CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF ELECTRICAL ENGINEERING
CENTRE FOR MACHINE PERCEPTION

NIFTi – Natural Human-Robot Cooperation in Dynamic Environments

2010 – 2014

EC project FP7-ICT-247870 NIFTi

Michal Reinštein

SEARCH AND RESCUE ROBOTICS

FUKUSHIMA 2010

- UGV: iRobot Packbot, Warrior, Talon, Bobcat, Dragon runner
- UAV: Honeywell T-Hawk

iROBOT Warrior

http://www.irobot.com/gi/ground/710_Warrior/

NREC Dragon Runner

http://www.rec.ri.cmu.edu/projects/dragonrunner/

NIFTI – PROJECT COOPERATION

Benif.#	Beneficiary name	Benef. short name	Country
1. (crd.)	Deutsches Forschungszentrum für Künstliche Intelligenz GmbH	DFKI	Germany
2.	Netherlands Organization for Applied Scientific Research	TNO	The Netherlands
3.	Fraunhofer Institut Intelligente Analyse- und Informationssysteme	Fraunhofer	Germany
4.	BlueBotics SA	BLUE	Switzerland
5.	Eidgenossische Technische Hochschule Zürich	ETHZ	Switzerland
6.	Czech Technical University Prague	CTU	Czech Republic
7.	'Sapienza' University of Roma	ROMA	Italy
8.	Institut für Feuerwehr und Rettungstechnologie FDDo	FDDo	Germany
9.	Corpo Nazionale Vigili del Fuoco	VVFF	Italy

NIFTI – PROJECT AIMS

- Developing a novel rover platform to meet the demands of operating in dynamic environments
- Minimizing task load for human and optimizing workflow
- Integration – bringing human factor into cognitive rescue robots
- Situation awareness – conceptual understanding of environment
- Flexible planning w.r.t. dynamic changes in environment
- User adaptive human-robot communication
- Multiple humans & robots cooperation
- Continuous evaluation with end user organizations
- Realistic missions in real-life training areas

NIFTI PLATFORM – HARDWARE

- Embeded PC: Kontron KTGM45/mITX Plus
- Embeded CPU: Kontron CPU KTGM45-CPU_Q9100
- 2D laser scanner: : SICK LMS-151
- Omnicam: Point Grey Ladybug 3
- IMU/GPS: X-sens MTI-G
- ASUS Xtion Pro
- Thermocam Micro-Epsilon TIM160

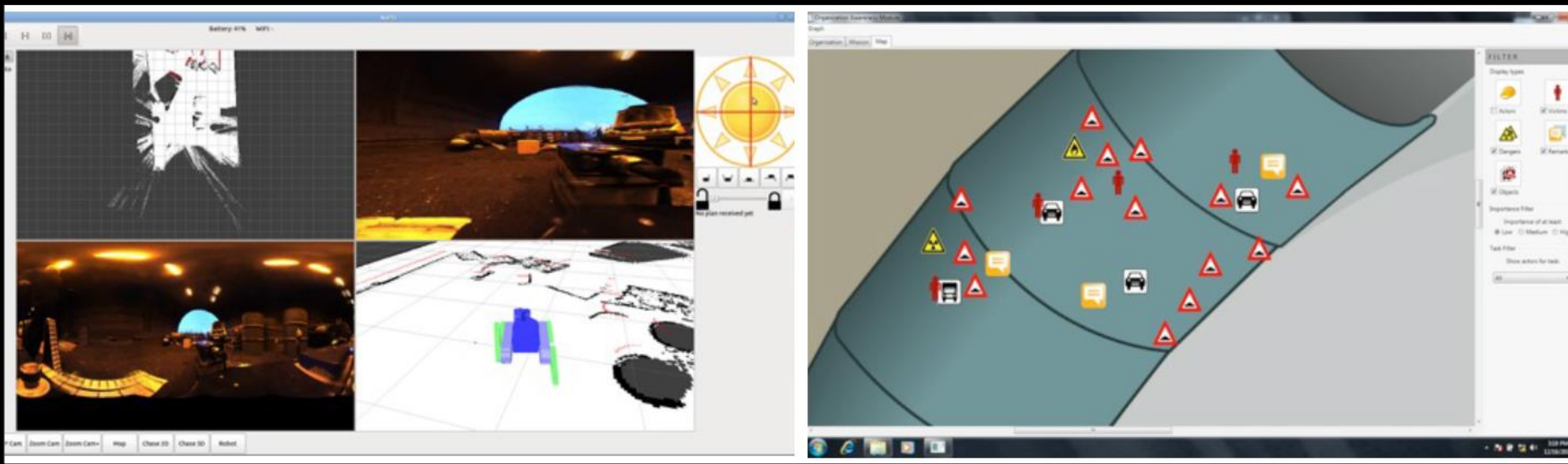
NIFTI PLATFORM – SOFTWARE

- UBUNTU 12.4 (64 bit)
- C++ / Python

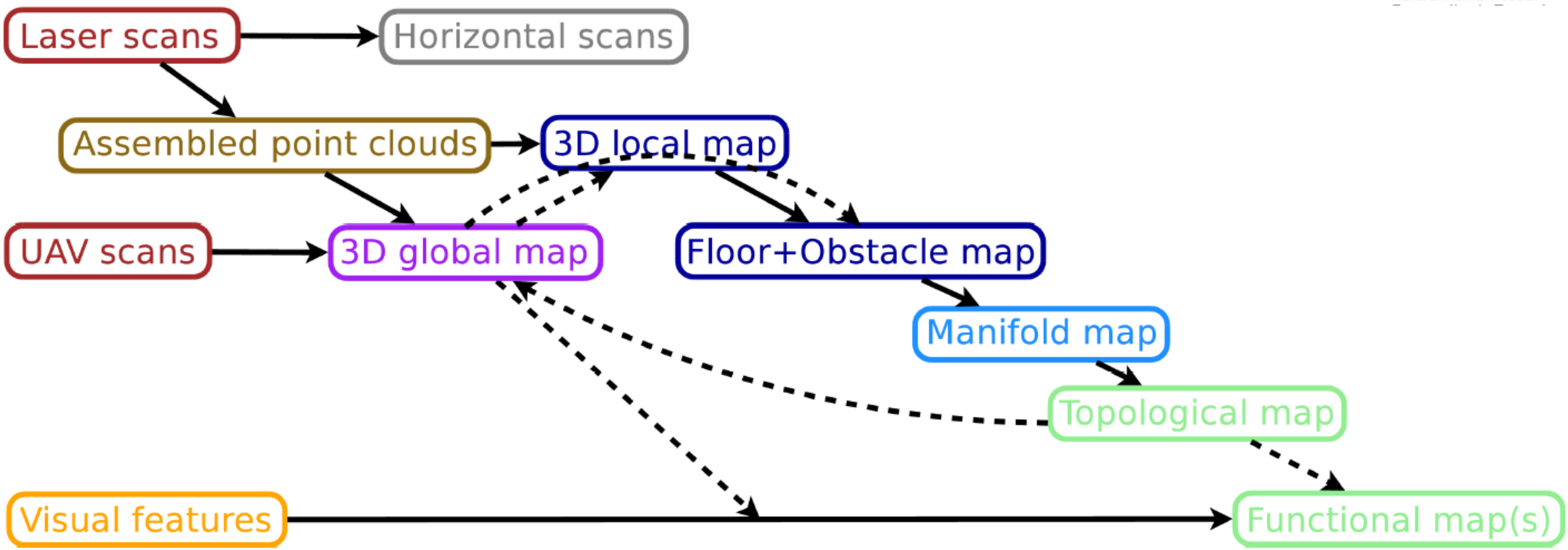
WILLOW GARAGE PRODUCTS

- ROS – Robot Operating System
- OpenCV
- PCL

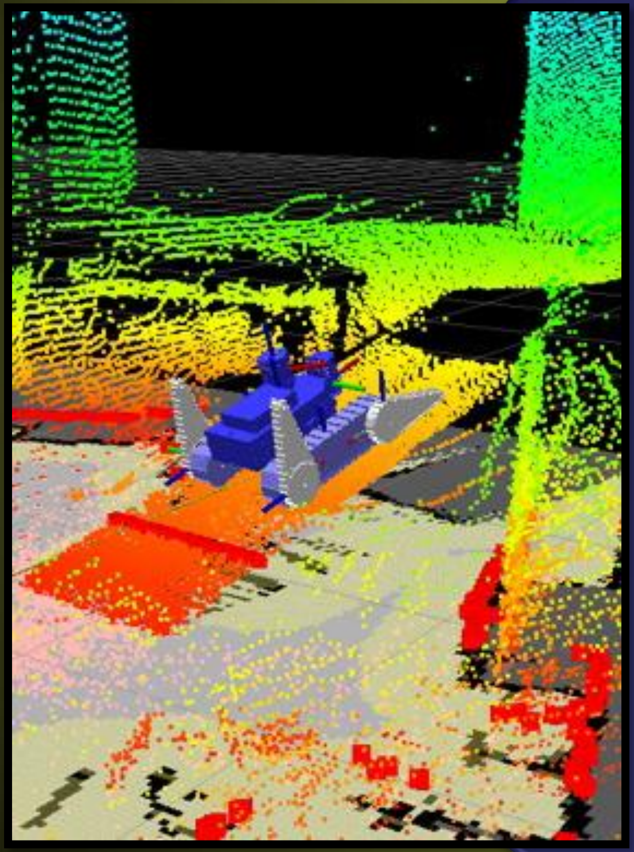
FROM DATA TO UNDERSTANDING



Natural Human-Robot

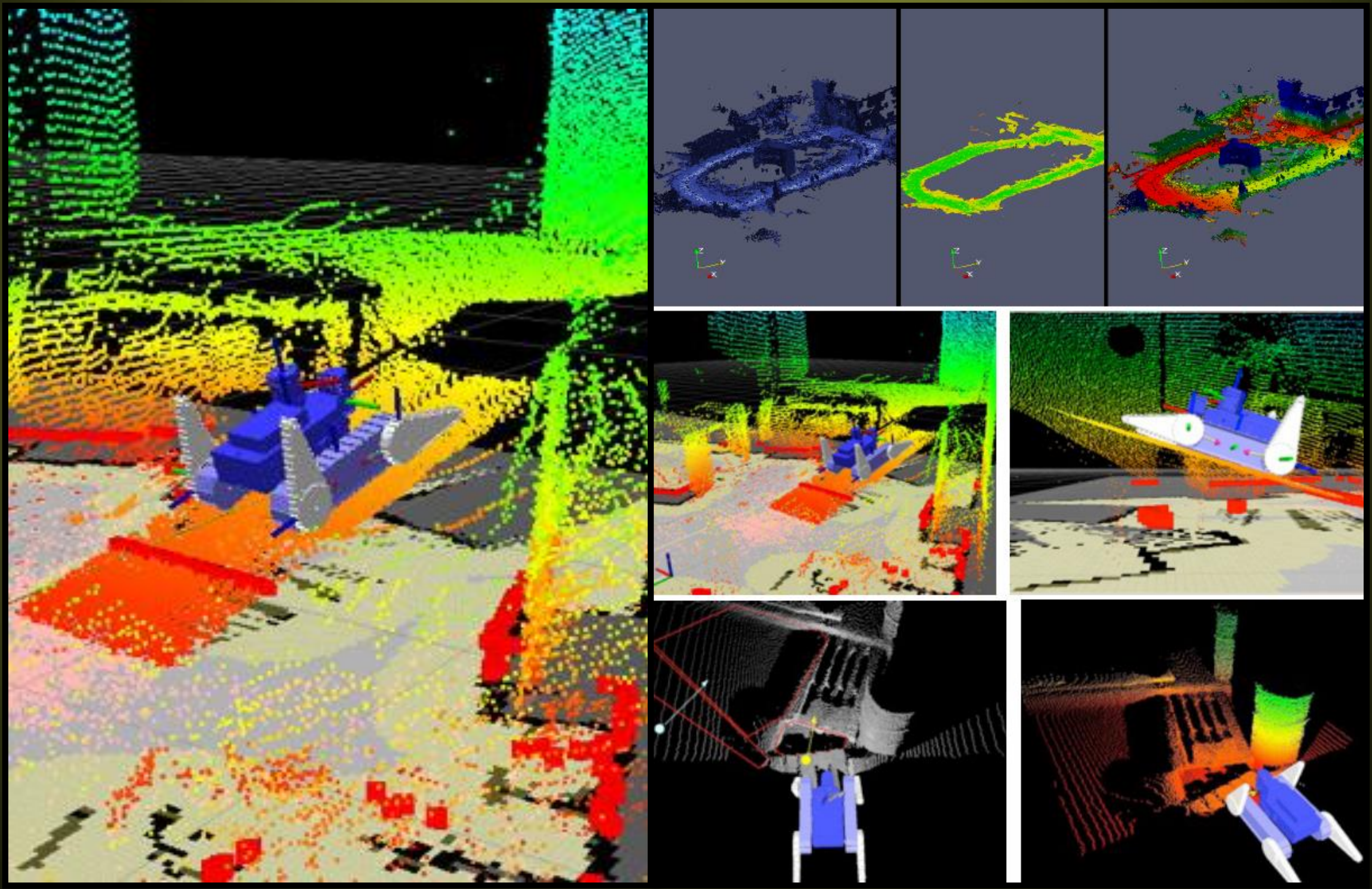


METRIC MAPPING

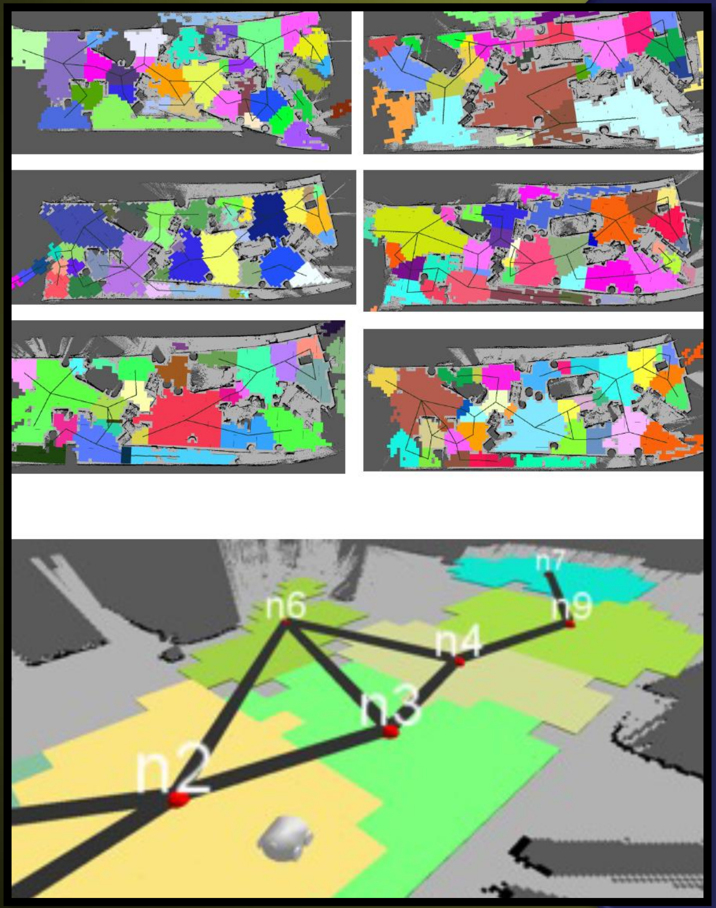


- Rotating laser in front of the robot
- Range data assembled into point clouds
  Fast ICP algorithm
  http://ros.org/wiki/ethzasl_icp_mapping
- Density subsampling (memory)
- Results in 3D metric map for SLAM
- No loop closure yet
- Gap detection
- Traversability analysis

METRIC MAPPING

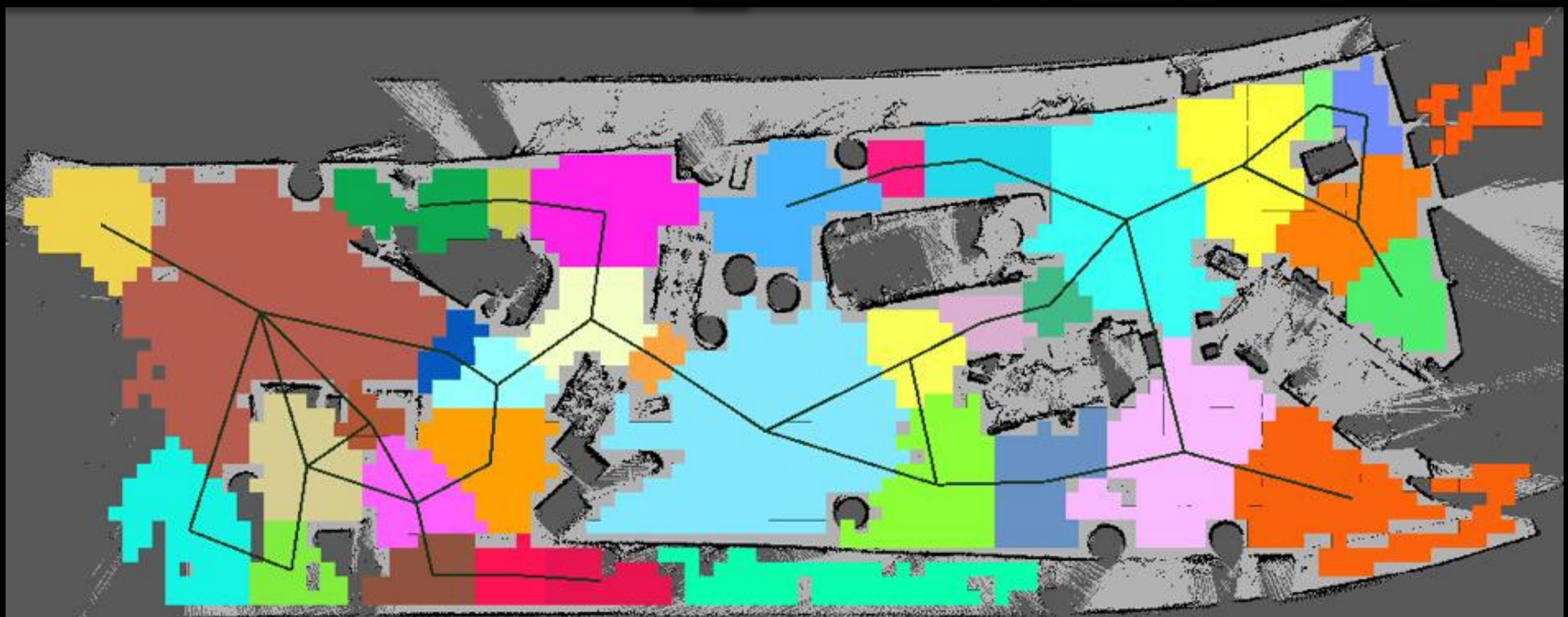


TOPOLOGICAL MAPPING

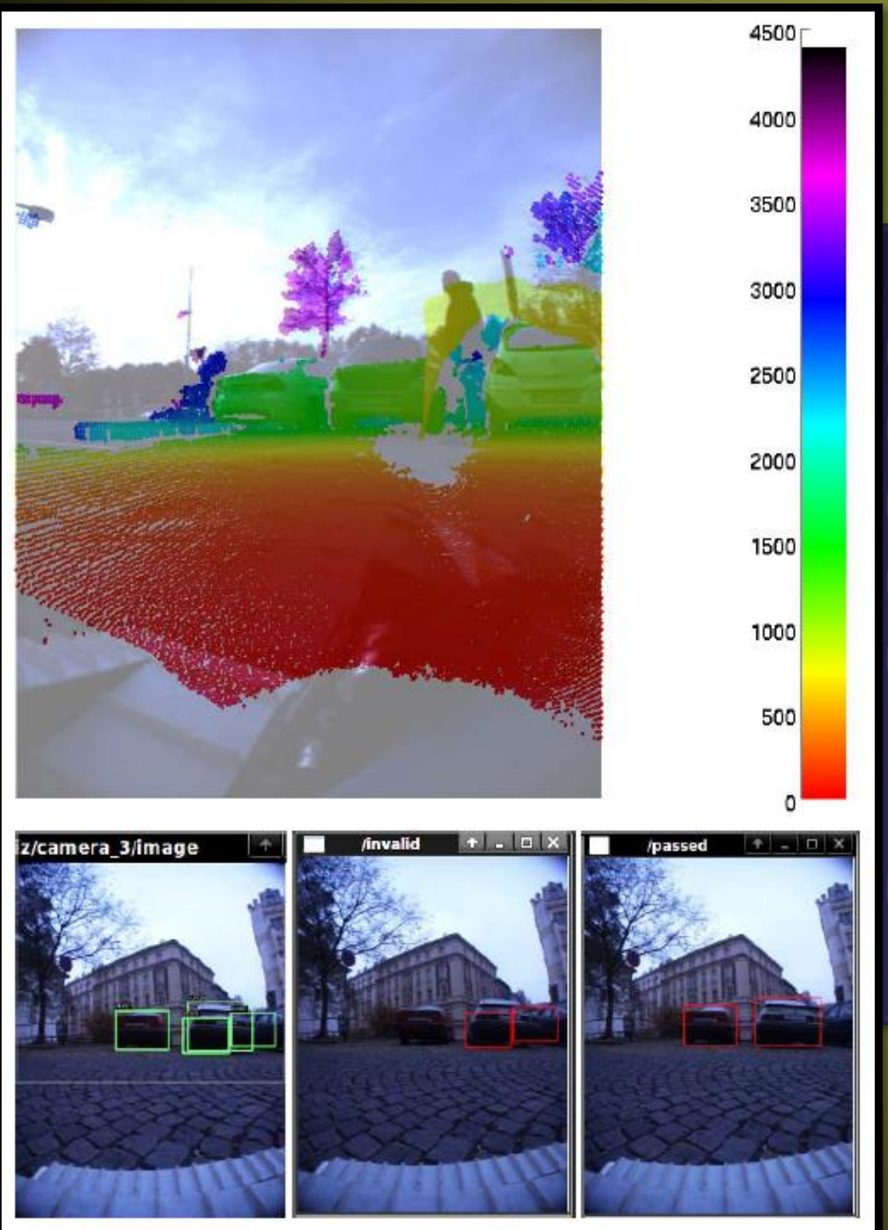


- Incremental segmentation
- Segmentation into discrete regions
- Voronoi diagram
- Identification of changes in metric map & recomputation
- Graph-based structure over (centroids of) regions
- Required for different levels of planning

