An analytical comparison of methods used for pose-estimation in surgical navigation systems

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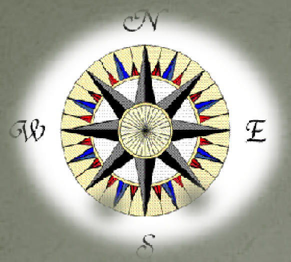
Basics

- CIS, MIS, IGS
- Surgical tracking systems
  - Optical
  - Electromagnetic
  - Other modalities
- Pre-operative 3D-model of the patient (mostly MRI- or CT-based)

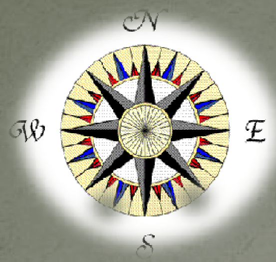
Utilities of intra-operative tracking

- Provides a feedback to the surgeon
- If robot operates: the joint-variables are well-known -> just for control (detect the crash of incremental encoders or the drift from the initial registration)



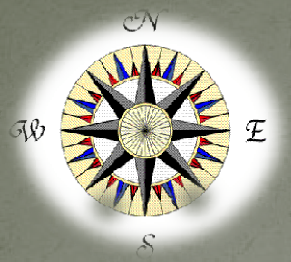
Objectives

1) To find the „optimal” representation for coordinate-transformation
2) Elaboration of a method, which makes us able to be more precise by the pose-estimation of the end-effector during the operation

