Calibrating IPTs

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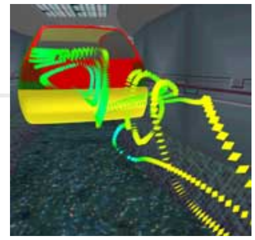
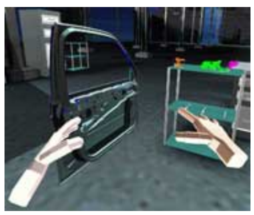
Overview

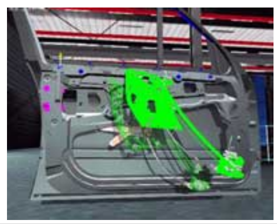
- Effect of erroneous camera position
- Sources of error
- Tracking system errors
- Correcting distortions

My background



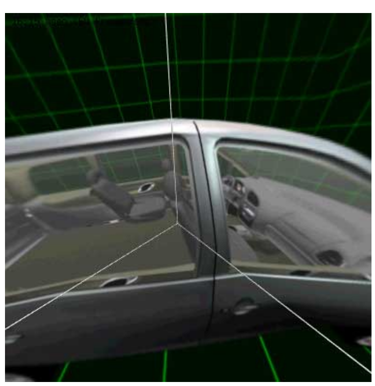
- Virtual prototyping:
  - Assembly simulation
  - Styling review
  - Scientific immersive visualization
  - Ergonomics

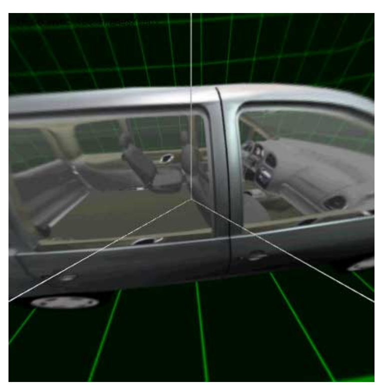




Effect of erroneous camera position

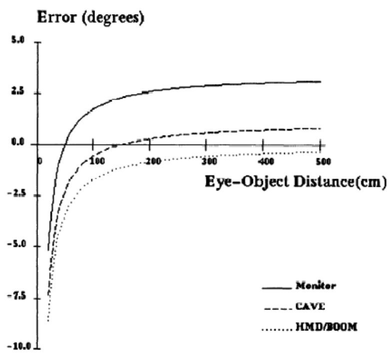
- Cave/Powerwall: image distortion
- HMD/Boom: precise manipulation/positioning



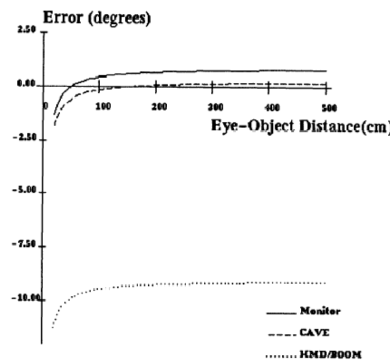


HMD/Boom vs. Cave/Powerwall

- Difference: projection plane moves / doesn't move
- Error analysis:



Angular error, head displacement



Angular error, head rotation

Different effects on different displays

- Translational camera displacement:
  HMD is usually better (has less error)
- Rotational camera displacement:
  Cave is better
- Problem in the Cave: image distortion
- Problem in the HMD: virtual hand doesn't appear where user knows his real hand is

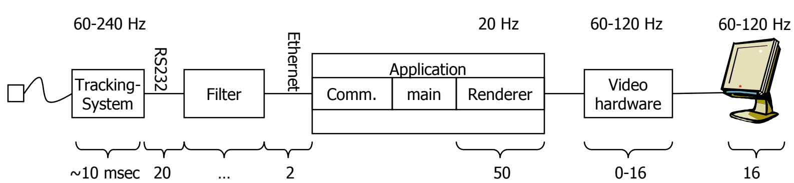
Introduction Error effects Error sources Tracking errors Correcting distortions

Sources of Error

- Objective:
  1. Delay
  2. Transformation pipeline
  3. Minor other sources
  4. Tracking system
- Subjective:
  - Reports from users, but …
  - Uncharted area!