TOPOLOGICAL MAPPING

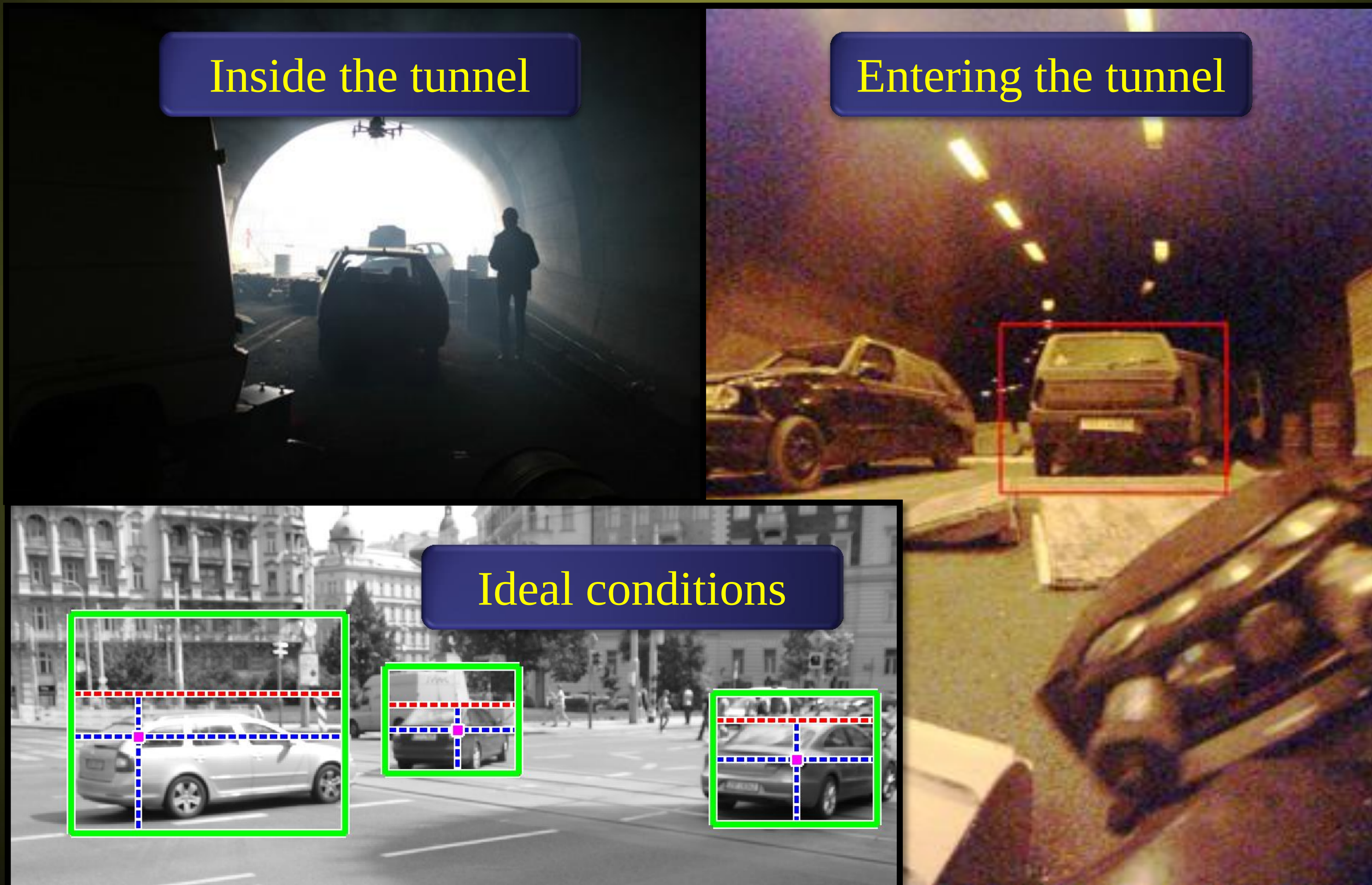


OBJECT DETECTION & LOCALIZATION - CARS

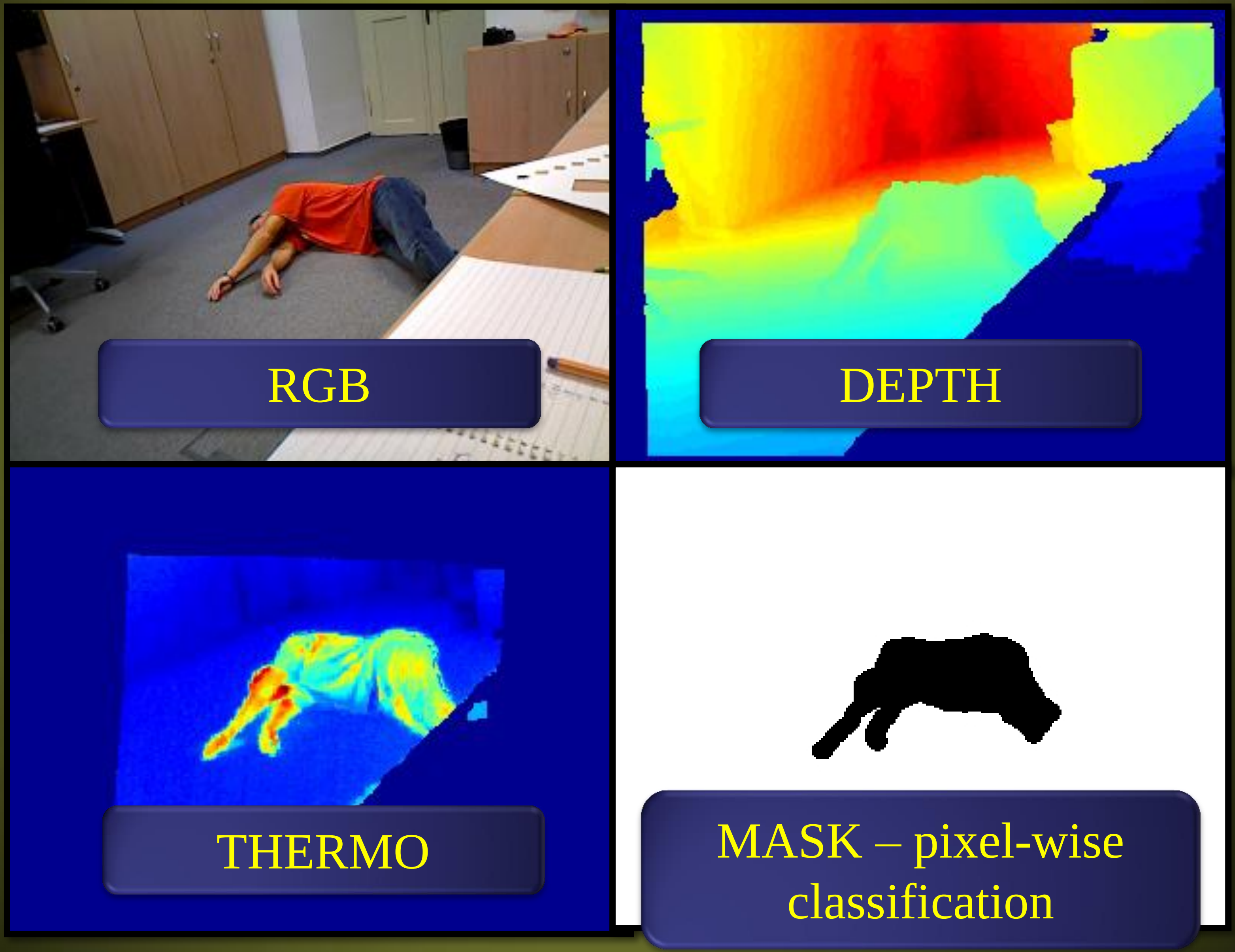


- Robust 2D & 3D object detection
- Using omni-directional camera
- Associating detection with laser
- Filtering out false positives
- False positives negatively impact situation wareness, human-robot interaction
- Visual features to 3D data