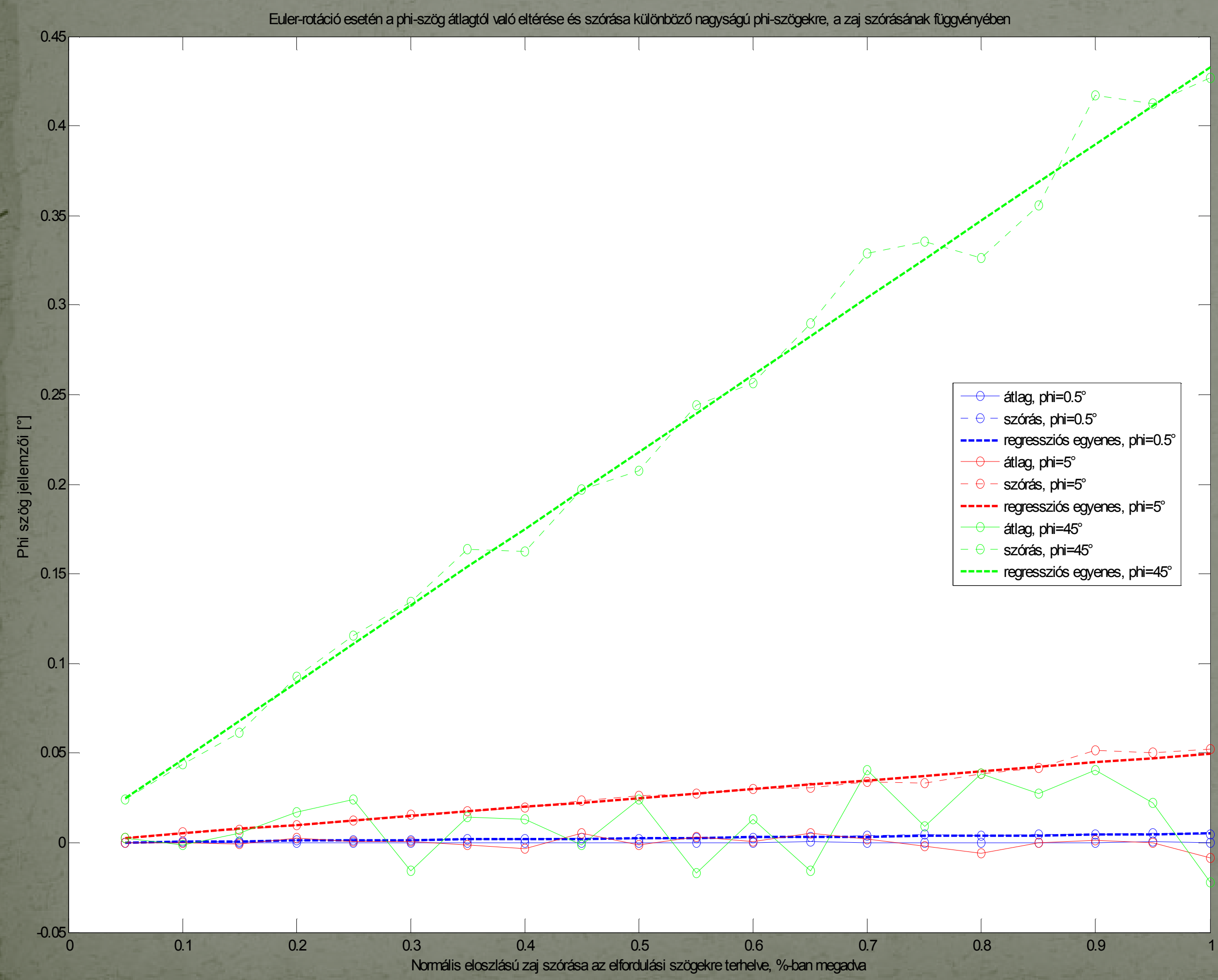


1. Coordinate transformation

- Translation + rotation -> homogeneous transformation matrix
- Comparison between 4 well-known representations (Euler, RPY, axis-angle and quaternion-based)
- Examined their sensitivity for disturbances and non-linear distortions deriving + ability for interpolation (linear or SLERP)
- Result: there aren't significant differences, but the quaternions are mathematically more favourable (matrix-operations, no gimbal lock)



Example: error of various angles depending on the variance of noise being superposed on them, Euler representation (MATLAB)



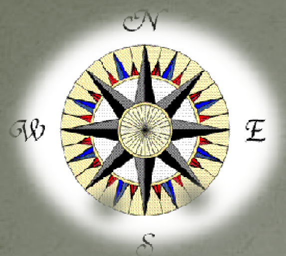
2. Filtering

- Problem: coupled disturbances can’t be removed from useful signal
- Goal: increased accuracy of the estimated pose -> rise of SNR
- Considerations:
  - Noise modeled with Gaussian distribution
  - Process can be stationary or dinamic
  - Filter specification in the time domain
- 2 methods were examined:
  - Moving average smoothing
  - Kalman filtering

