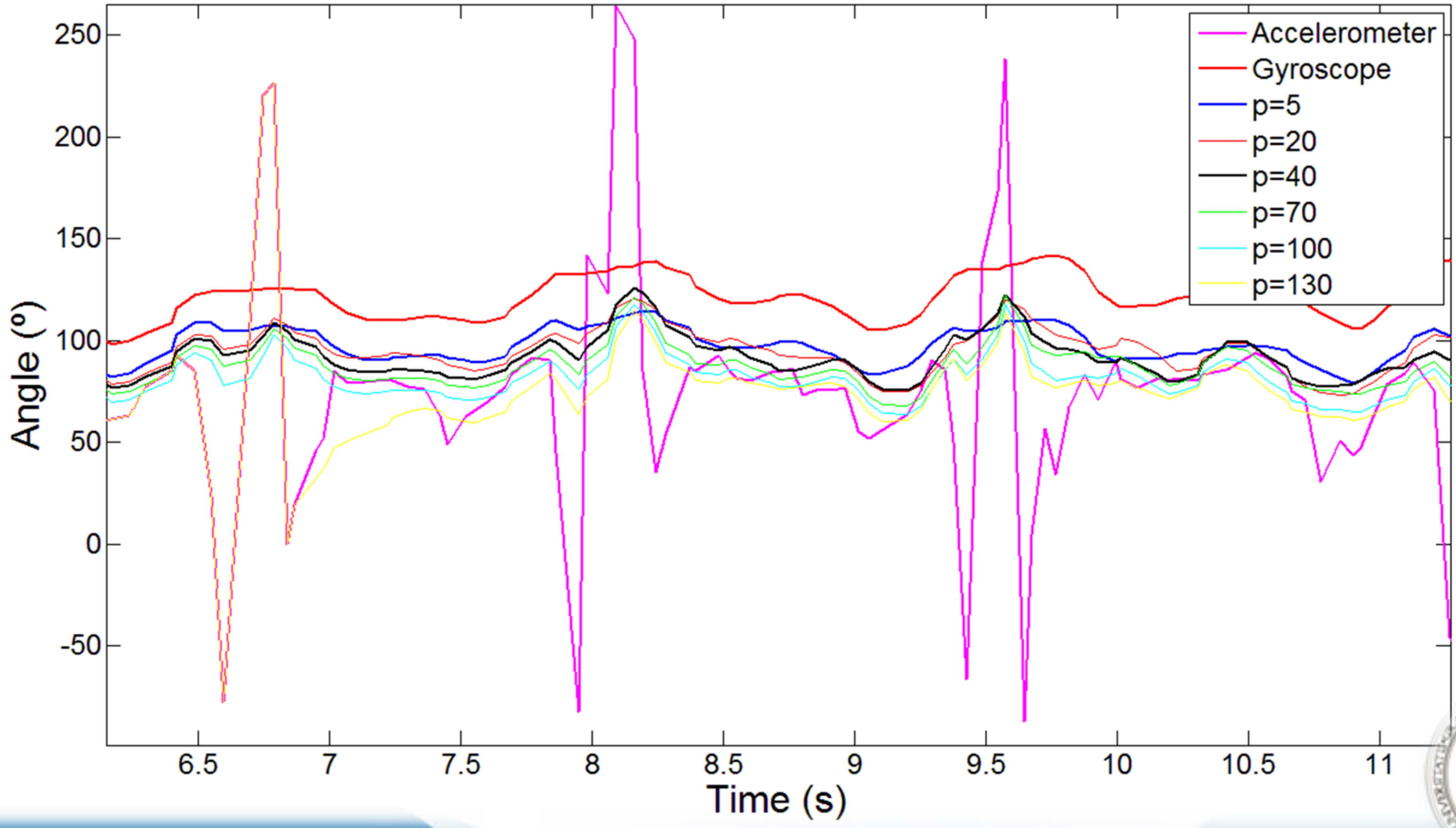
6. Results

- Application on real signals: Series of vertical jumps.
  - Gathered signals (filter’s inputs).