Delay (latency / lag)

- Time span from user action until display update
- Types of lag
  - Device
  - Transport
  - Software
  - Synchronisation
- Latency pipeline:



Human factors

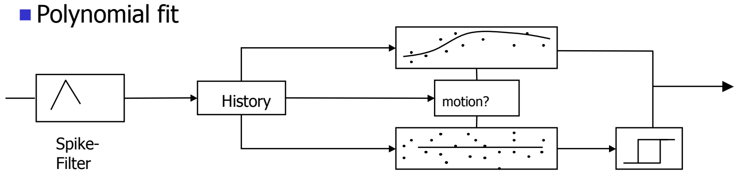
- Effect of latency

Latency / millisec	Effect on user
5	Noticeable
30	User performance decreases (possibly "simulator sickness")
500	Immersion collapses

- Head motion
  - Typically 10 cm/sec and 20 deg/sec
  - Max. most of the time 50 cm/sec and 50 deg/sec
  - Peak 1000 deg/sec

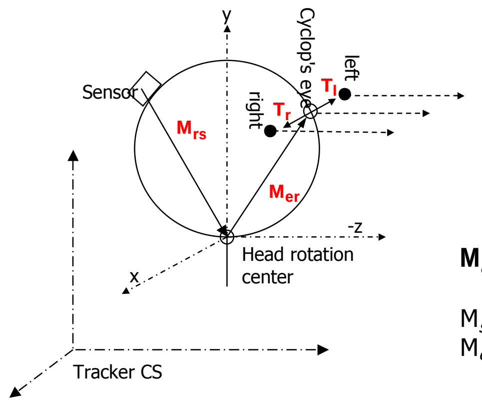
What you should do against latency

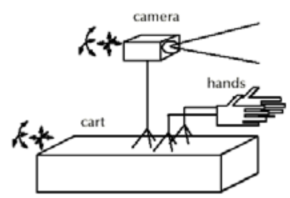
- Device:
  - "Continuous mode" for device and device server
  - Activate only those sensors the app really uses
- Time-critical computing
  - Predictive LOD estimation for constant frame
  - CFD visualization (streamlines, isosurface, ...)
- Predictive tracker filtering!
  - Kalman
  - Autoregression
  - Polynomial fit



Transformation errors

- User model

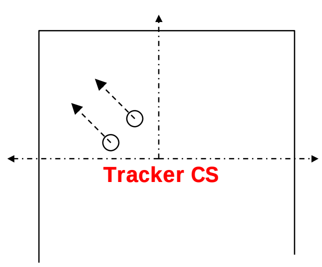


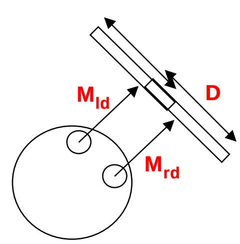


$$\mathbf{M}_e = \mathbf{T}_{l|r}\mathbf{M}_{er}\mathbf{M}_{rs}\mathbf{M}_s$$

M_s = current sensor position
M_e = viewpoint transf. for eye

- Where is the display?

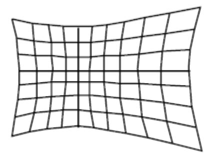




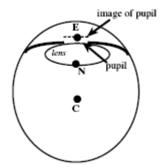
M_{xd} = trf. from left/right eye to display
D = display geometry

Minor error sources

- Optical distortion by the display
  - Possible solution: render twice

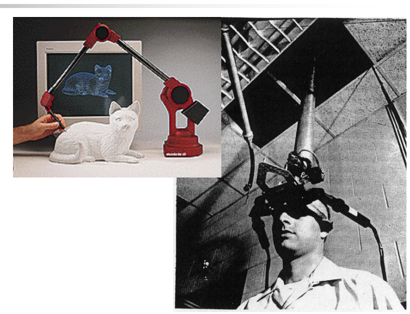


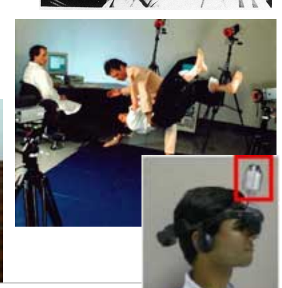
- Eye tracking?
  - Error is negligible,
    if projection center = eye center



Tracking system technologies

- Electro-magnetic
- Mechanical
- Optical
- Acoustic
- Inertia-sensing
- GPS
- Computer-vision based
- …