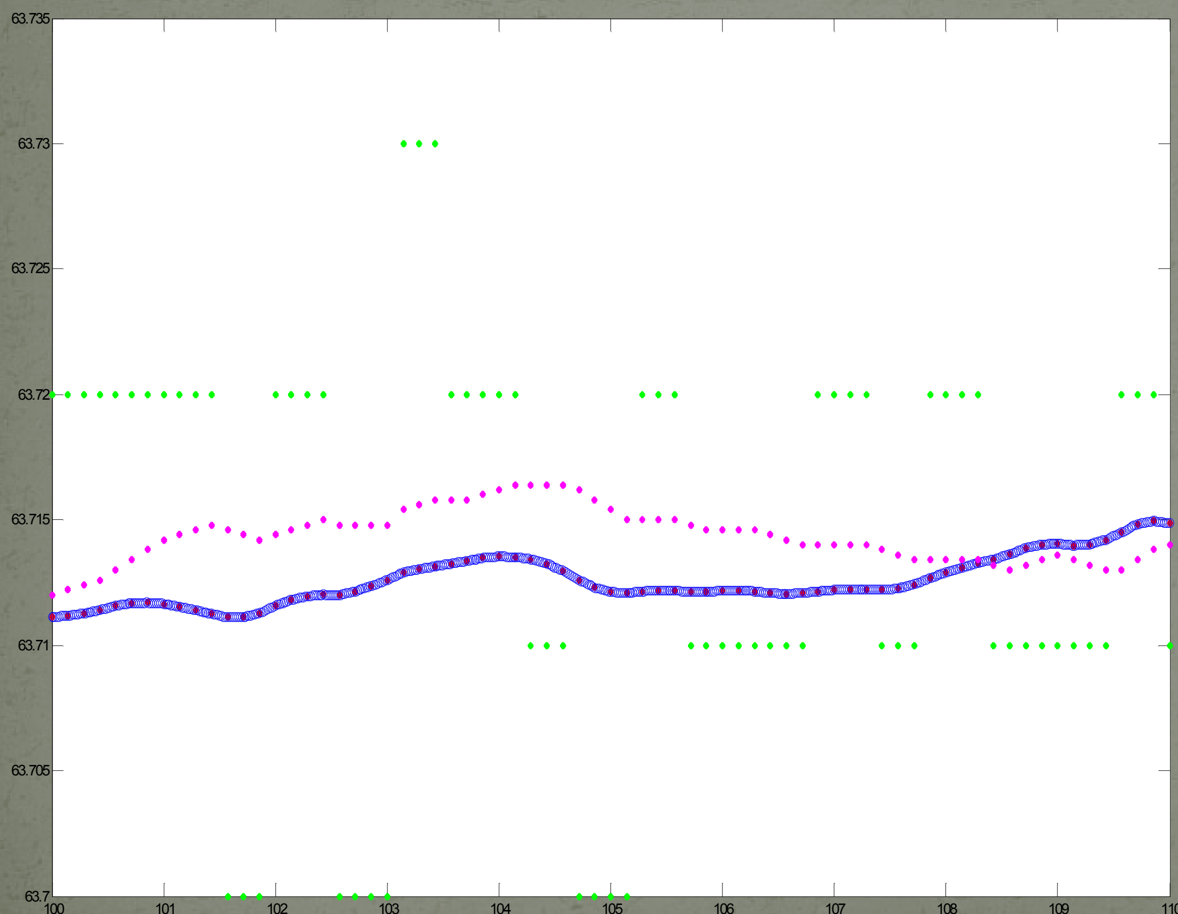
Moving average smoothing

- LPF, where span ~ cut-off frequency
- Wider window -> smoother signal, but worse dinamic characteristics (slow response time)
- Conclusion: only for stationary signals

$$v_{i,adj} = \frac{\sum_{j=-k}^{k} v_{i+j}\, w(d_j)}{(2k+1)}$$



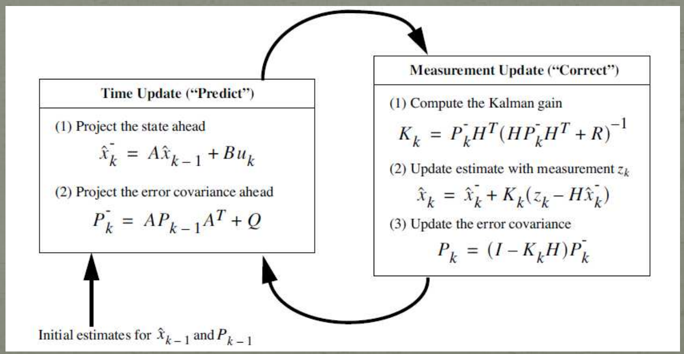
Moving averaging (MATLAB)