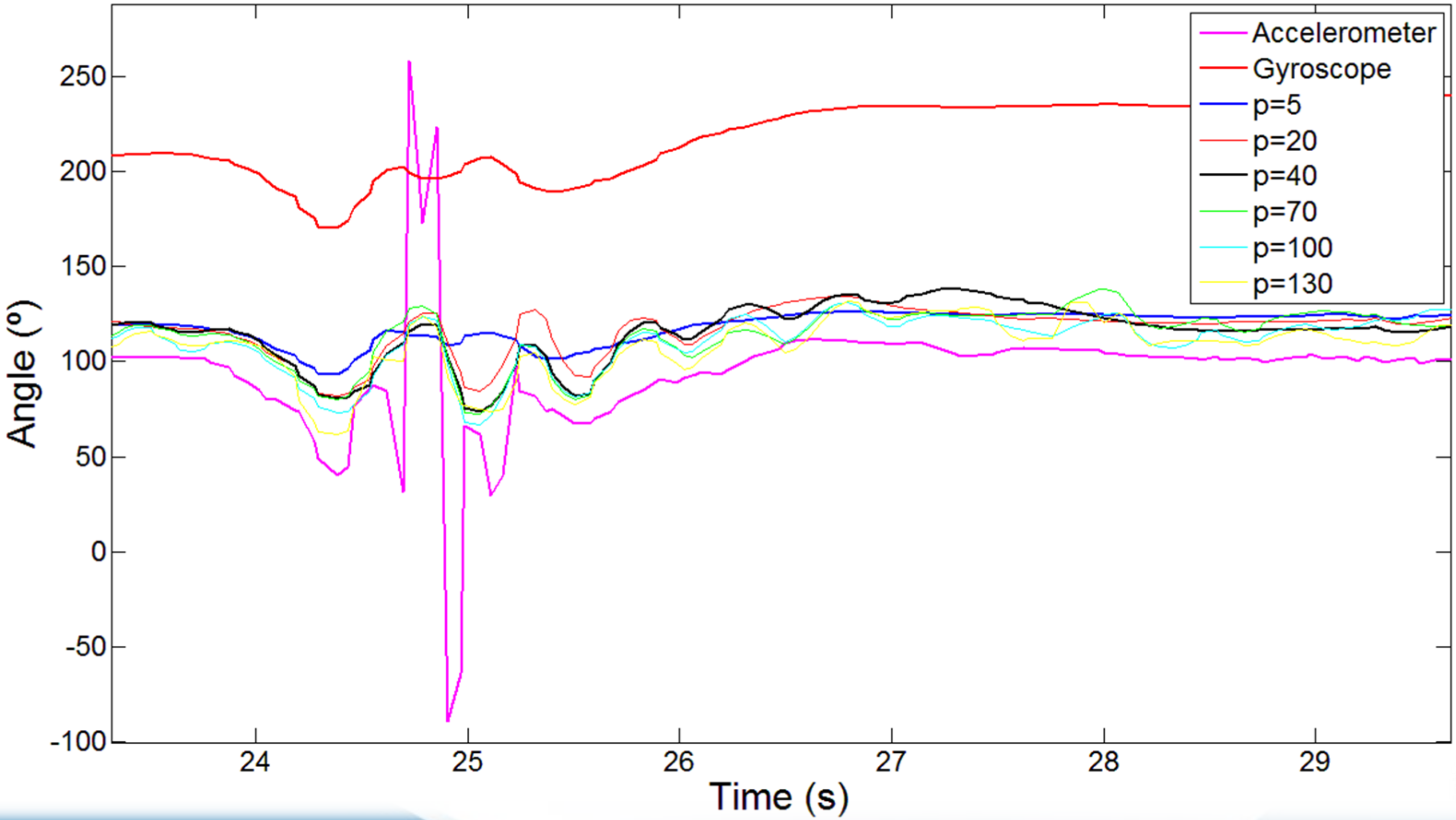
6. Results

- Application on real signals: Series of vertical jumps.
  - RLS filter (beginning)