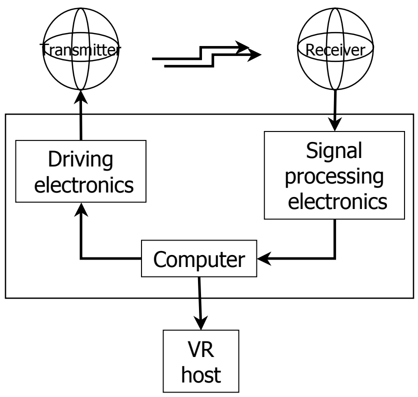
- Prices (2001)

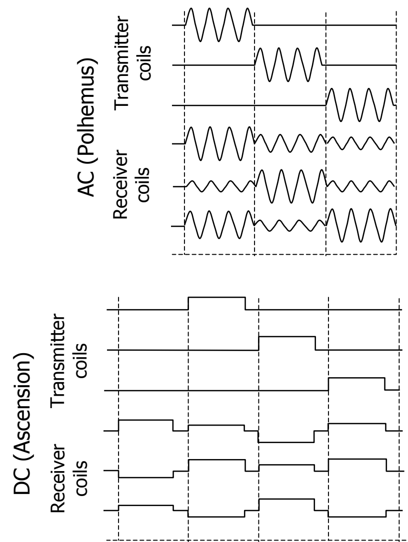
System	Approx. Price (EUR)
Ascension Flock-of-Birds (ERT)	10,000
Polhemus Fastrak (long ranger)	13,000
Intersense IS600	19,000
MotionAnalysis	100,000 – 300,000

Tracking system errors

- Static:
  - Mis-alignment
  - Distortions
- Dynamic:
  - Noise
  - Drift
  - Drop-outs

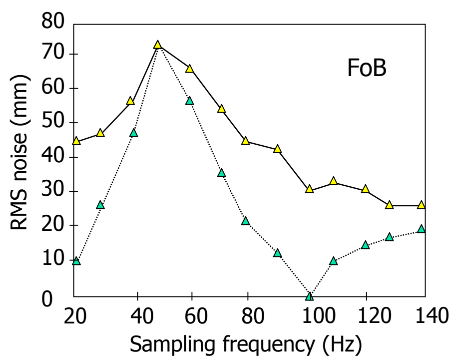
Principle of electro-magnetic tracking

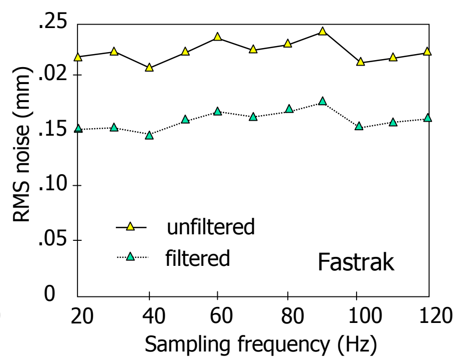




Sources of noise

- Power supplies:

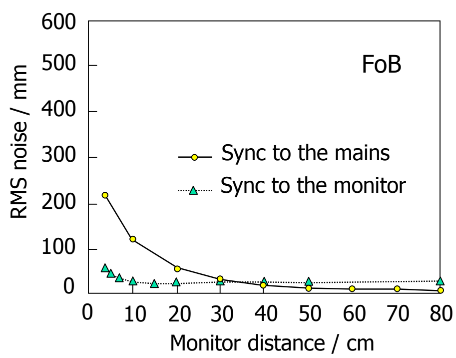


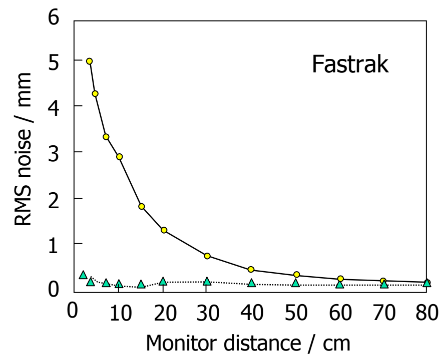


→ if you use Ascension:

- don't sample at 50 Hz!
- Try to sample at 100 Hz and average 2 adjacent samples

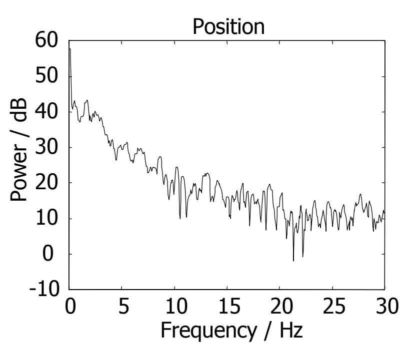
Monitor:

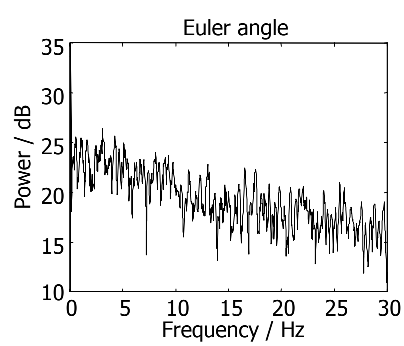




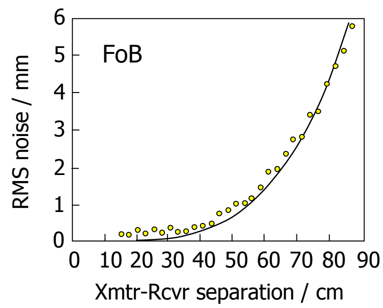
→ put monitors at least 50cm away.

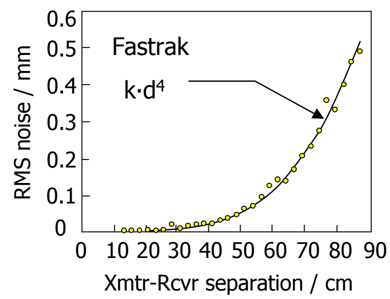
Power spectrum (Fastrak):





- Distance between receiver and transmitter:



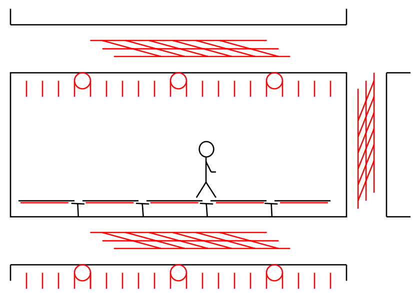


→ place the transmitter close to the work area
→ use a long-range transmitter

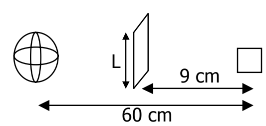
- Other sources of noise:
  - Receiver / transmitter cables
  - Cell phones

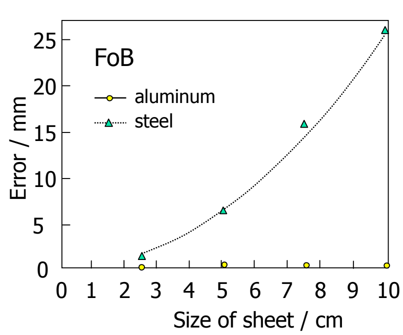
Sources of distortion

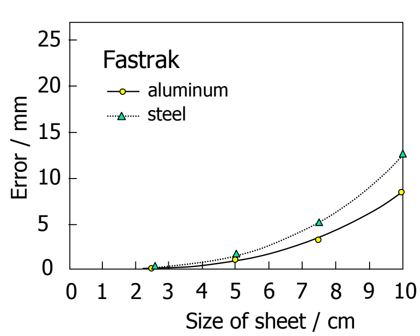
- Where is all the metal hidden?
  - Floor covering (and ceiling of next lower floor)
  - Ceiling (lamps, covering, air conditioning, …)
  - Walls (steel grid of reinforced concrete)
  - Monitors (coils), computers (shielding), projectors



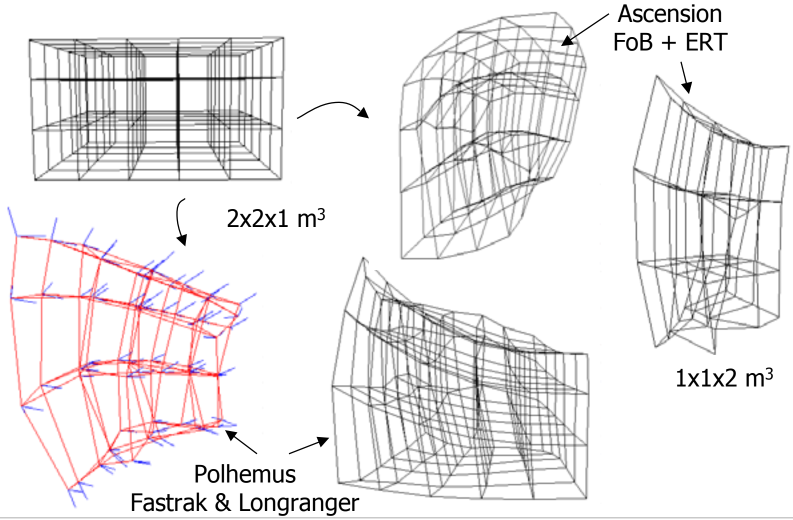
- Effect of size of different sheet metal:



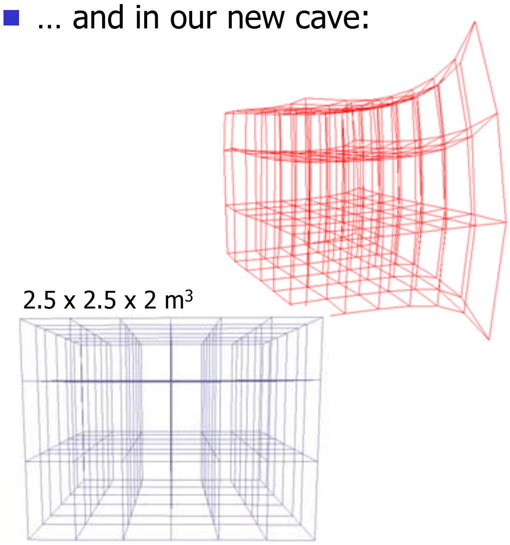




- Some measurements in real labs:

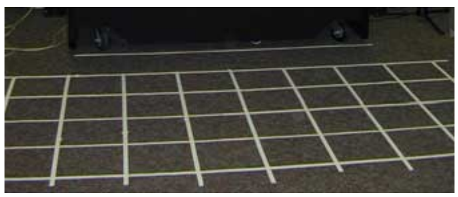


- … and in our new cave:

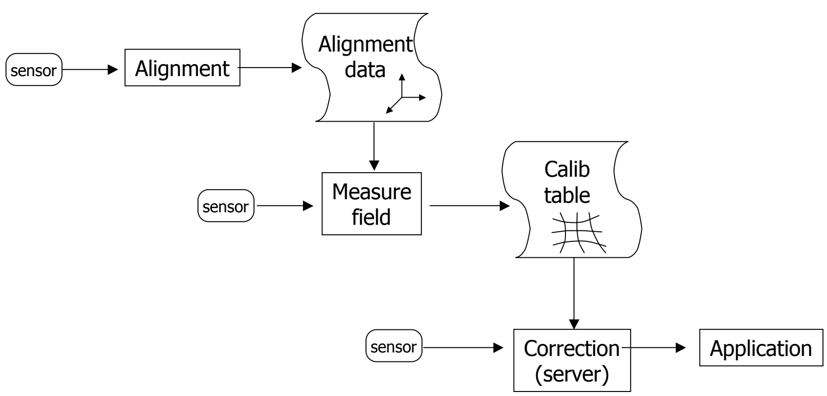


Correcting distortions

- Ingredients for building a calibration table:
  - Markers on the floor, possibly on paper
  - Metal-free holding device for the senor, possibly several sensors
  - Calibration measurement tool
- Time needed:
  - Preparation ≈ 1-2 hours
  - Measurement ≈ 30 minutes



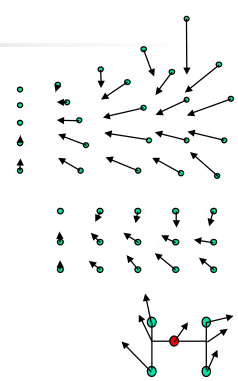
- Data flow:



Correction algorithms

- Problem: interpolation
- Verified empirically:
  - Position error does not depend on sensor orientation
  - Orientation error depends on sensor position only
- Approaches:
  - Look-up tables
  - Polynomial interpolation/approximation
  - B-spline volumes
  - Shape functions
  - Radial basis functions (Hardy's Multi-Quadric)

Lookup table



- Given:
  measured points and errors
- Resample into regular grid
  using Gauss kernel $\mathbf{v}_Q = \sum_P \mathbf{v}_P e^{-\frac{|P-Q|^2}{d^2}}$
- Correction at run-time
  = trilinear interpolation
- Is the grid dense enough?
  Test: calculate correction vector for known measured points using trilinear interpolation, compare with the measured error vectors.
- Orientations: use quaternions and spherical linear interpolation