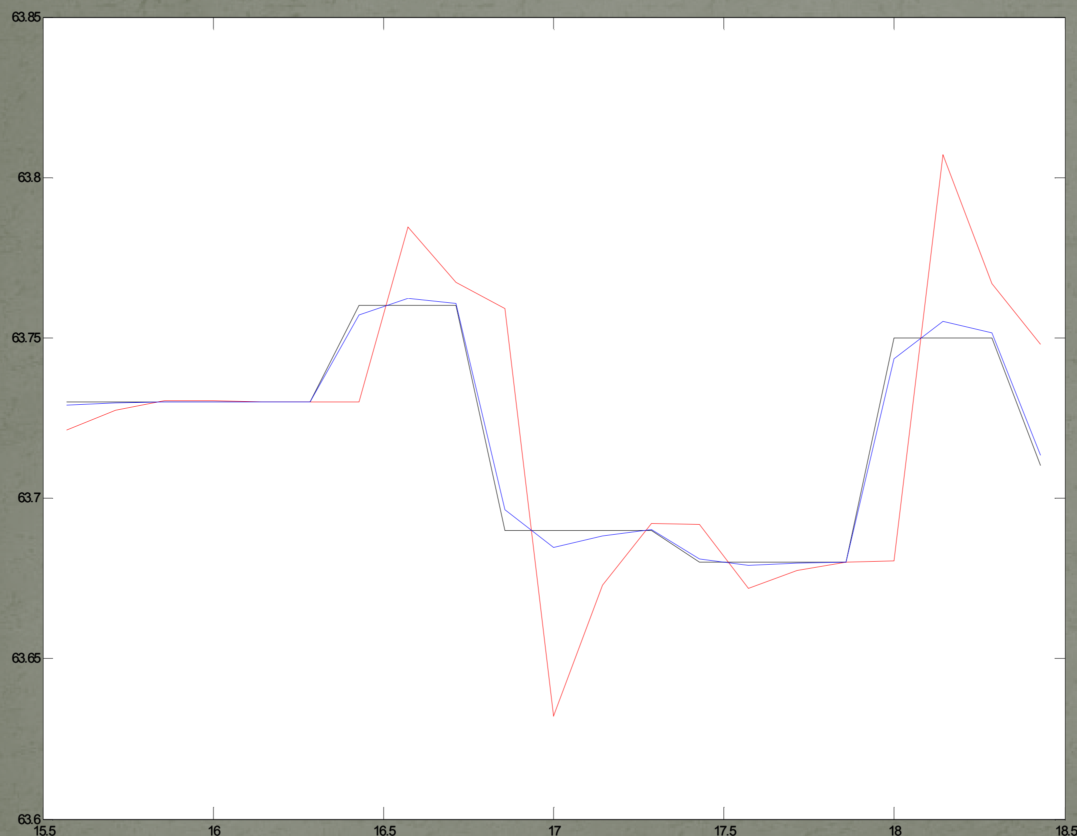
green = samples of a 7 Hz signal
magenta = averaged 7Hz signal
red = on value-changes averaged 7 Hz signal
blue = 60 Hz interpolated red signal

Kalman filtering

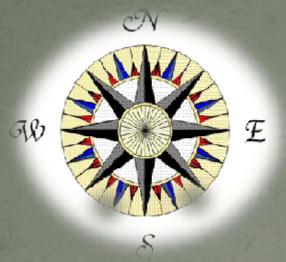
- Optimal linear estimator, one-step predictor-corrector algorithm
- Weighting between actual measured and formerly estimated value during the Kalman gain
- State space model
- Succeed in tracking dinamic signals too, but with overshoots can't be admitted in surgical applications



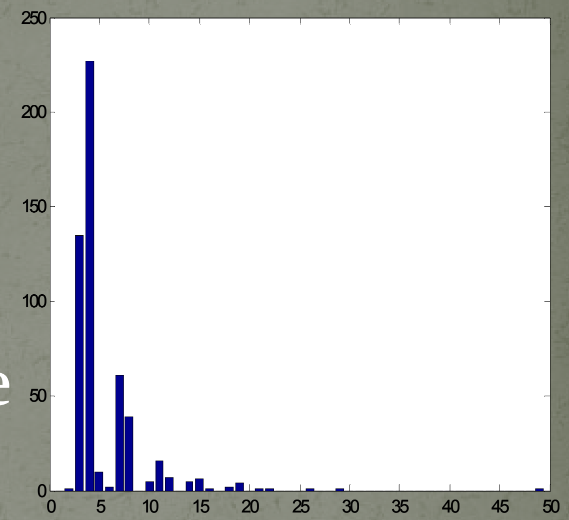
Kalman filtering (MATLAB)



black = original signal
blue = filtered signal
red = pre-estimated signal



Other problems emerging



- Not steadily acquired data
- Low resolution camera -> certain values exist during more samples (see histogram)
- Solution: only the value-changes are taken into consideration
- Rate changing (interpolation and decimation) – not integer factor

Future work

- EKF, UKF, Markov-chains, Monte Carlo simulation
- Sensor fusion, hybrid systems
- Development of an intelligent filter by means of a filter bank (event-based estimation)
- Physical modelling (noise still can be removed?) – e.g. with finite element method by electromagnetic disturbances

References

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- http://www.ndigital.com/medical

Thank you for your attention!

Any questions?

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