OBJECT DETECTION & LOCALIZATION - CARS

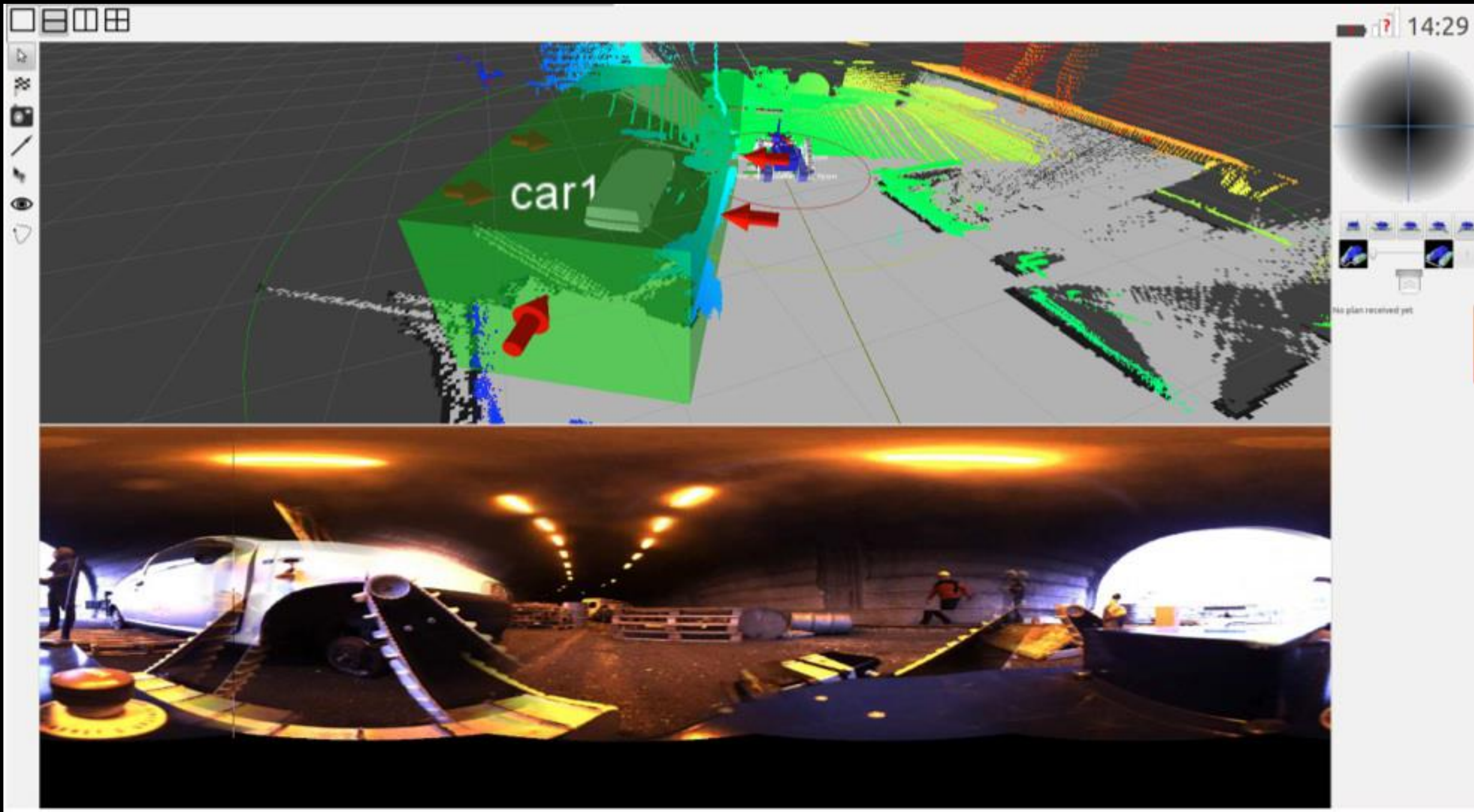


OBJECT DETECTION & LOCALIZATION - VICTIMS

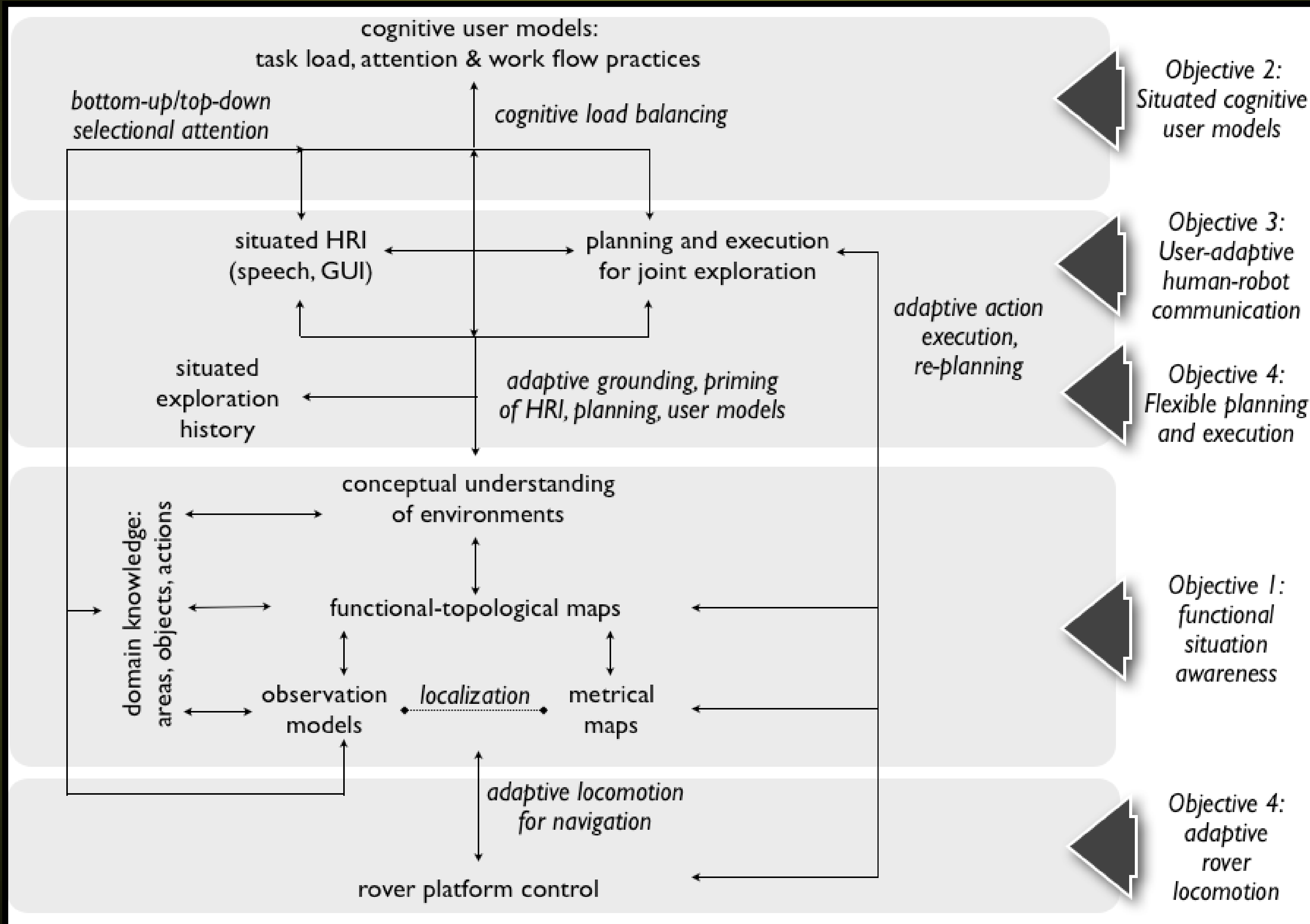


FUNCTIONAL MAPPING

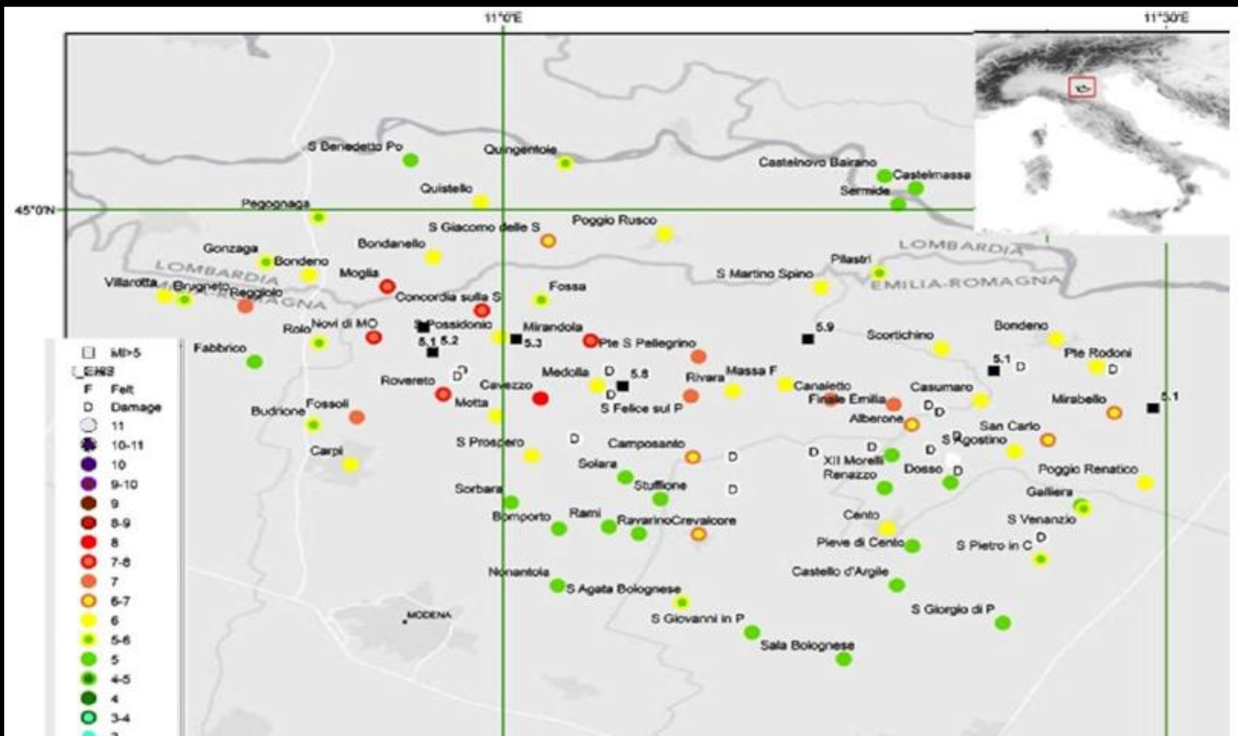
OCU – OPERATION CONTROL UNIT

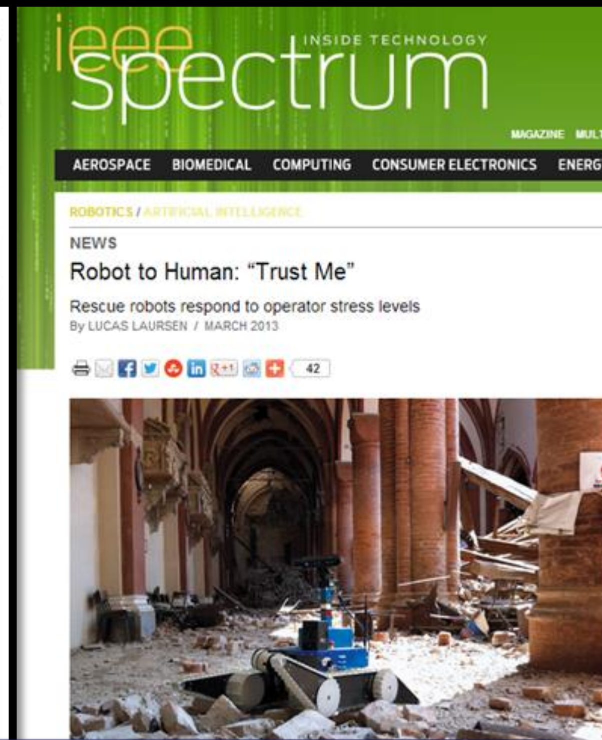


INTEGRATED INTELLIGENCE

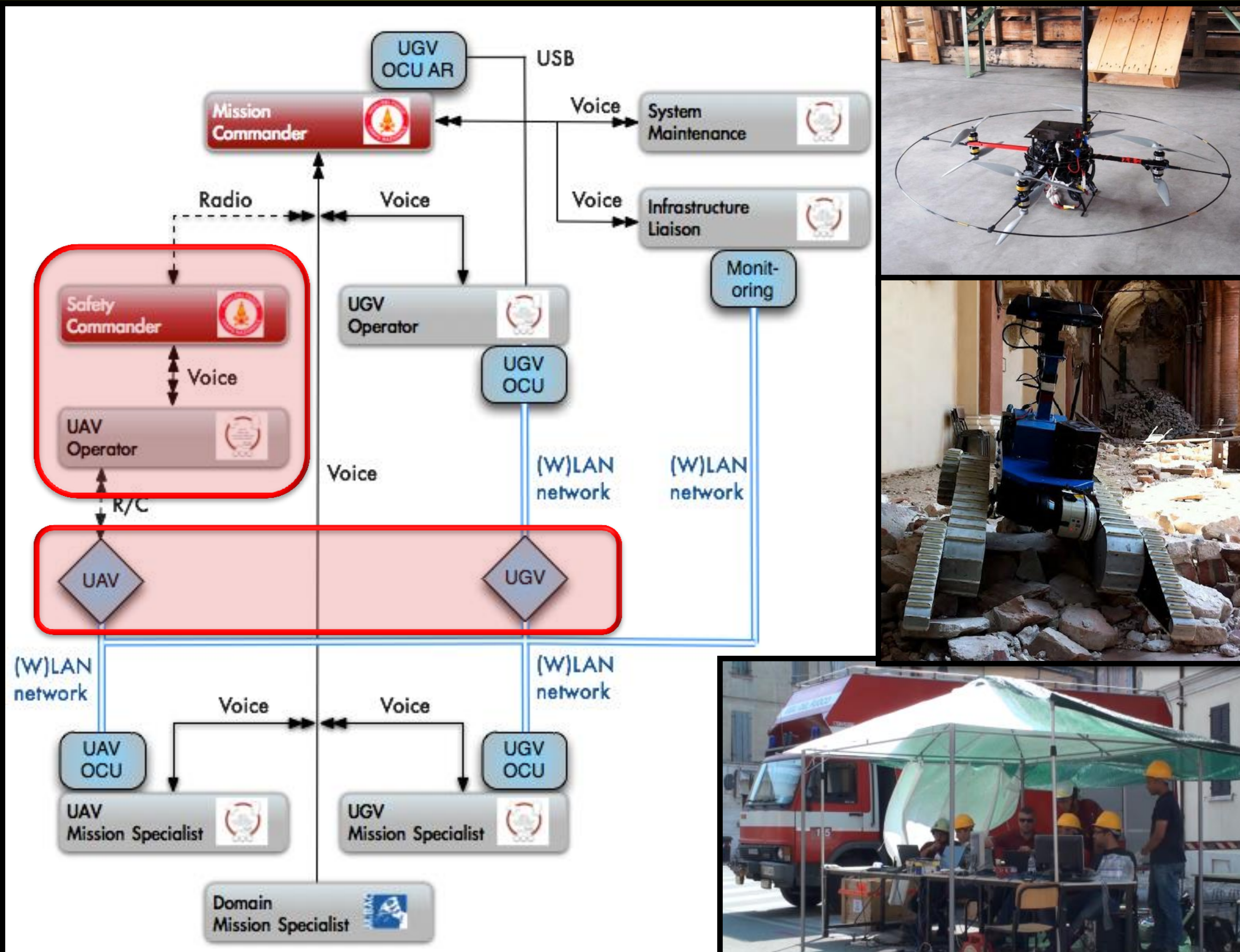


USAR MISSION – MIRANDOLA, IT 2012

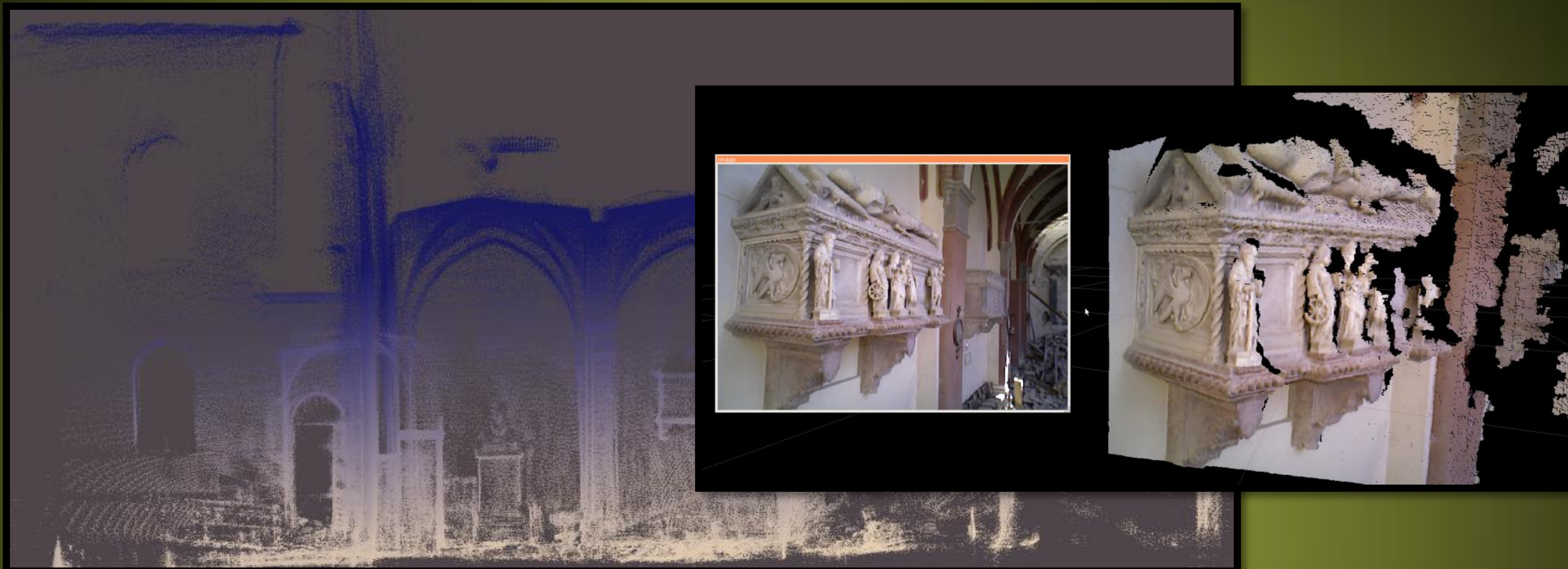


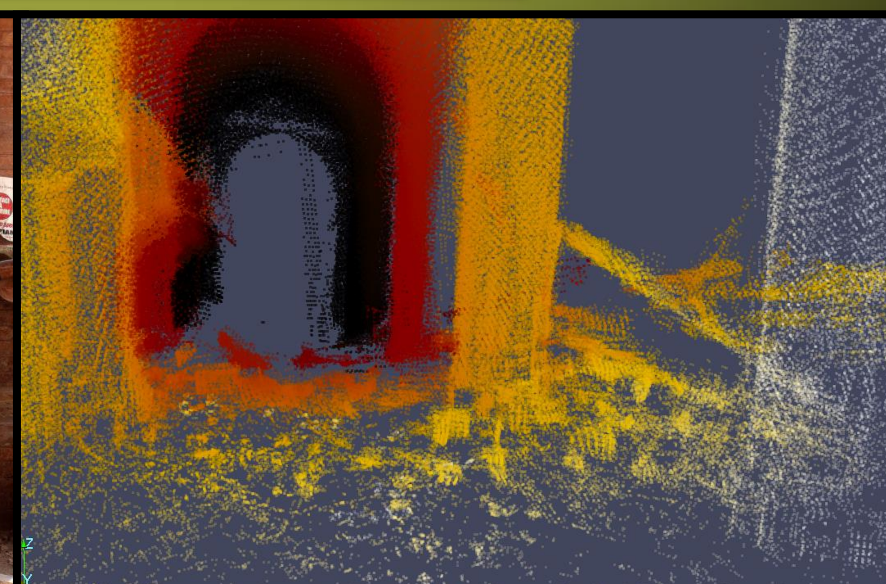


May 20 – June 18, 2012, Mirandola, Italy
246 seismic activities of magnitudes 3 – 6.1
Radius of 50 km, 900 000 people affected
Red area: San Francesco church


UGV OCU AR
USB
Mission Commander
Voice
System Maintenance
Radio
Voice
Voice
Infrastructure Liaison
Monit-oring
Safety Commander
UGV Operator
Voice
UGV OCU
UAV Operator
Voice
(W)LAN network
(W)LAN network
R/C
UAV
UGV
(W)LAN network
(W)LAN network
Voice
Voice
UAV OCU
UGV OCU
UAV Mission Specialist
UGV Mission Specialist
Domain Mission Specialist

USAR MISSION – MIRANDOLA,ITALY 2012





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NIFTi
Inertial Navigation System

2010 – 2014
EC project FP7-ICT-247870 NIFTi

Michal Reinštein

Natural Human-Robot Cooperation in Dynamic Environments

INERTIAL SENSORS

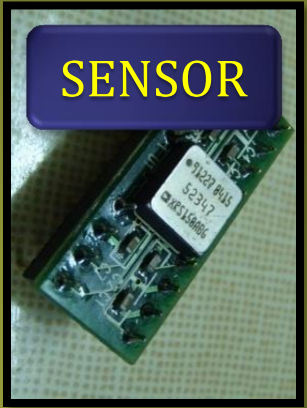
LOW-COST INS

=

Time correlated degradation in precision due to sensor errors

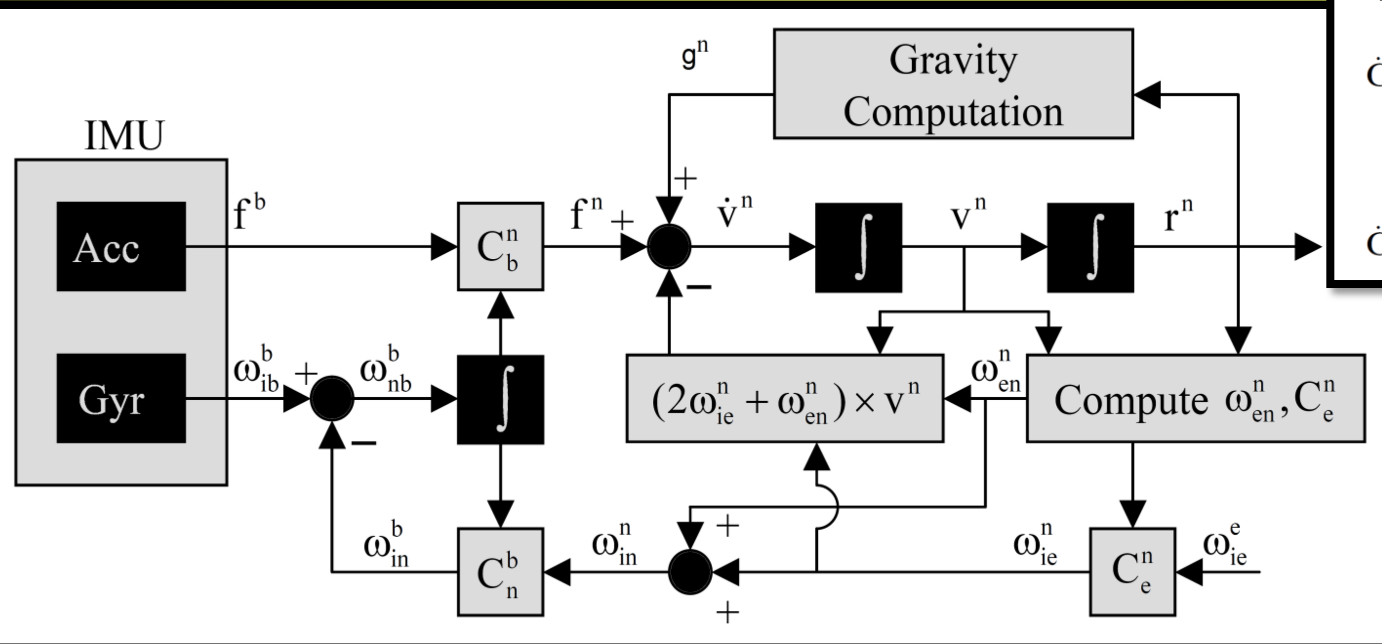
SOLUTION:

- Aiding : odometry, visual odometry, laser range data, ultrasound, GPS / GLONAS, magnetometer
- Sensor Error Calibration & Estimation (KF, EKF, UKF)



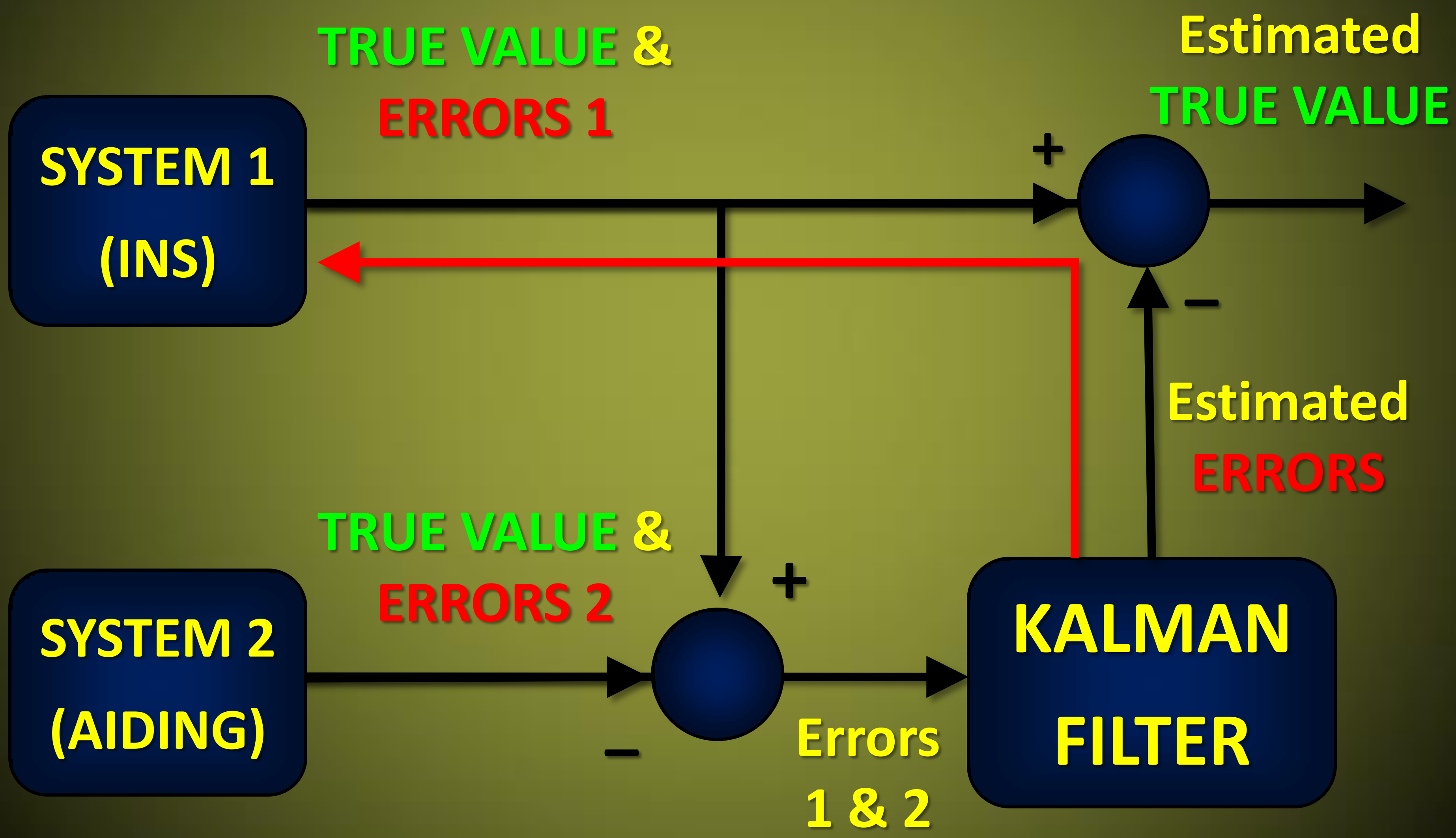
INERTIAL NAVIGATION SYSTEM

- Double integration of accelerations to obtain position
- Integration of angular rates to obtain angle of direction of the accelerometers' sensing axes
- Transformation from body frame **b** to navigation frame **n**
- Compensation: gravity, Earth rate, Coriolis force, centripetal acceleration, systematic & stochastic sensor errors

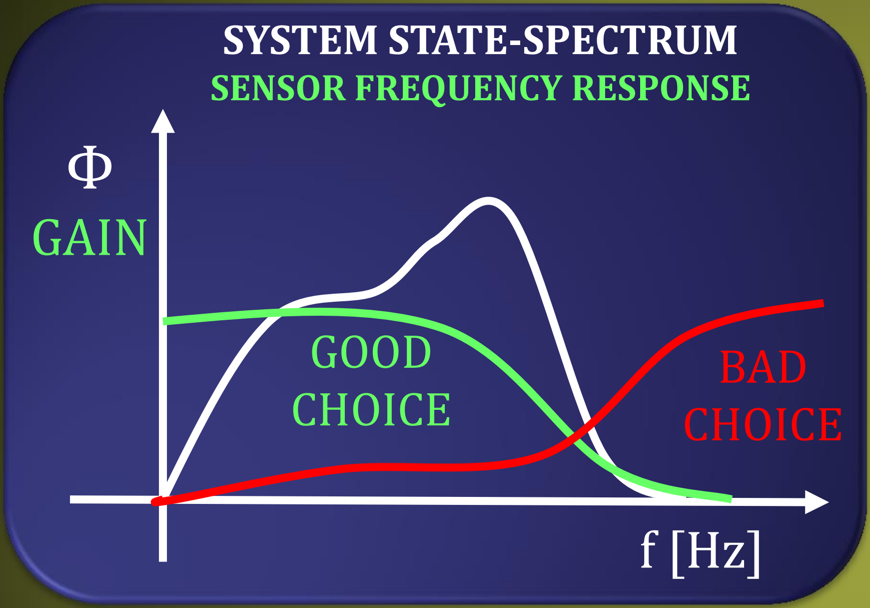


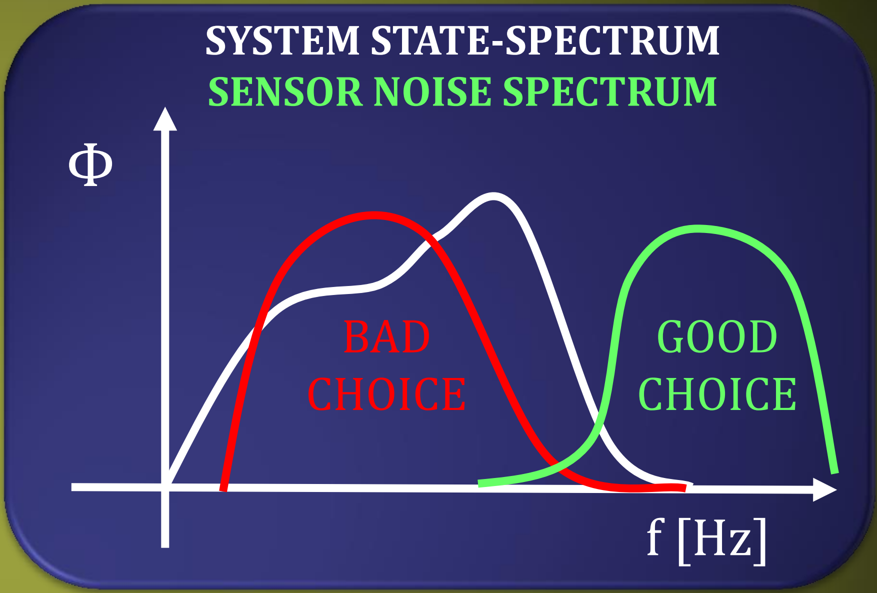
$$
\begin{aligned}
\dot{\mathbf{v}}^n &= \mathbf{C}^n_b \mathbf{f}^b + \mathbf{g}^n - (2\boldsymbol{\omega}^n_{ie} + \boldsymbol{\omega}^n_{en}) \times \mathbf{v}^n \\
\dot{\mathbf{C}}^e_n &= \mathbf{C}^e_n (\boldsymbol{\omega}^n_{en} \times) \\
\dot{h} &= -v_D \\
\dot{\mathbf{C}}^n_b &= \mathbf{C}^n_b (\boldsymbol{\omega}^b_{ib} \times) - (\boldsymbol{\omega}^n_{in} \times) \mathbf{C}^n_b
\end{aligned}
$$

DATA FUSION


TRUE VALUE &
ERRORS 1
SYSTEM 1
(INS)
Estimated
TRUE VALUE
+
–
Estimated
ERRORS
TRUE VALUE &
ERRORS 2
SYSTEM 2
(AIDING)
+
–
Errors
1 & 2
KALMAN
FILTER

SENSOR SELECTION

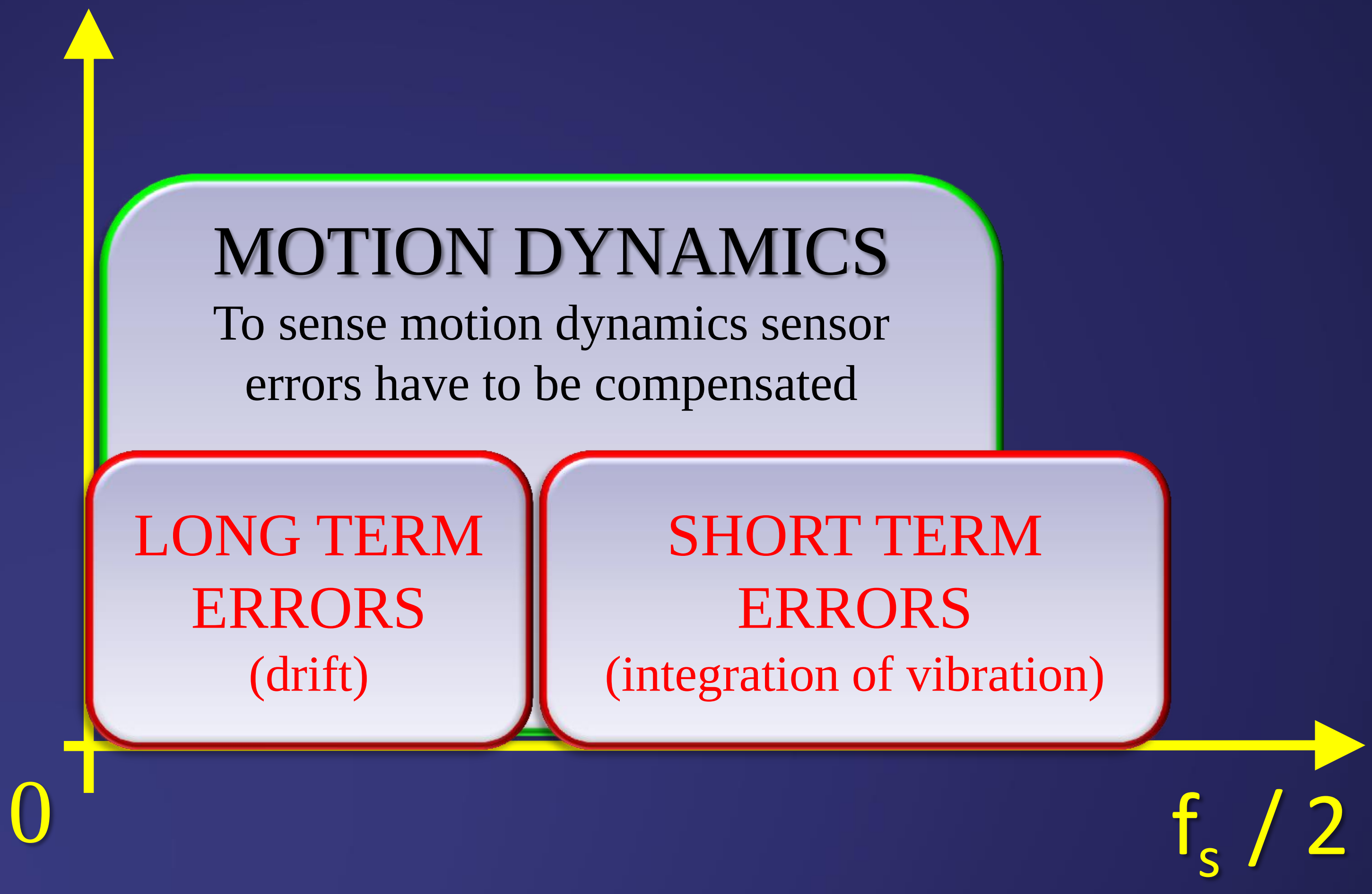




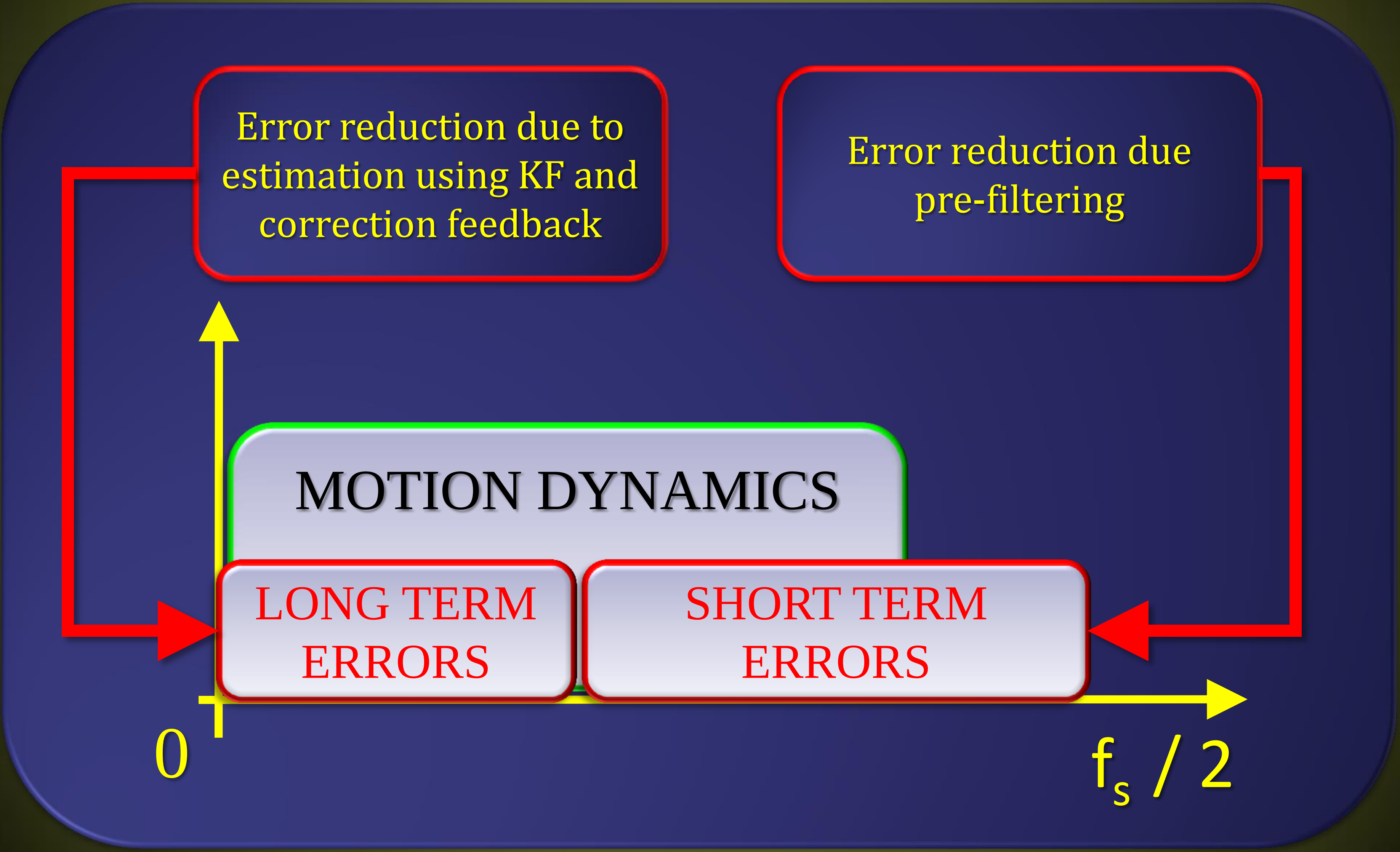
The frequency response of the sensor should be compatible with the system state-spectrum.