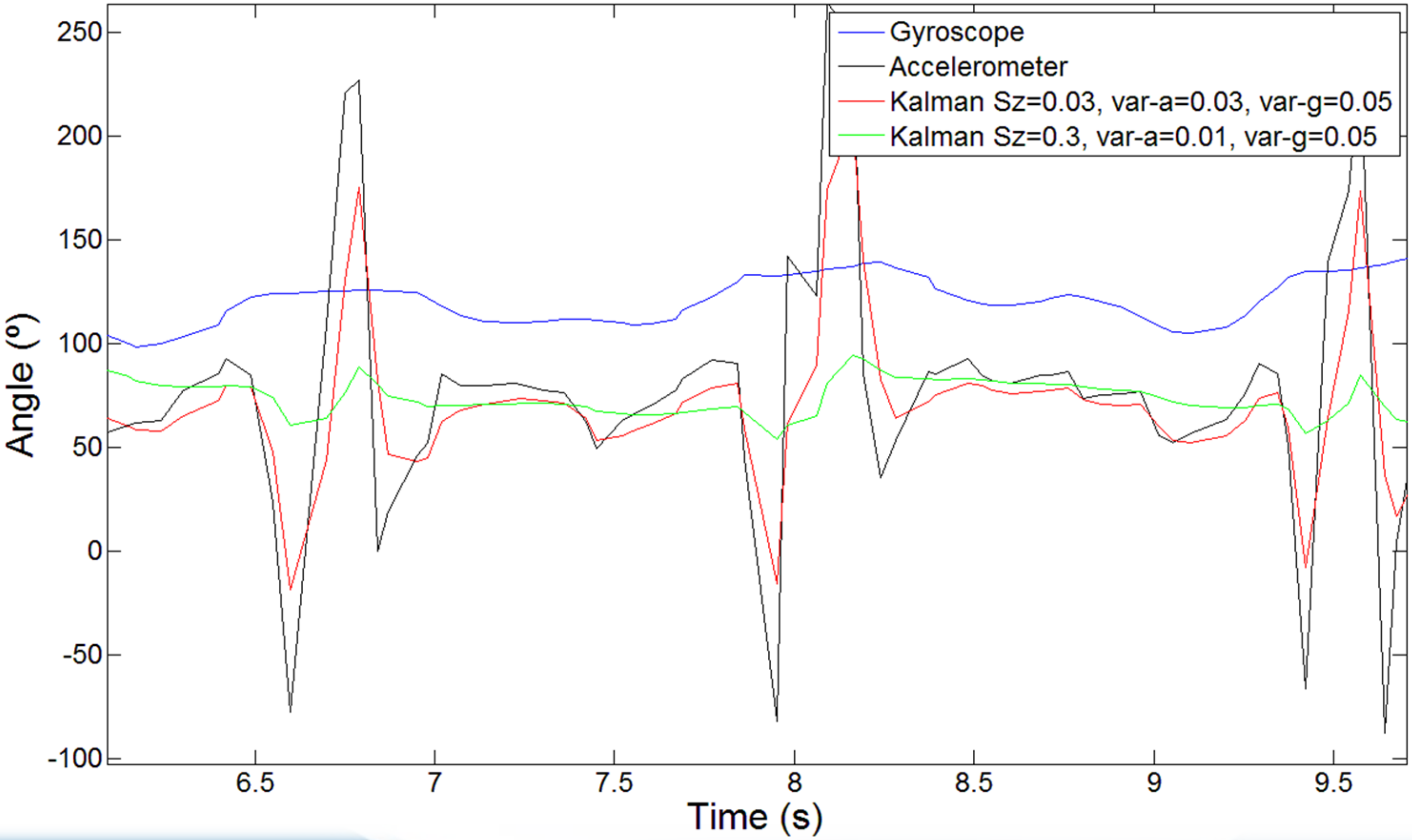
6. Results

- Application on real signals: Series of vertical jumps.
  - RLS filter (end)