The sensor noise spectrum should be separable from the system state-spectrum.

INERTIAL SENSORS ERRORS



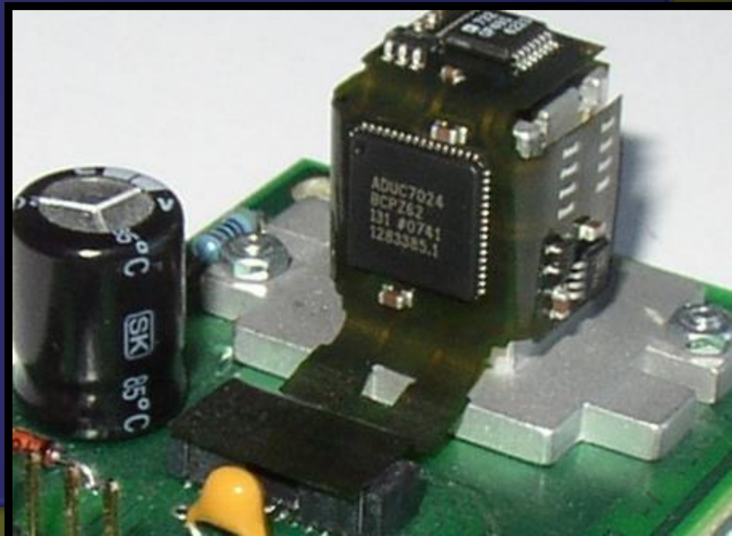
INERTIAL SENSORS ERRORS



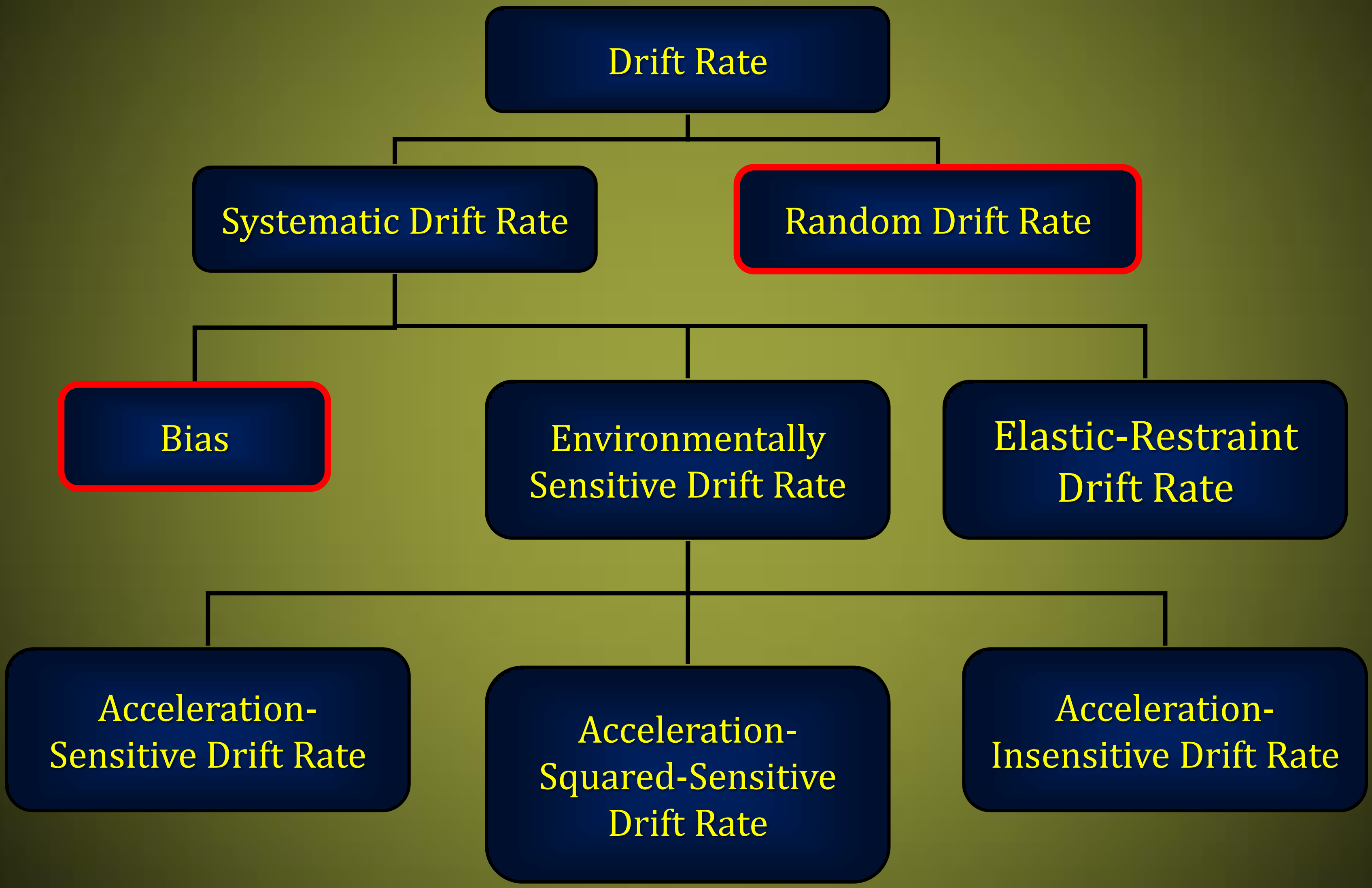
INERTIAL SENSORS ERRORS

SENSOR DRIFT

- Result of manufacturing imperfections of the sensors
- Systematic component (bias) quantified by calibration (can be compensated)
- Stochastic component approximated by random process (can be modelled and estimated)
- No correlation to the input
- Refers to the rate at which the error accumulates with time



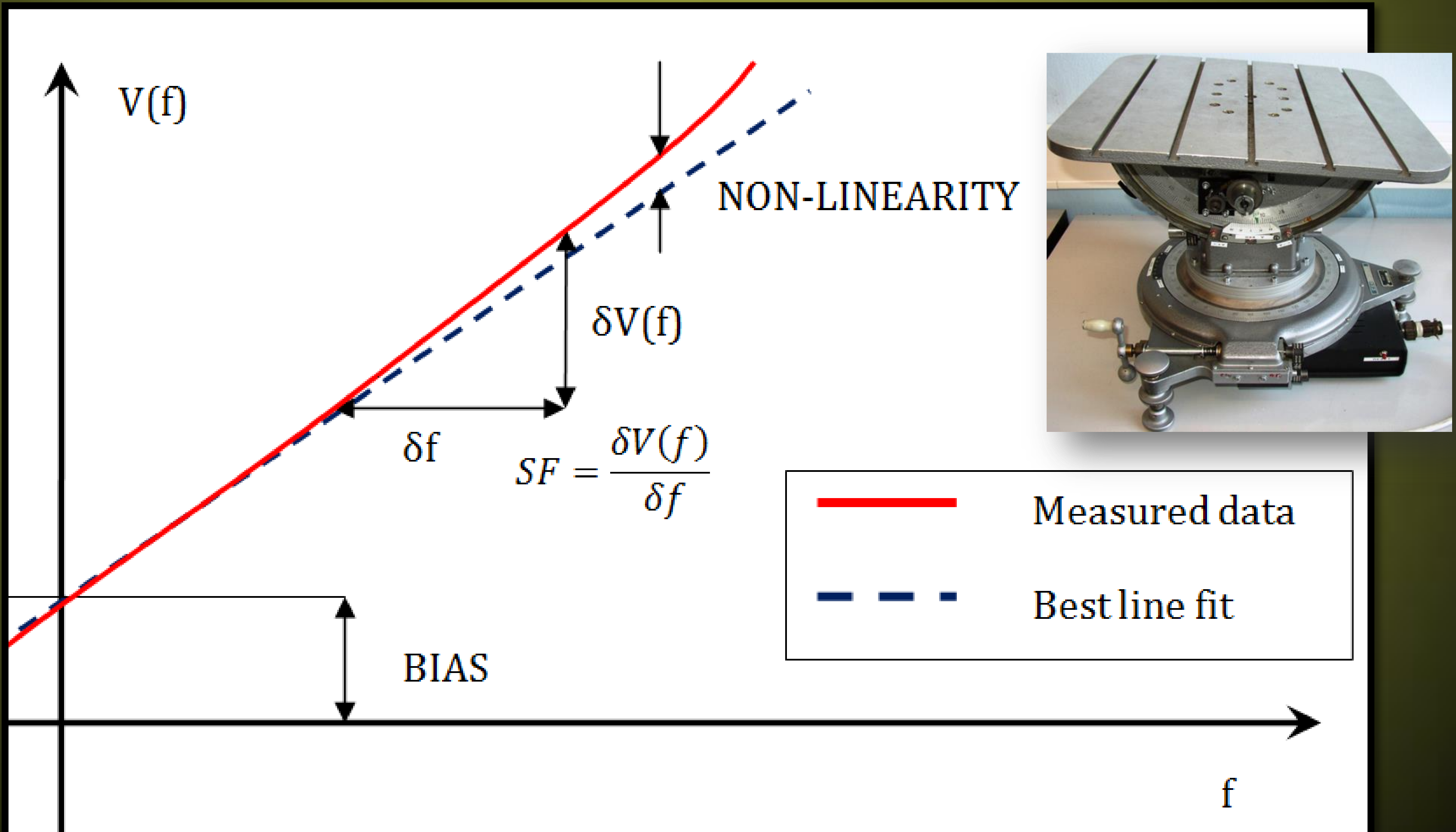
INERTIAL SENSORS ERRORS



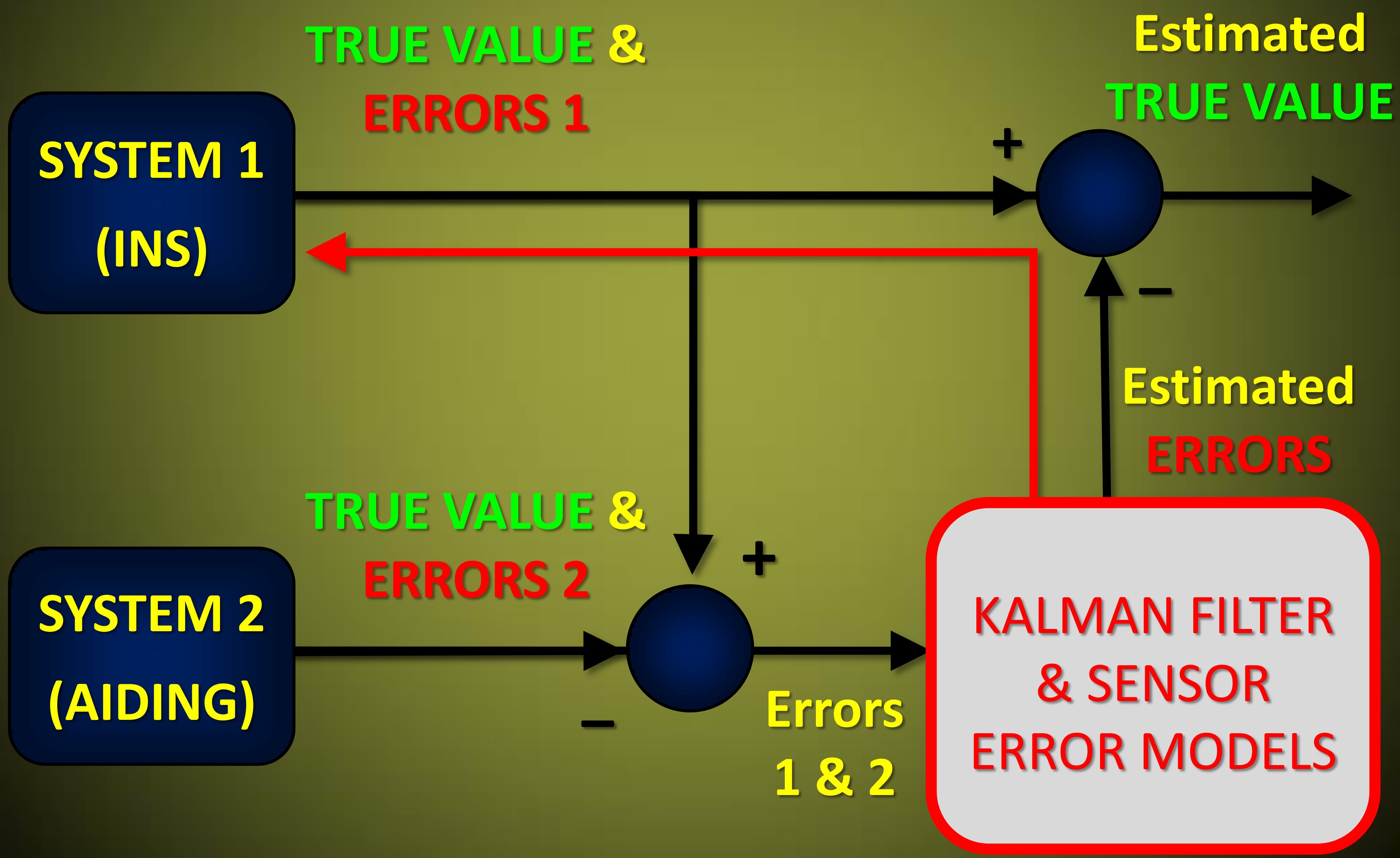
IEEE Std 528-2001: Standard for Inertial Sensor Terminology

INERTIAL SENSORS ERRORS

Projection of sensor bias, scale factor and non-linearity to the sensor conversion characteristics – CALIBRATION required

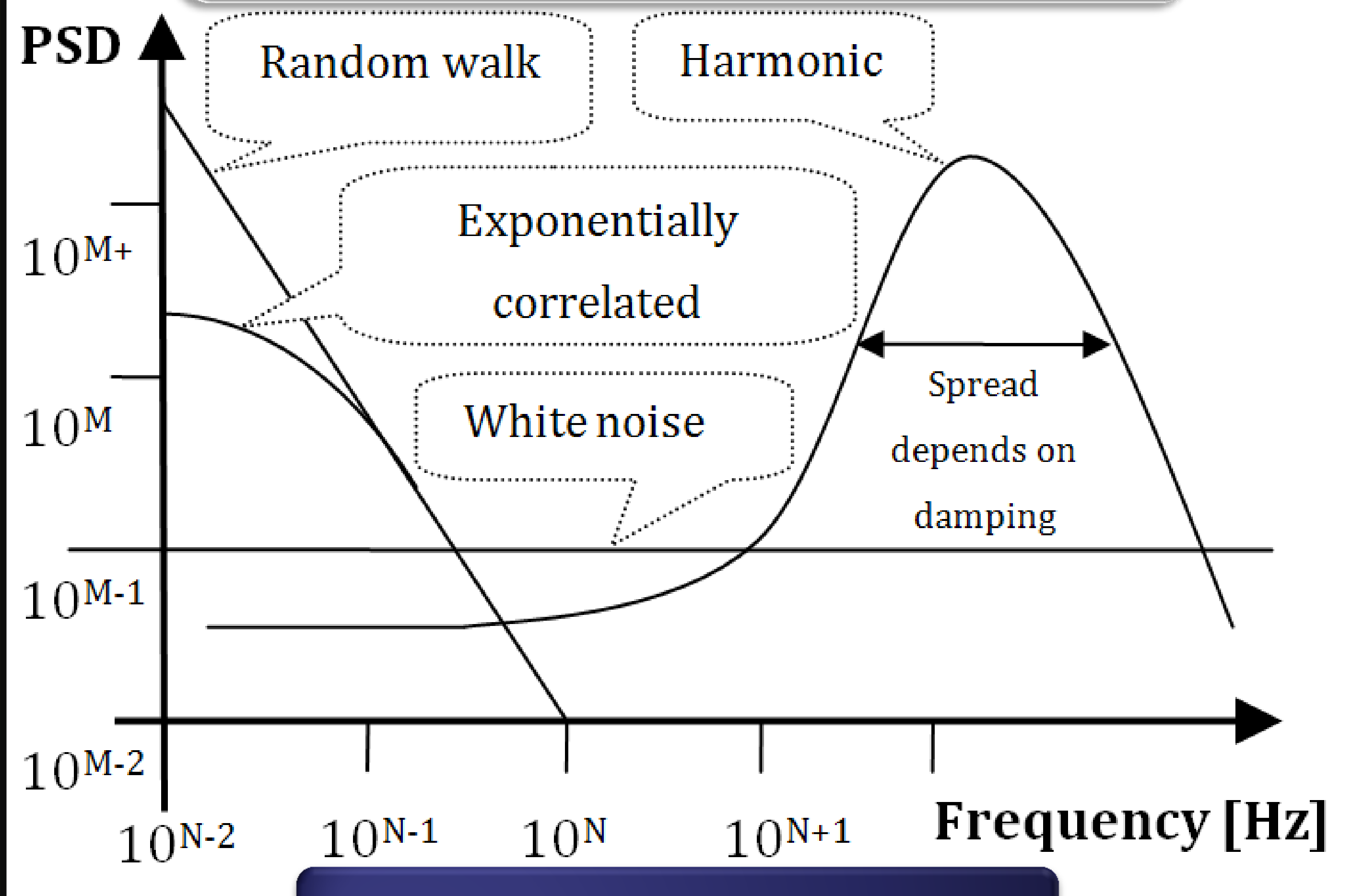


DATA FUSION – ERROR MODELS



PSD/ACF ANALYSIS

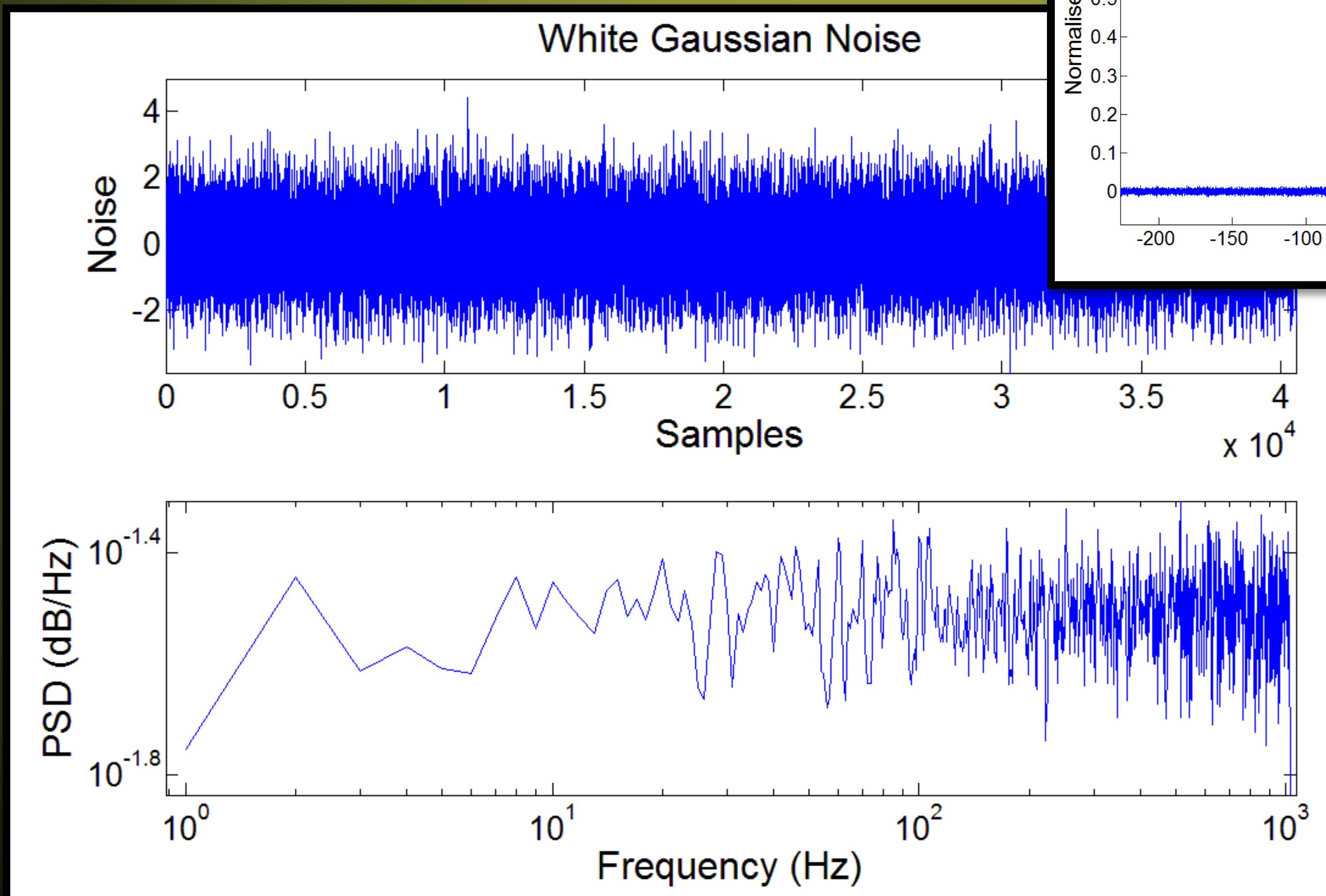
$$\psi_x(\tau) = E[x(t)x(t+\tau)], \Psi_x(\omega) = \int_{-\infty}^{\infty} \psi_x(\tau) e^{-j\omega\tau} d\tau$$

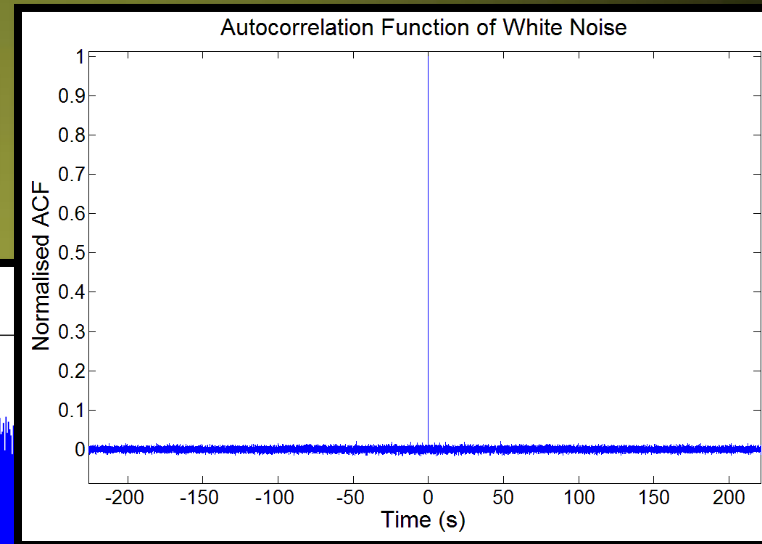


MATLAB: pwelch / xcorr

PSD/ACF ANALYSIS

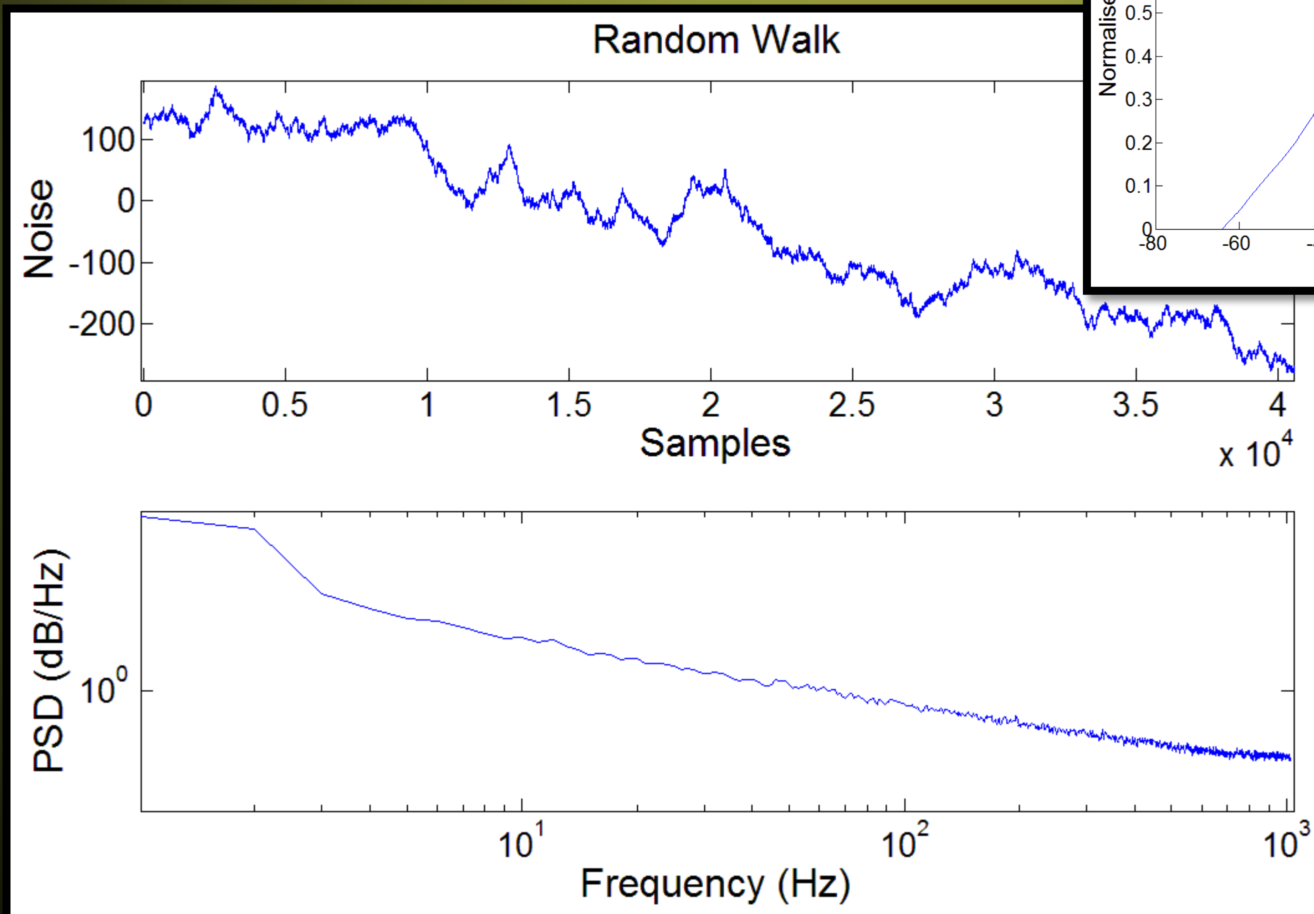
White noise PSD is flat and constant

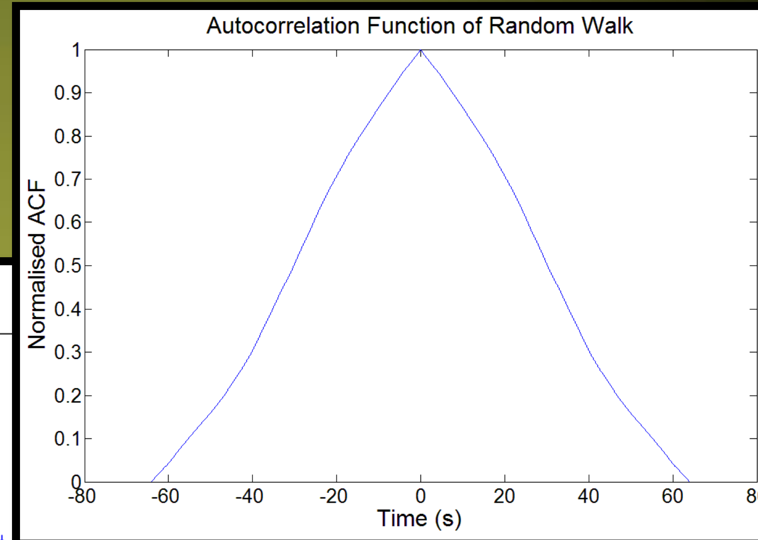




PSD/ACF ANALYSIS

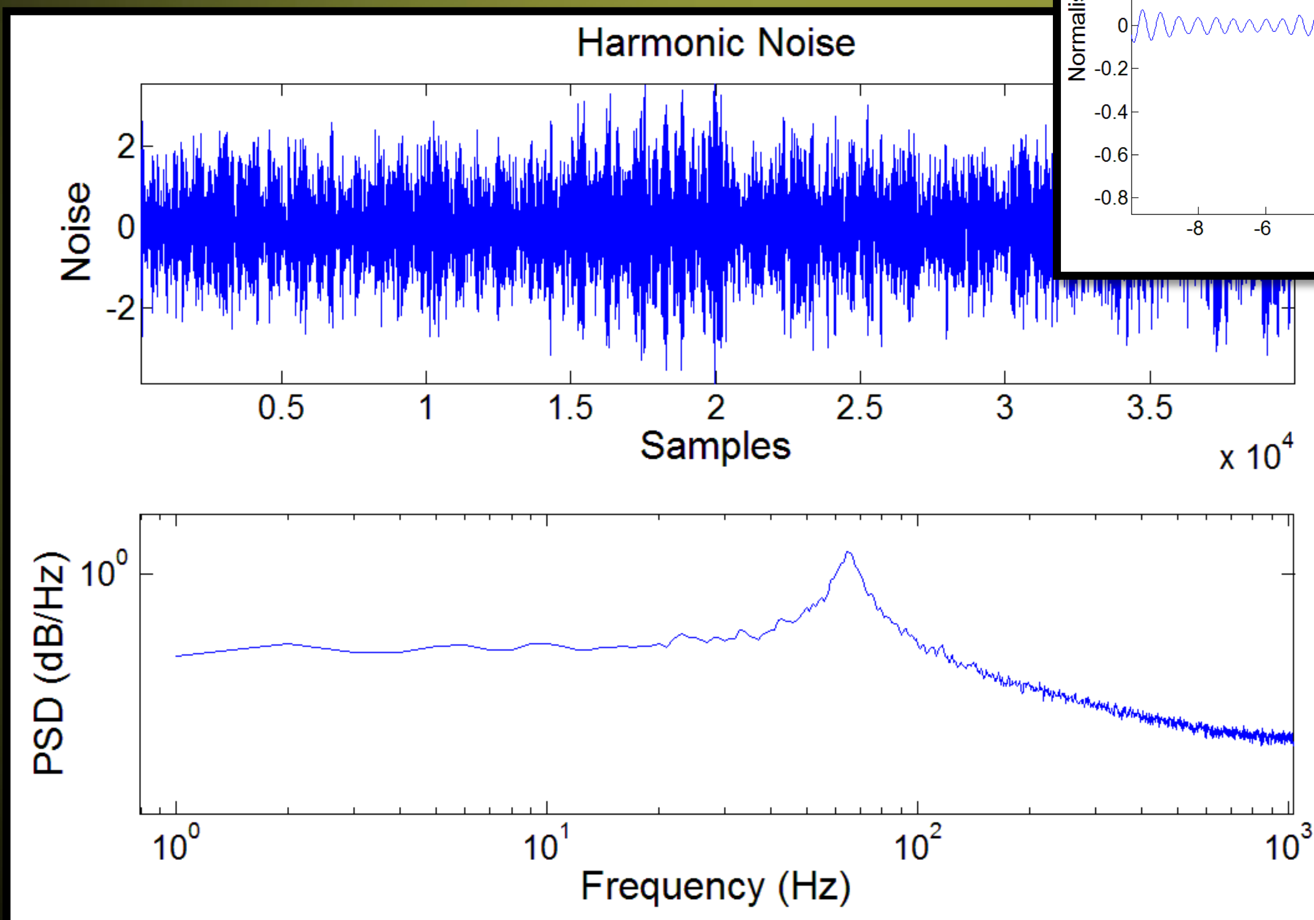
Random walk noise PSD decreases at -20dB/decade

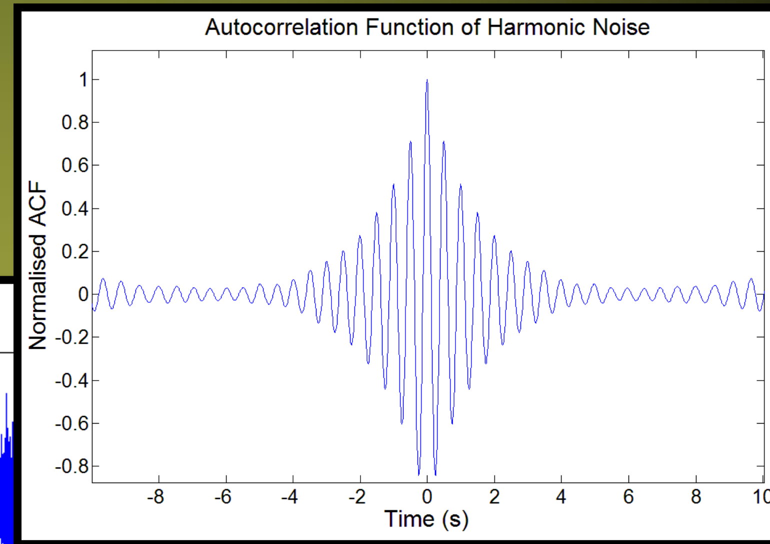




PSD/ACF ANALYSIS

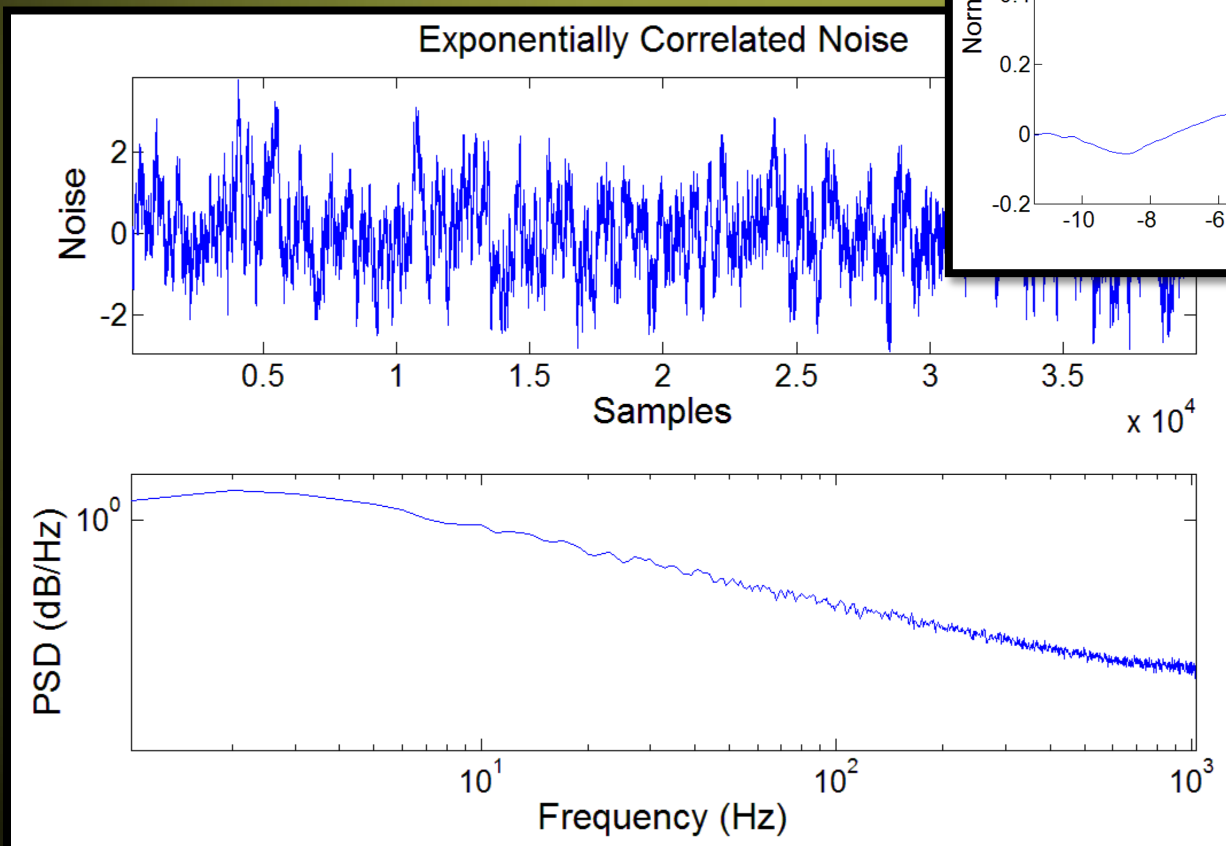
Harmonic noise PSD has bumps (spread ≈ damping)

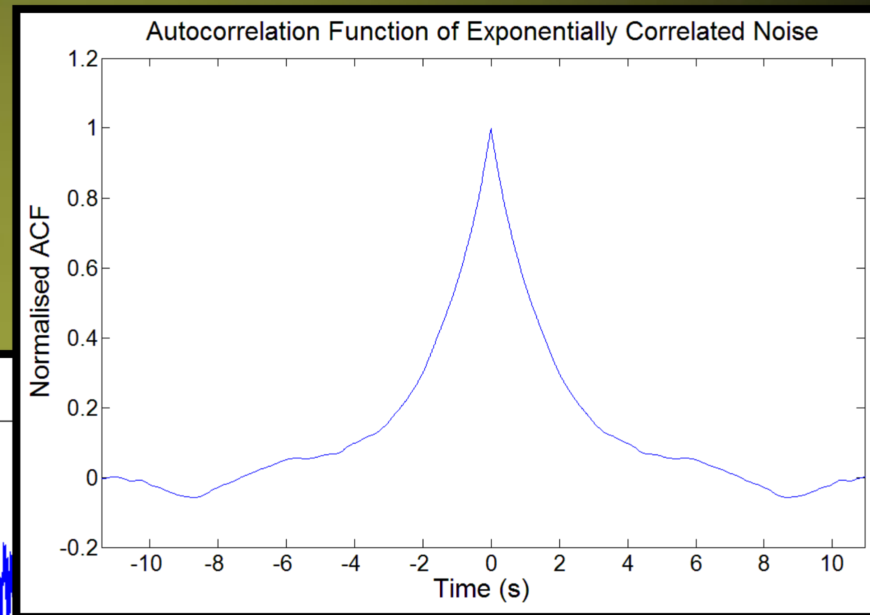




PSD/ACF ANALYSIS

Exponentially correlated noise PSD flattens near DC



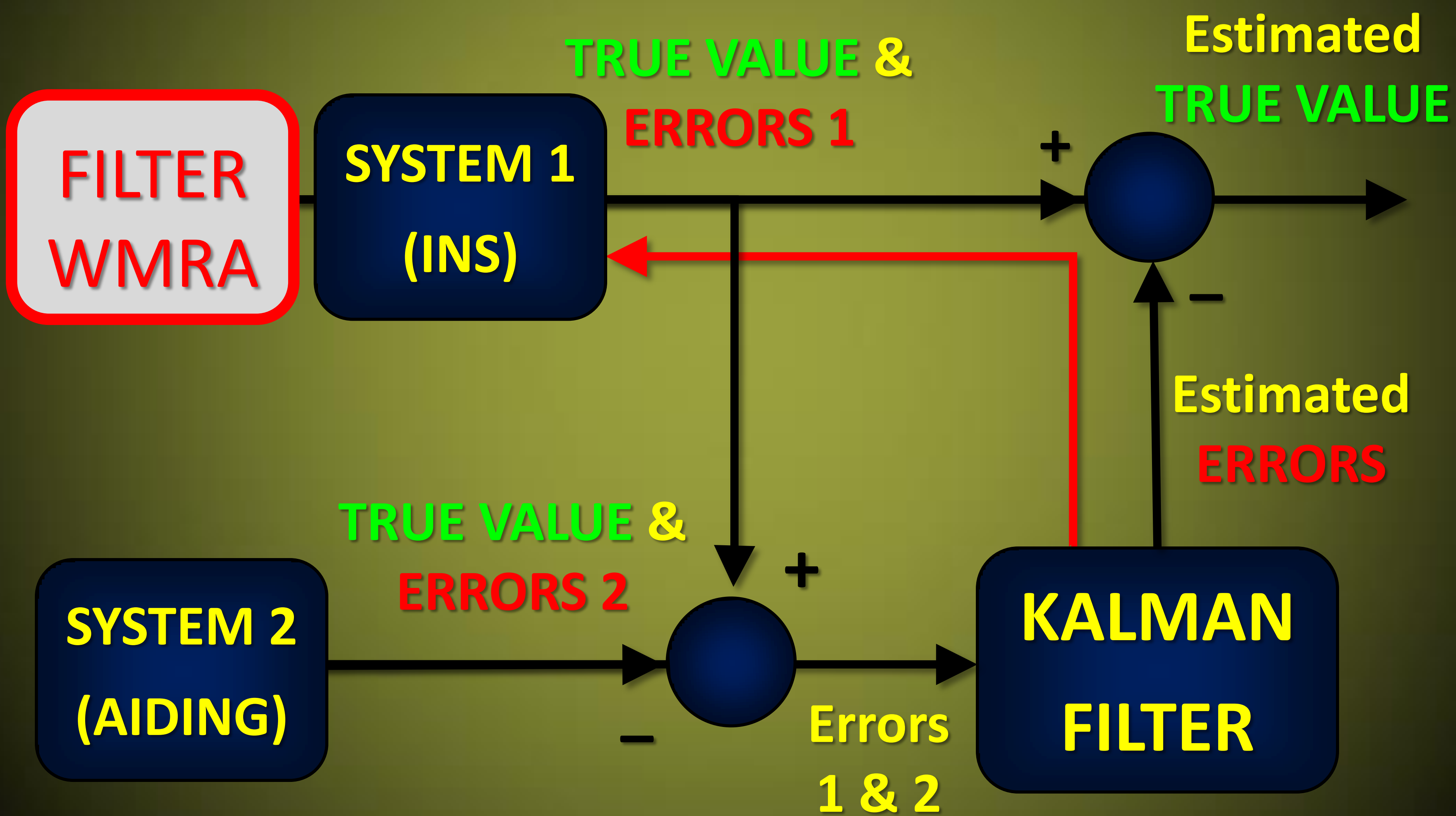


NOISE MODEL EQUATIONS

Noise Type	Autocorrelation Function ψ_x Power Spectral Density Ψ_x	State-Space Formulation And Model	
White noise	$\psi_x(\tau)=\sigma^2\delta^2(\tau)$ $\Psi_x(\omega)=\sigma^2$	Always treated as measurement noise	
Random walk	$\psi_x(\tau)=(undefined)$ $\Psi_x(\omega)\approx\sigma^2/\omega^2$	$\dot{x}=w(t)$ $\sigma_x^2(0)=0$	$x_k=x_{k-1}+w_{k-1}$ $\sigma_x^2(0)=0$
Random constant	$\psi_x(\tau)=\sigma^2$ $\Psi_x(\omega)=2\pi\sigma^2(\omega)$	$\dot{x}=0$ $\sigma_x^2(0)=\sigma^2$	$x_k=x_{k-1}$ $\sigma_x^2(0)=\sigma^2$
Harmonic	$\psi_x(\tau)=\sigma^2\cos(\omega_0\tau)$ $\Psi_x(\omega)=\pi\sigma^2\delta(\omega-\omega_0)$ $+\pi\sigma^2\delta(\omega+\omega_0)$	$\dot{x}=\begin{bmatrix}0 & 1\\ -\omega_0^2 & 0\end{bmatrix}x$	$P(0)=\begin{bmatrix}\sigma^2 & 0\\ 0 & 0\end{bmatrix}$
Exponentially correlated	$\psi_x(\tau)=\sigma^2e^{-\alpha\lvert\tau\rvert}$ $\Psi_x(\omega)=\dfrac{2\sigma^\alpha\alpha}{\omega^2+\alpha^2}$	$\dot{x}=-\alpha x+\sigma\sqrt{2\alpha}\,w(t)$ $\sigma_x^2(0)=\sigma^2$	$x_k=e^{-\alpha}x_{k-1}$ $+\sigma\sqrt{1-e^{-2\alpha}}\,w_{k-1}$ $\sigma_x^2(0)=\sigma^2$
p^{th} order GM process	$\psi_x(\tau)=\sigma^2e^{-\alpha_p\lvert\tau\rvert}\sum_{n=0}^{p-1}\dfrac{(p-1)!(2\alpha_p\lvert\tau\rvert)^{p-n-1}(p+n+1)!}{(2p-2)!n!(p-n-1)!}$		