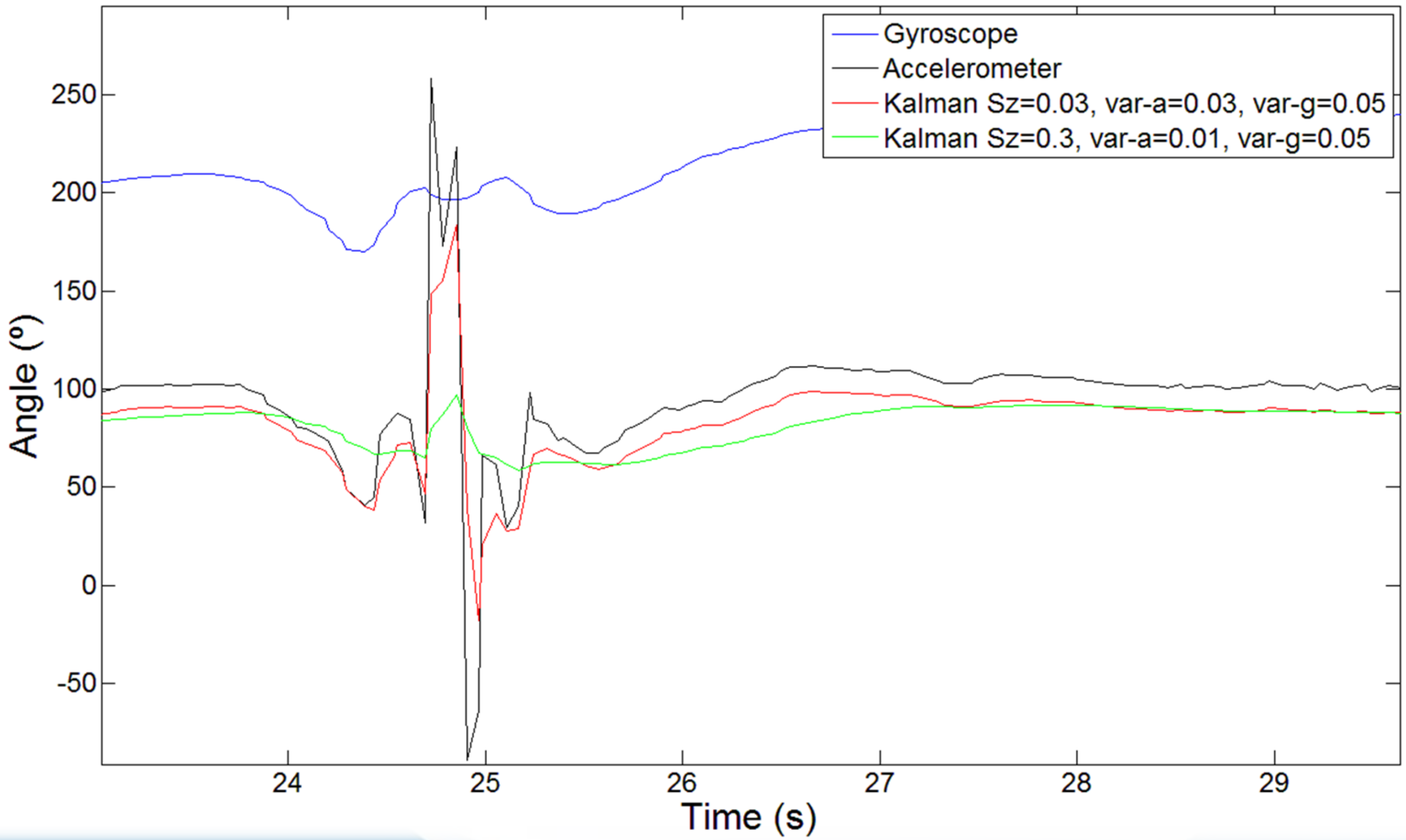
6. Results

- Application on real signals: Series of vertical jumps.
  - Kalman filter (beginning).



6. Results

- Application on real signals: Series of vertical jumps.
  - Kalman filter (end).



7. Conclusions

- We can conclude that the standard **RLS sensor fusion approach** used to calculate the position angle, based on inertial signals, **outperforms the existing Kalman filter approach.**
- **RLS has shown its superior capability** of filtering large peaks of dynamic acceleration and its good performance to remove the dynamic bias present in the gyroscope angle signal.
- Other filters such as **QRDRLS and NLMS** have revealed themselves to be **unsuitable for this purpose** as they do not filter peaks properly or converge too slowly.
- It is also **very important to know the nature of the exercise** to be performed **to tune properly the filters** as their performance will vary depending on the nature of the exercise.

THANK YOU FOR YOUR ATTENTION

Q&A