Table Shaping Filter Equations with σ Being Standard Deviation, δ Kronecker Delta, 1/α Correlation Time, P Covariance Matrix And k Discrete Time Step

DATA FUSION – PRE-FILTERING



WAVELET TRANSFORMATION

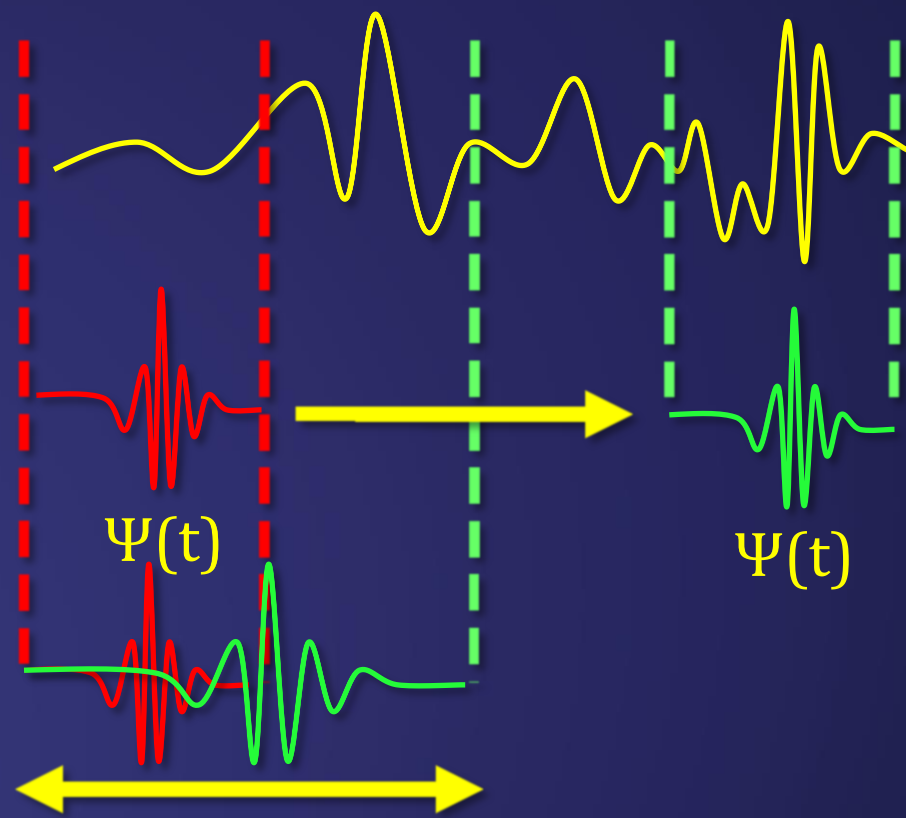
$$CWT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\Psi\left(\frac{t-b}{a}\right)dt$$

$$x(n) = \sum_{j}\sum_{k} C_{j,k}\Psi_{j,k}(n)$$

ANALYSED SIGNAL x(t)

WAVELET SHIFTING … b

WAVELET SCALING … a

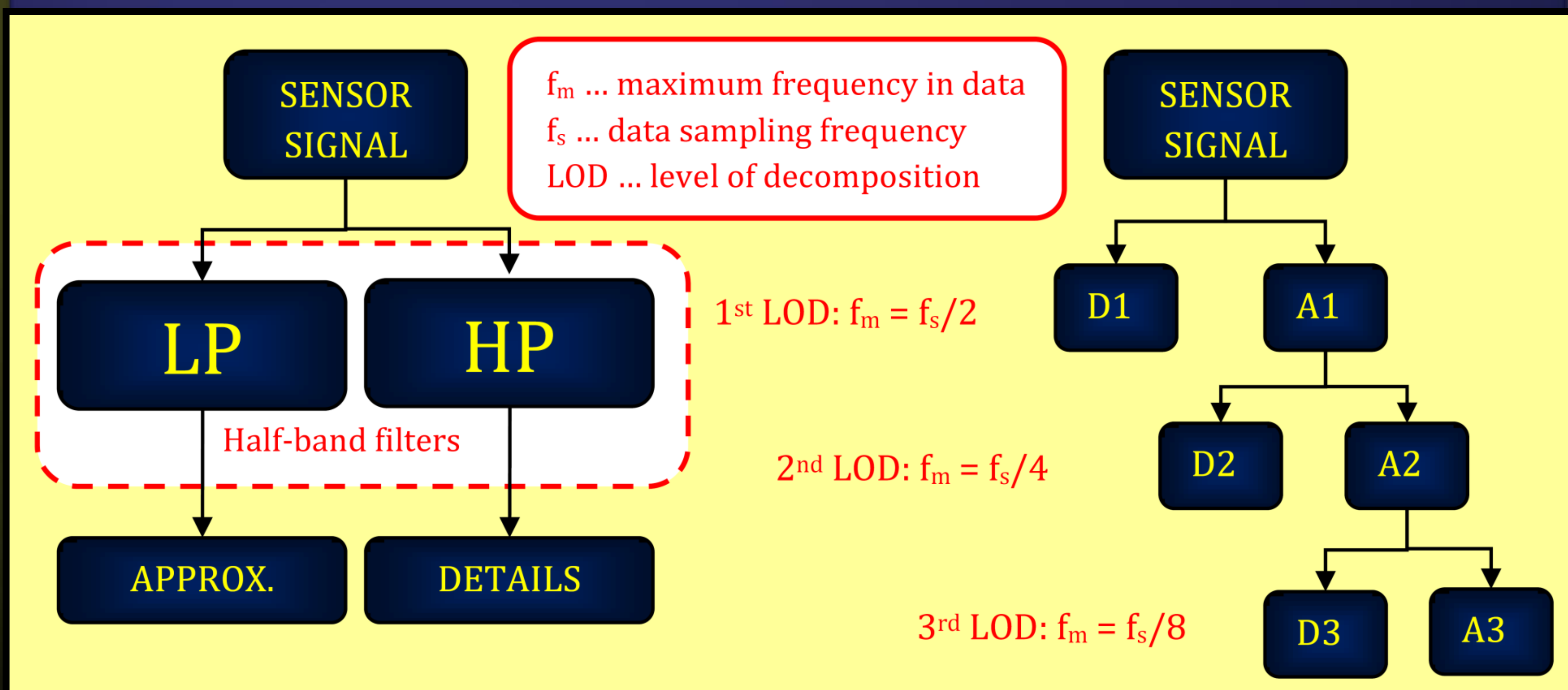


CWT(a , b) = CORRELATION COEFFICIENT

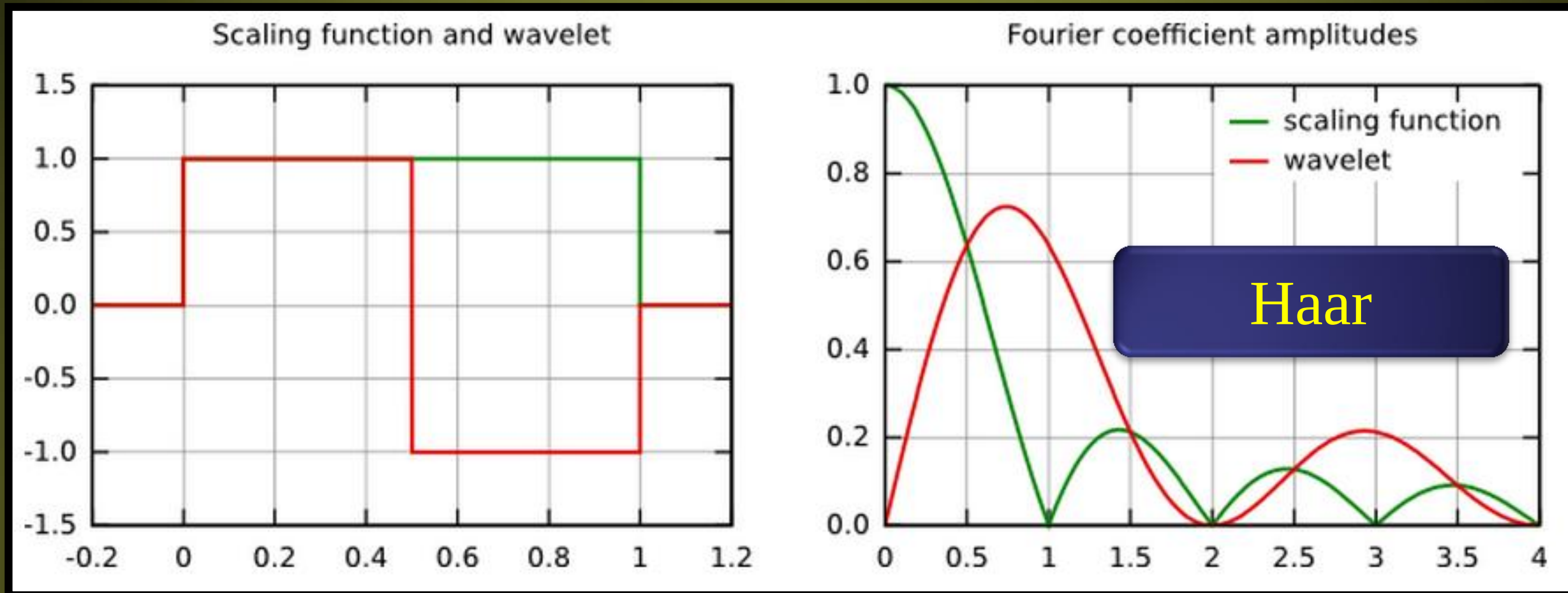
WMRA DATA DE-NOISING

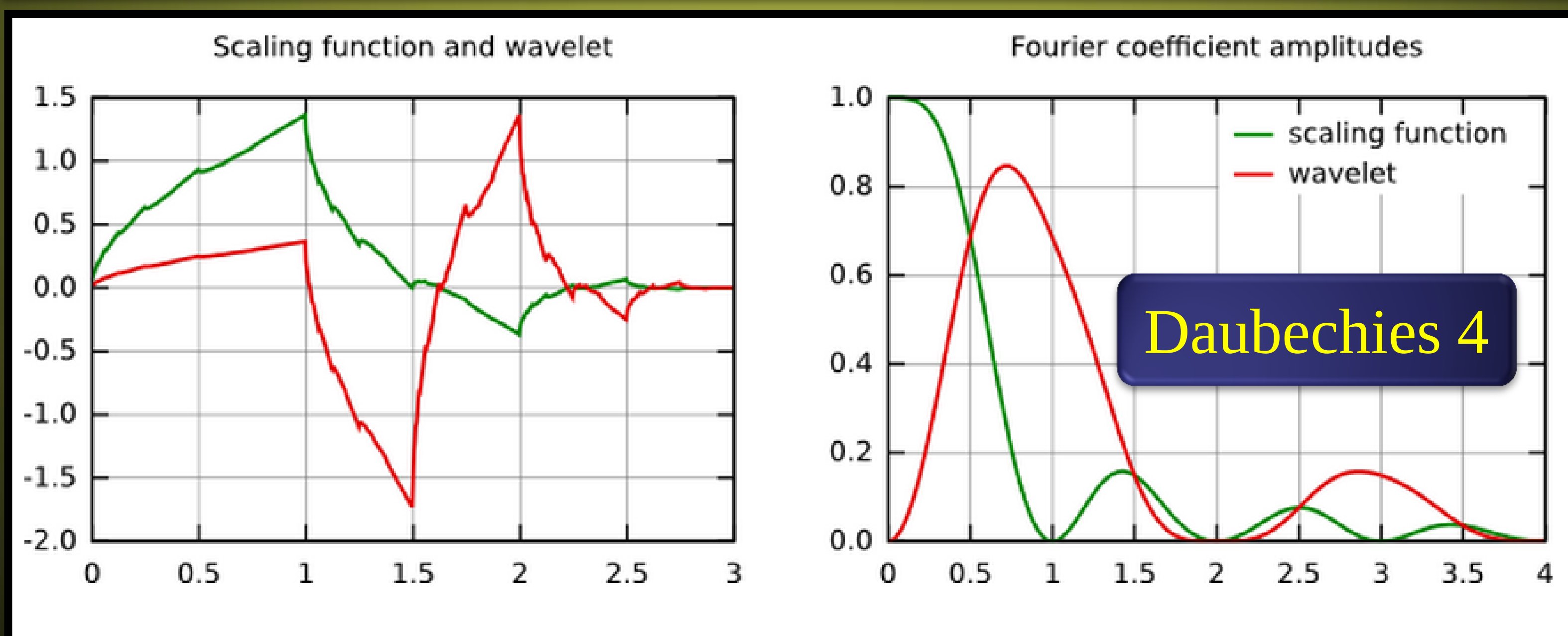
THE PRINCIPLE OF WMRA:

- Procedure of successive signal decomposition
- Scaling (LP) & wavelet (HP) filters & down-sampling 2
- MATLAB: *wden(signal, wavelet, LOD, threshold)*

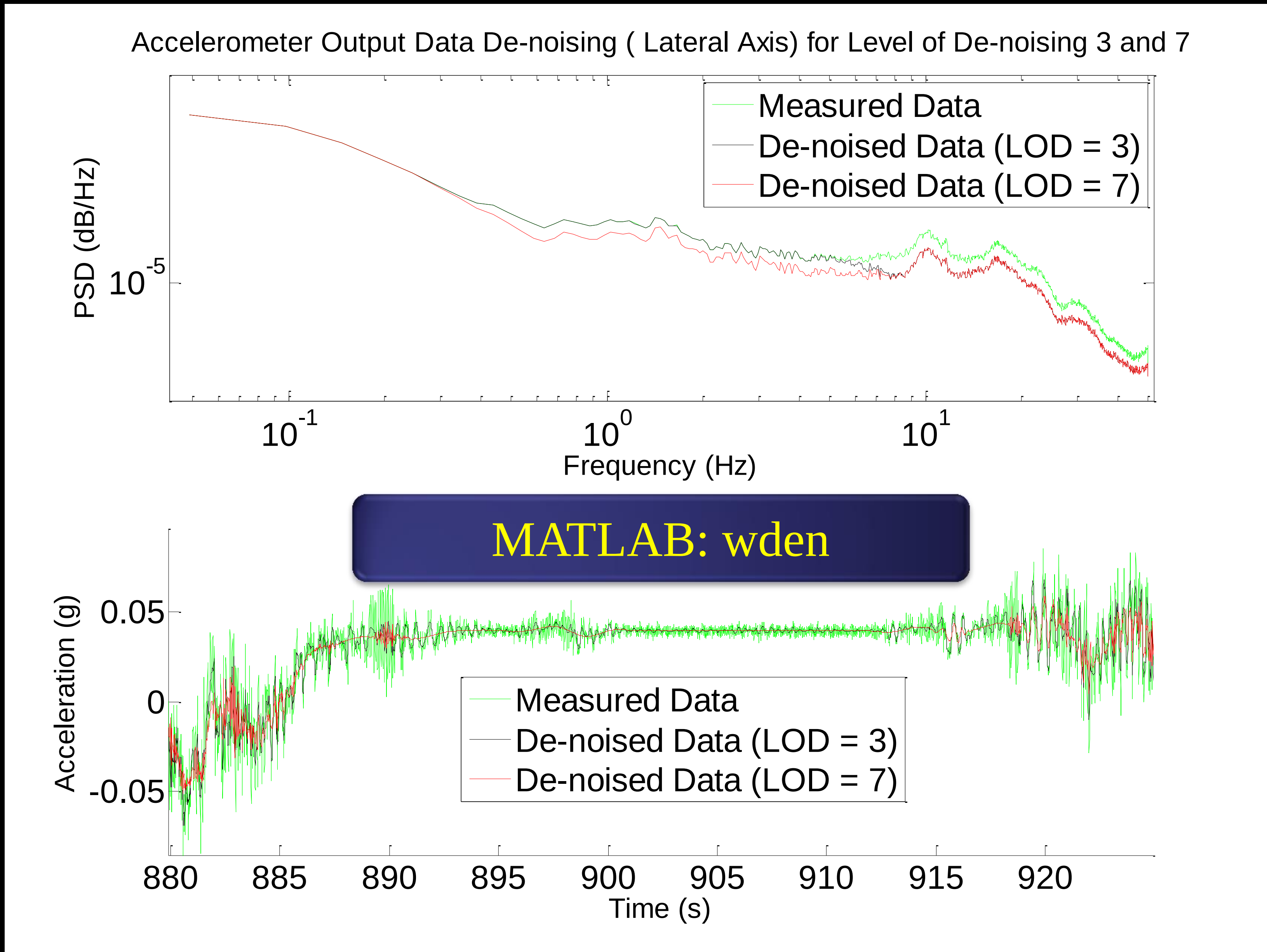


WAVELET TRANSFORMATION

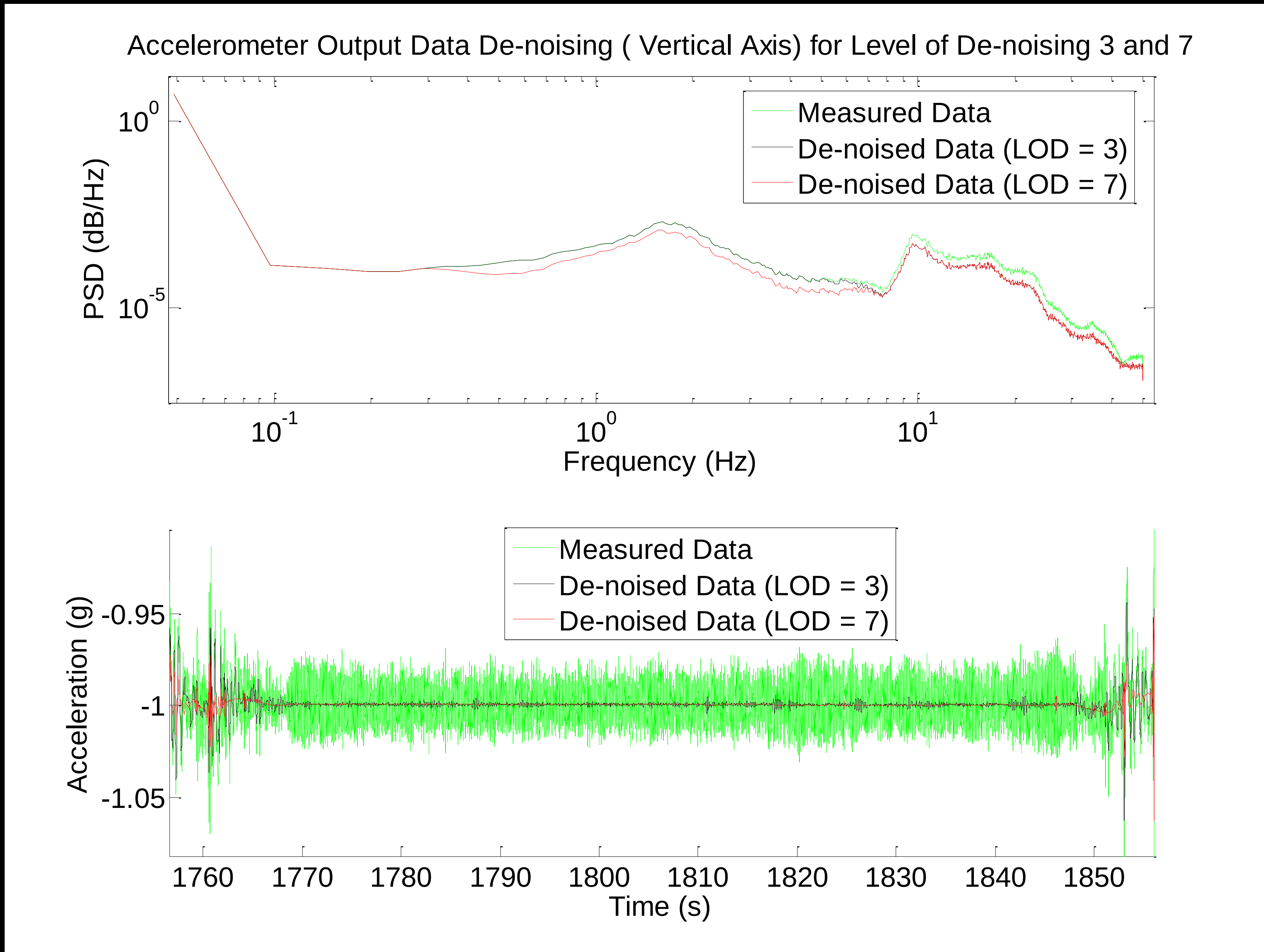




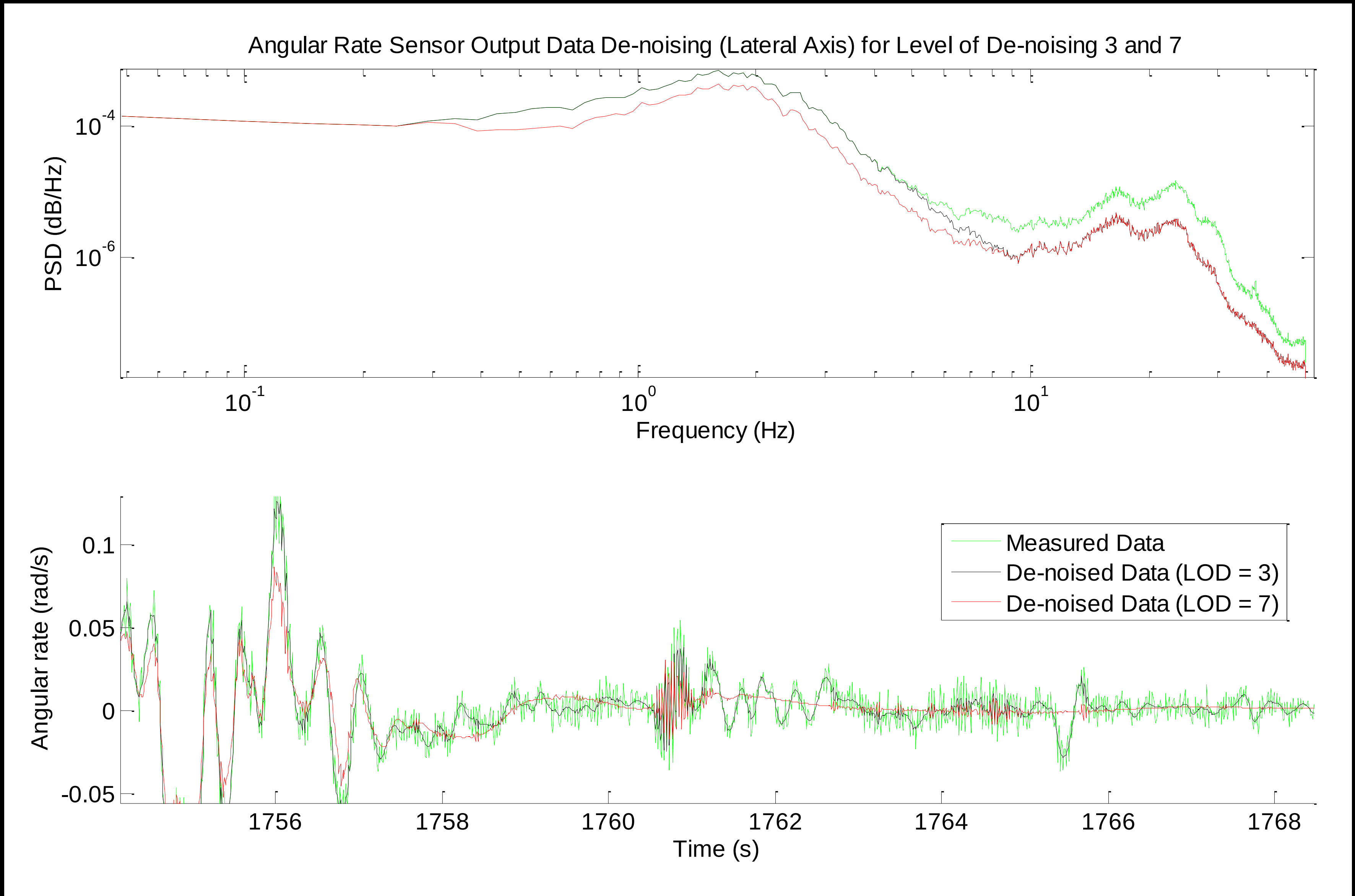
WMRA EVALUATION



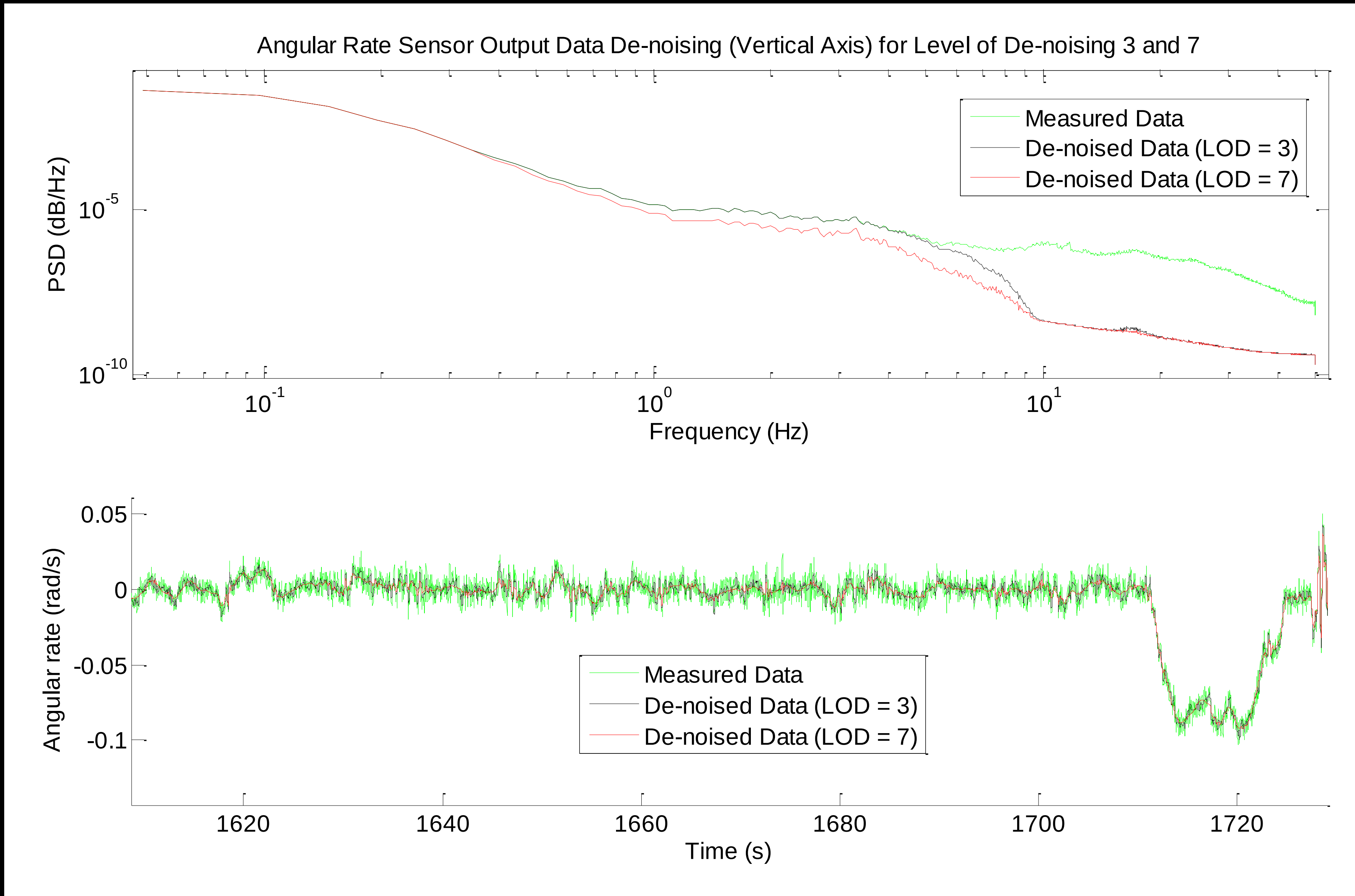
WMRA EVALUATION



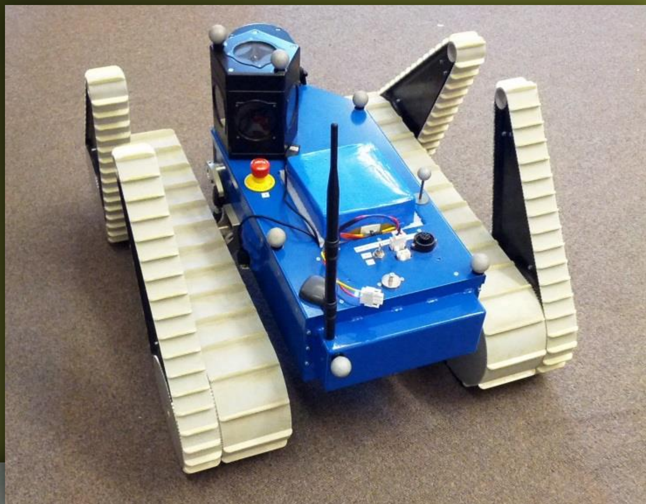
WMRA EVALUATION



WMRA EVALUATION



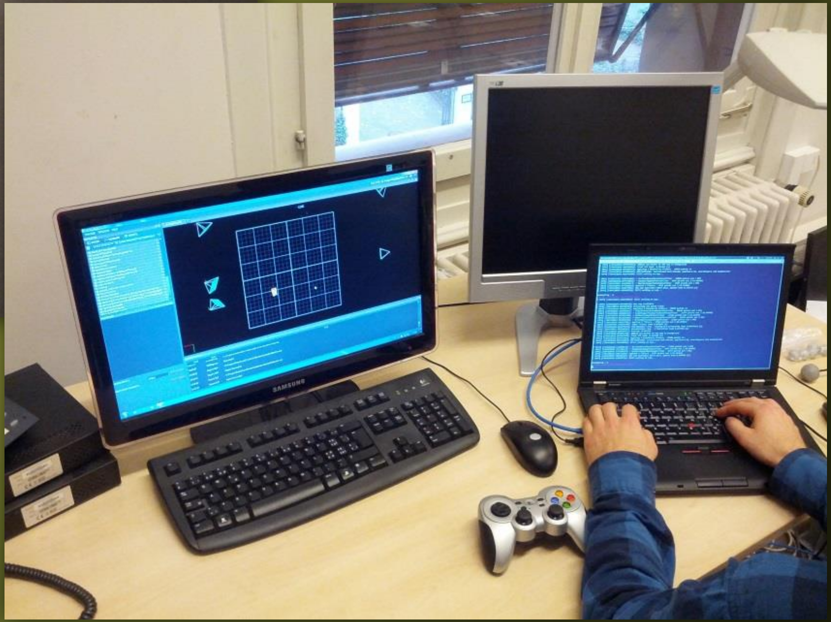
VICON EXPERIMENTS



- 6DOF pose data at 100Hz
- Latency of about 10 ms
- Usually 4 markers per robot
- 12 cameras
- Precision approx. 1 mm

Vicon Room at ASL, ETH, Zurich

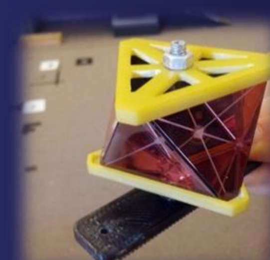
VICON EXPERIMENTS



Vicon output directly to ROS

LEICA GEOSYSTEMS EXPERIMENTS

- 3DOF position data at 5-10 Hz
- Automatic target tracking
- Delay 200ms
- Range 3.5 km
- Precision approx. 1-3mm



CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF ELECTRICAL ENGINEERING
CENTRE FOR MACHINE PERCEPTION

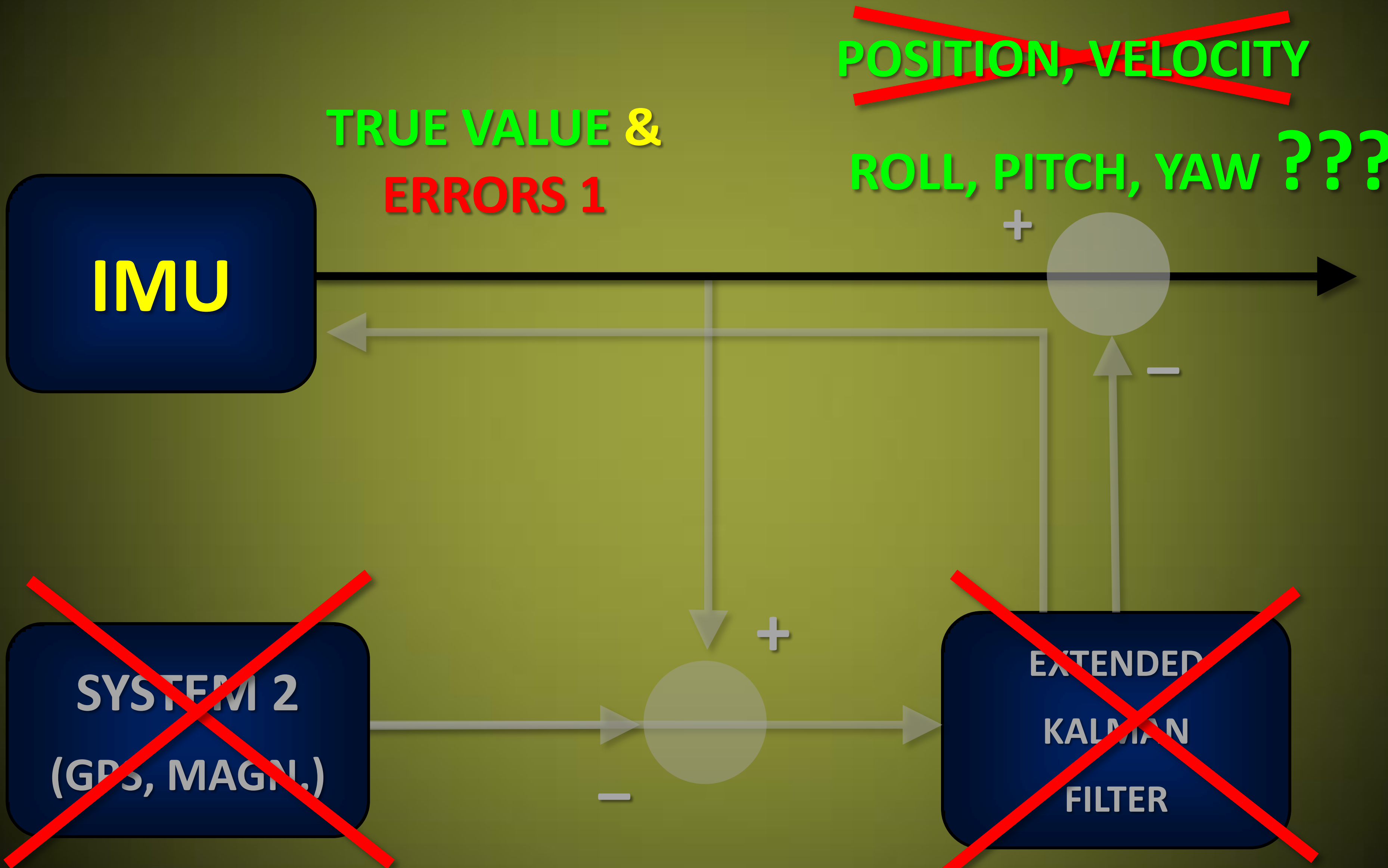
NIFTi
Complementary Filtering

2010 – 2014
EC project FP7-ICT-247870 NIFTi

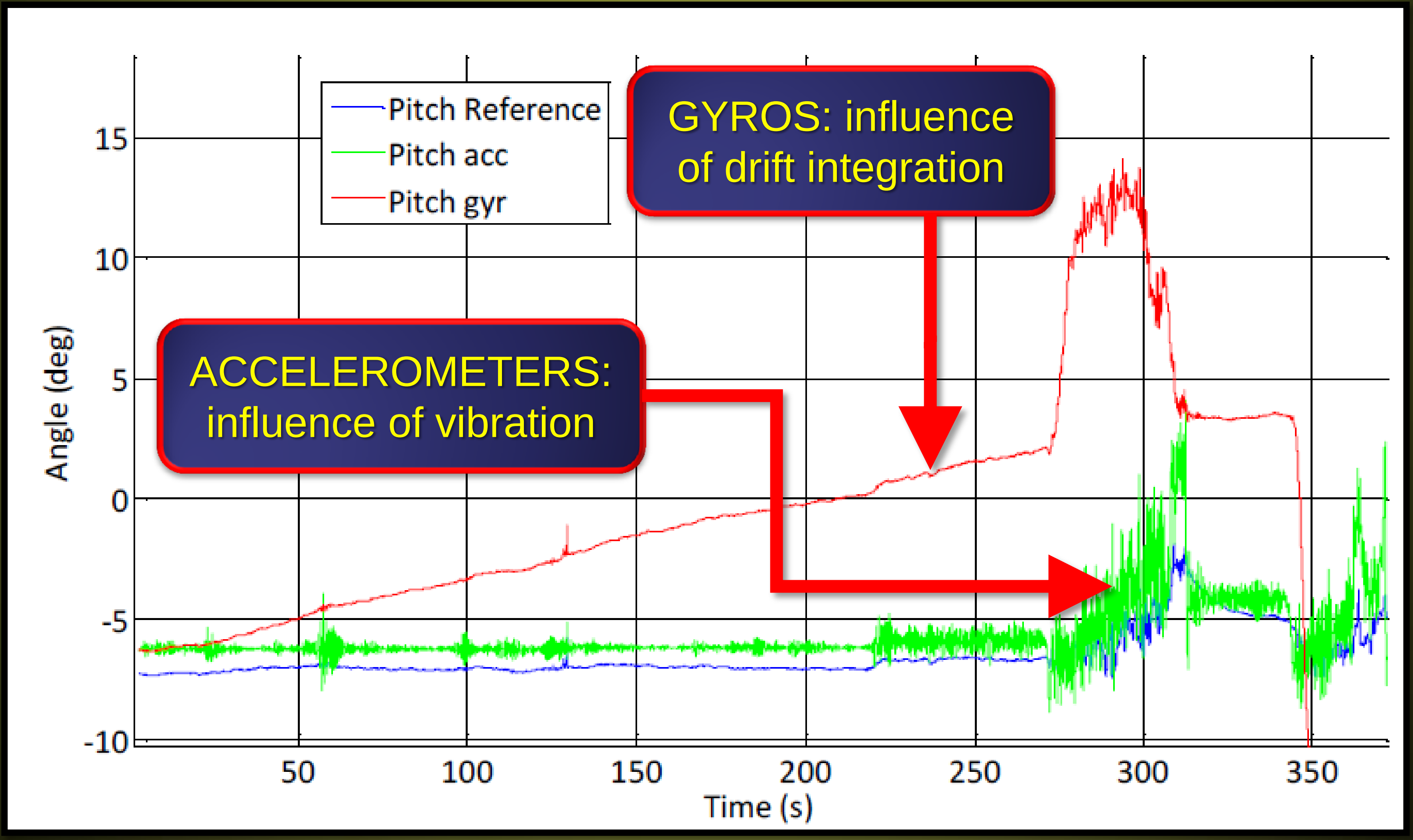
Michal Reinštein

Natural Human-Robot Cooperation in Dynamic Environments

STANDALONE IMU



INFLUENCE OF DRIFT & VIBRATION



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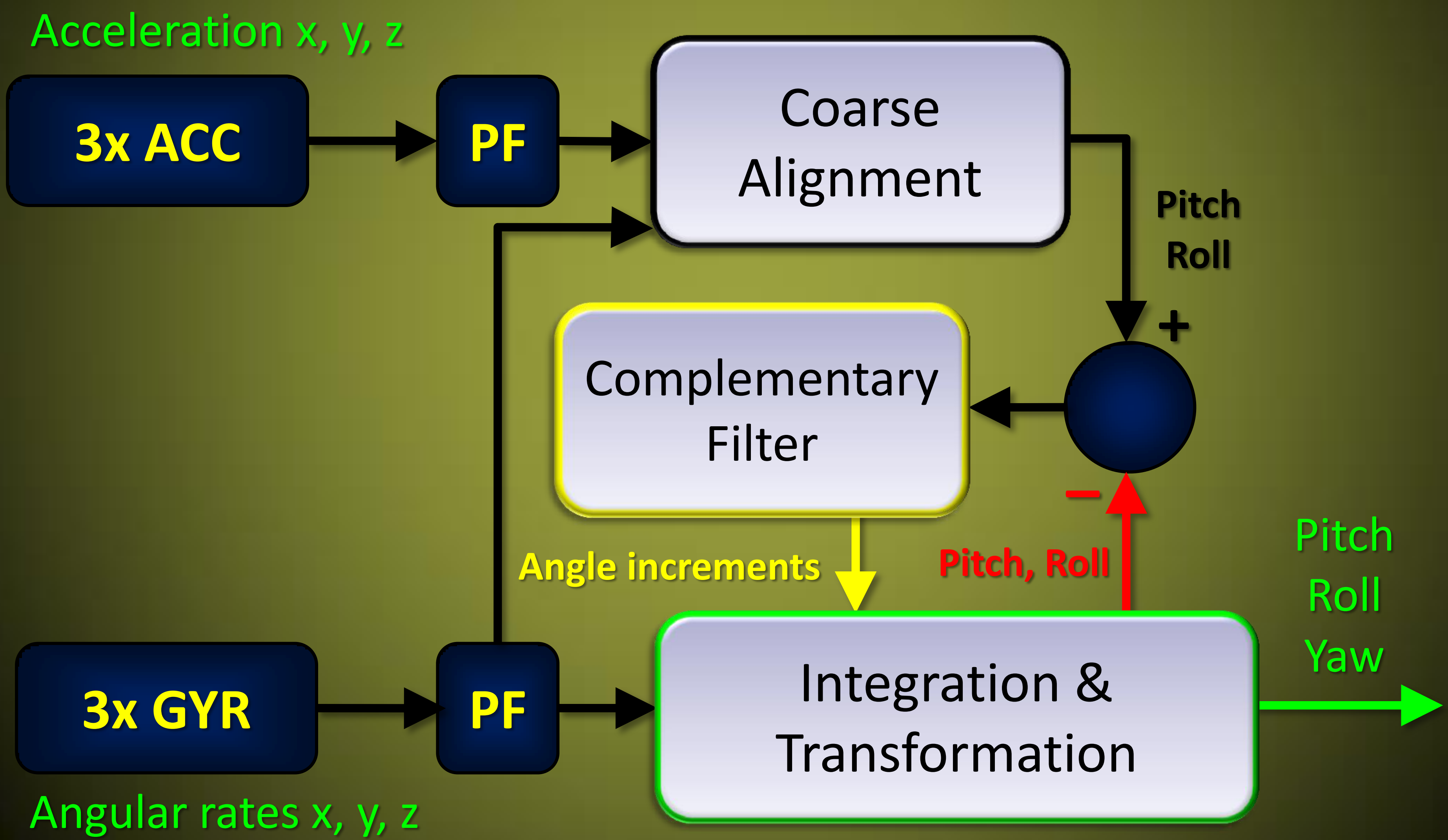

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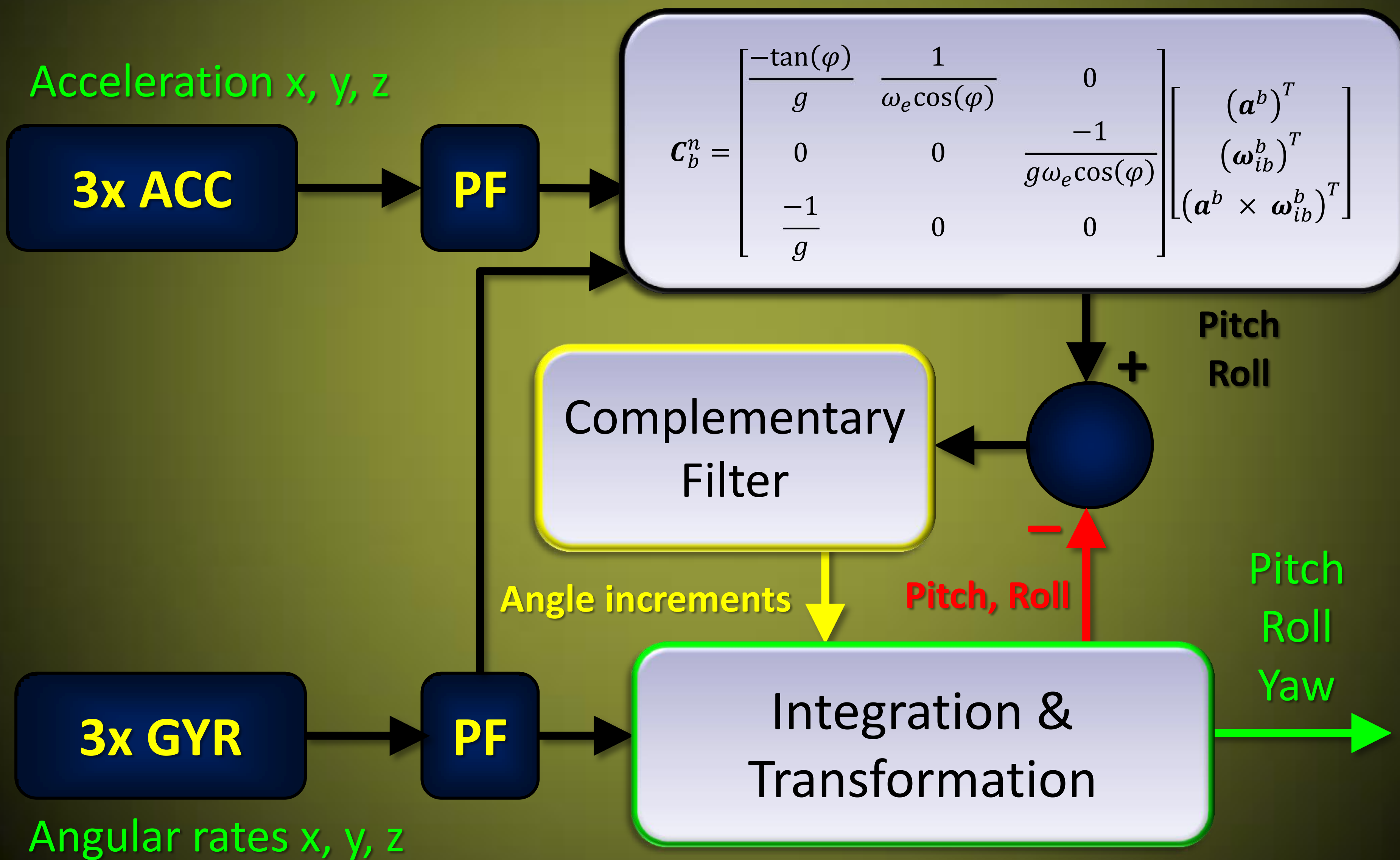

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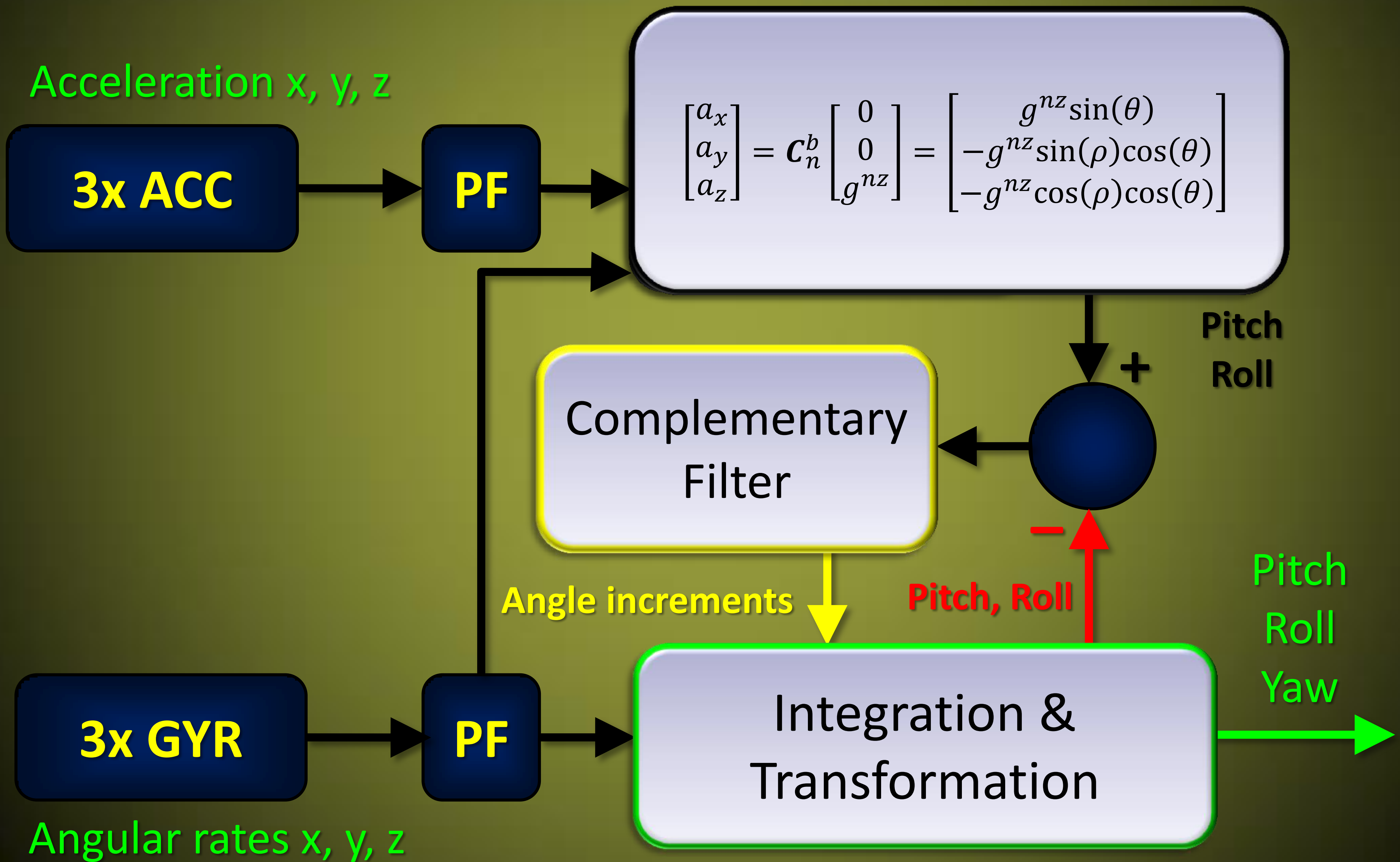
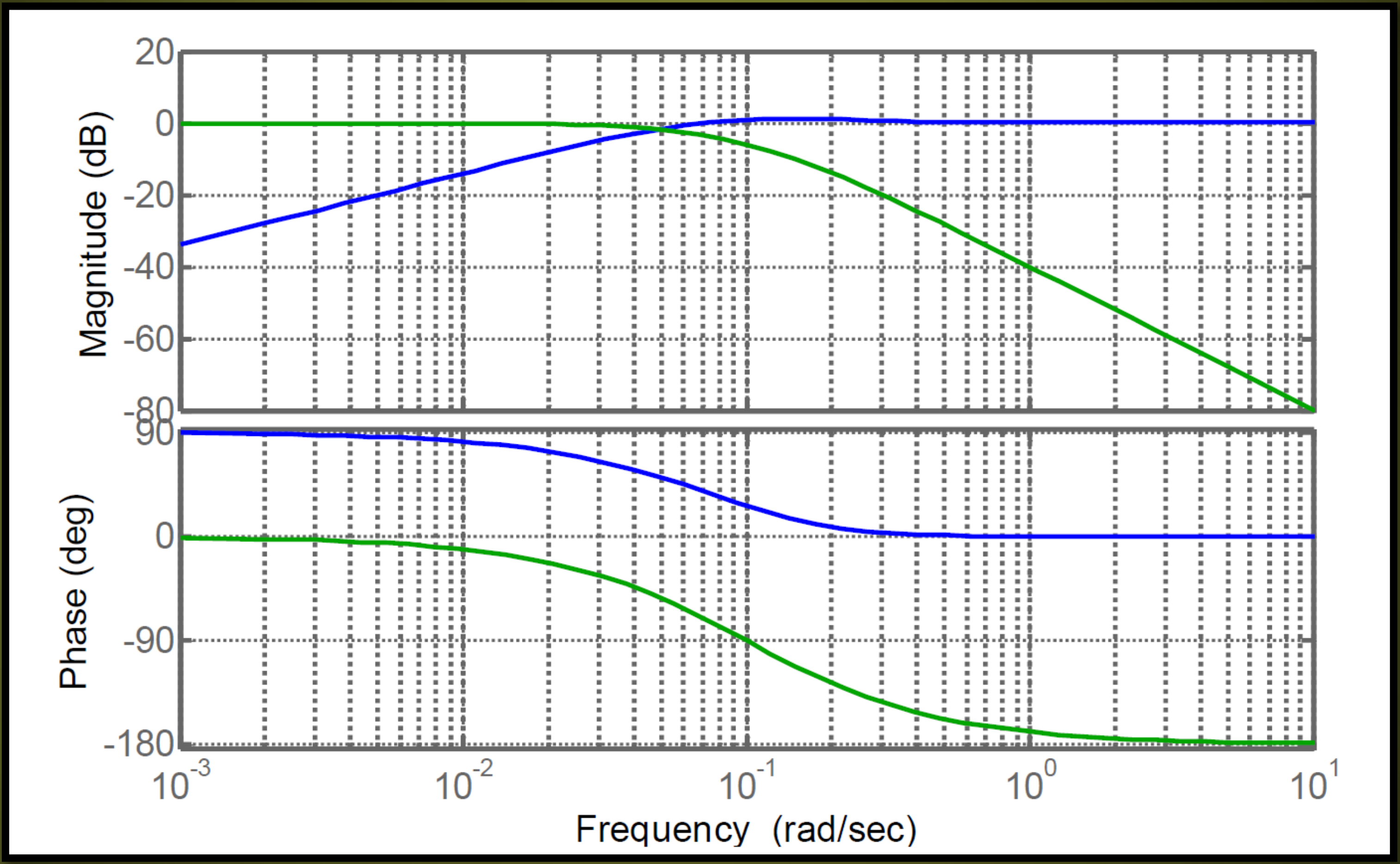
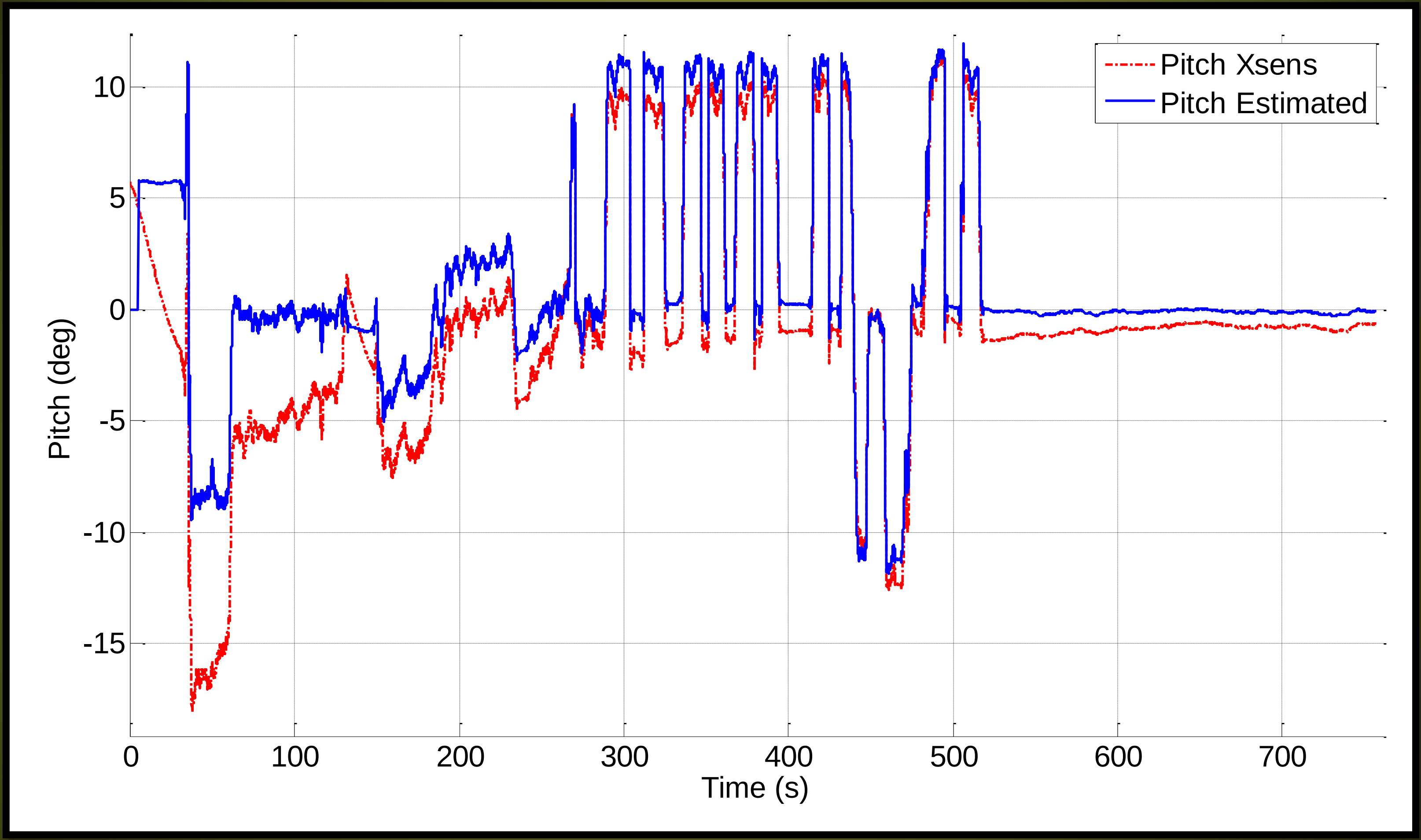


COMPLEMENTARY FILTER DESIGN



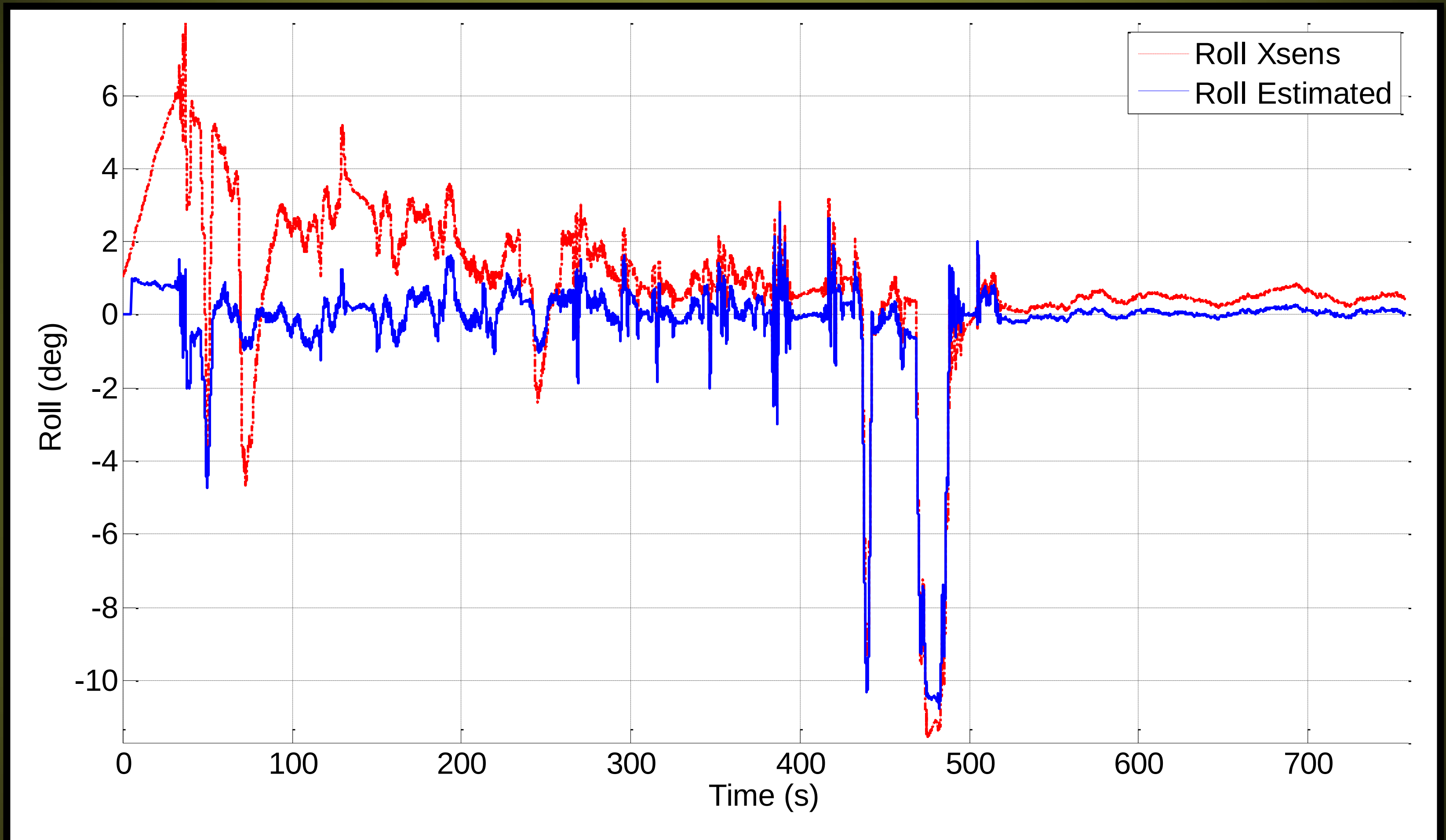
Frequency characteristics of the transfer functions for the combination of attitude angles obtained using coarse alignment (low-pass) and integration of angular rates (high-pass)

RESULTS – NIFTI PITCH



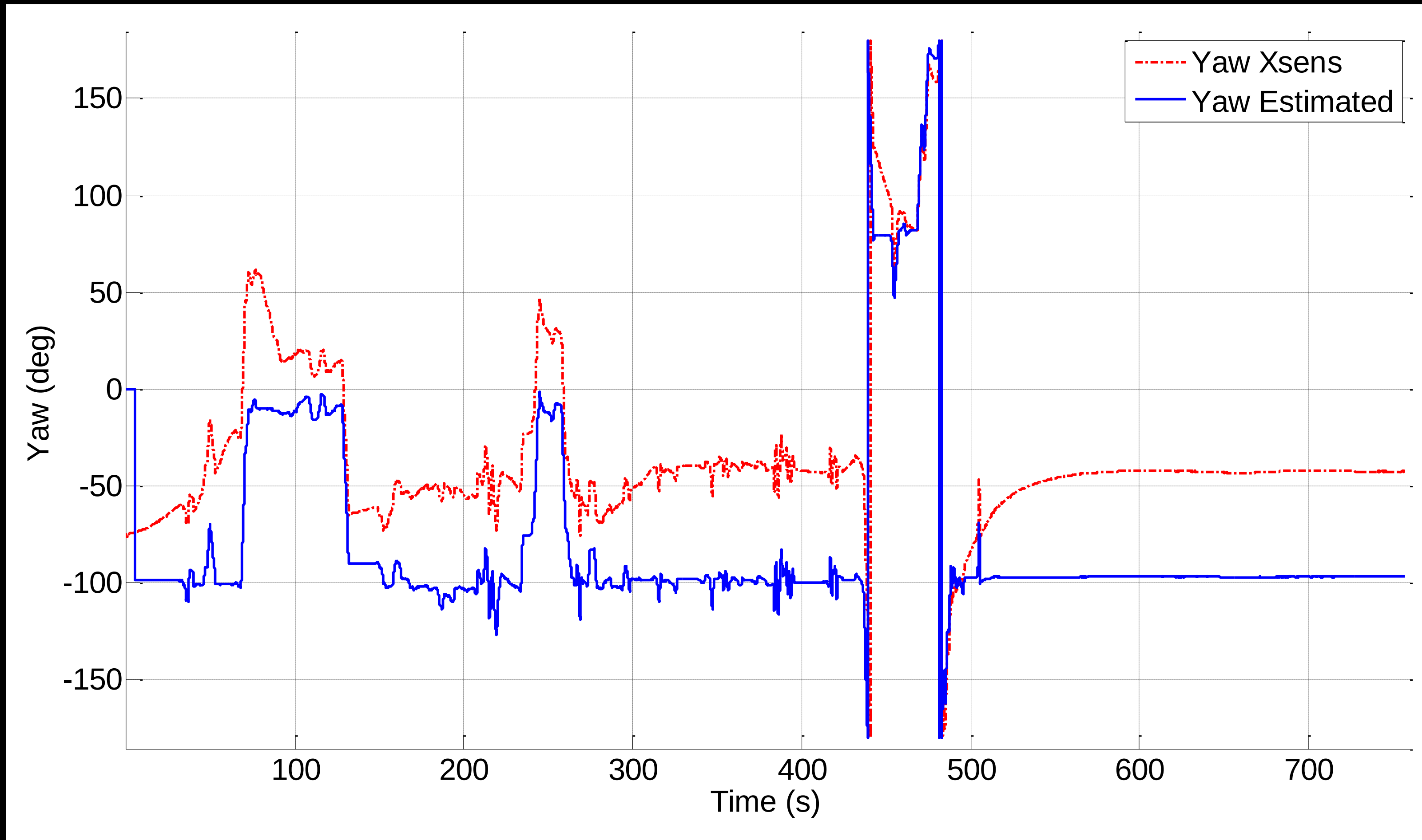
Pitch angle estimated during UGV field-testing on ramps of given slope: pitch angle estimated using complementary filtering (blue), standard pitch angle output using MTi-G Xsens (red)

RESULTS – NIFTI ROLL



Roll angle estimated during UGV field-testing on ramps of given slope: roll angle estimated using complementary filtering (blue), standard roll angle output using MTi-G Xsens (red).

RESULTS – NIFTI YAW



Yaw angle estimated during UGV field-testing on ramps of given slope: yaw angle estimated using proposed complementary filtering (blue), standard yaw angle output using MTi-G Xsens (red).