Polynomial approximation

- Polynomial fit:

$$f(x,y,z)=\sum_{j=1}^{R}\mathbf{c}_j x^{s_j} y^{t_j} z^{u_j}$$

$$\mathbf{c}_j \in \mathbb{R}^3 \quad , \quad 0 \le s_j + t_j + u_j \le r \quad ,$$

$$R=(r+1)(r+2)(r+3)/6$$

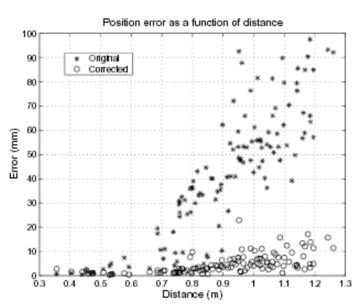
- Minimze

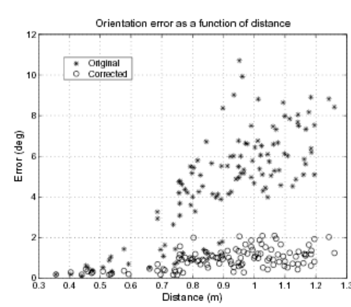
$$S=\sum_{j=1}^{N}\left\| e^j - f(\mathbf{P}^j)\right\|$$

by least squares method

- Rotations: exactly analogously with $g(x,y,z)$

- Result (Ikits, Brederson, Hansen, Hollerbach):





Hardy's Multi-Quadric (HMQ)

Approach for translation

$$f : \mathbb{R}^3 \to \mathbb{R}^3$$

$$f(\mathbf{P}) = \sum \mathbf{A}_i \omega_i(\mathbf{P}) \quad , \quad \mathbf{A}_i \in \mathbb{R}^3$$

$$\omega_i(\mathbf{P}) = \left[(\mathbf{P} - \mathbf{P}_i)^2 + R^2 \right]^{\mu}$$ "radial basis functions"

$$\mu_i = \frac{1}{2}, \frac{1}{4}, 2, -\frac{1}{2}, |\;|$$

plug in measured points

$$f(\mathbf{P}_j) = \mathbf{Q}_j \quad , \quad j = 1,..,N$$

yields 3 LES

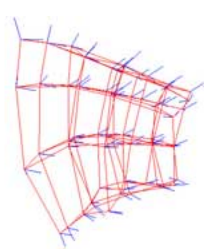
$$\begin{pmatrix} \omega_1(\mathbf{P}_1) & \cdots & \omega_N(\mathbf{P}_1) \\ \vdots & & \vdots \\ \omega_1(\mathbf{P}_N) & \cdots & \omega_N(\mathbf{P}_N) \end{pmatrix} \begin{pmatrix} \mathbf{A}_1 \\ \vdots \\ \mathbf{A}_N \end{pmatrix} = \begin{pmatrix} \mathbf{Q}_1 \\ \vdots \\ \mathbf{Q}_N \end{pmatrix}$$

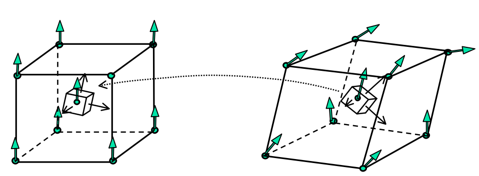
- Orientation:
  - Should still correct, even in cave:
    - Vertical parallax
    - Hand tracking (virtual hand, pointer, ...)
  - Interpolation function $g : \mathbb{R}^3 \to \mathbb{R}^6$
  - Calibration table contains measured ori $\mathbf{M}_P^0$ of "zero orientation"
  - To correct orientation $\mathbf{M}_P^{measured}$ at point P compute

$$\mathbf{M}_P^{correct} = \mathbf{M}_P^{0^{-1}} \cdot \mathbf{M}_P^{measured}$$

with

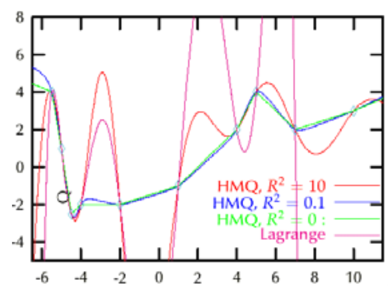
$$\mathbf{M}_P^0 = g(P)$$



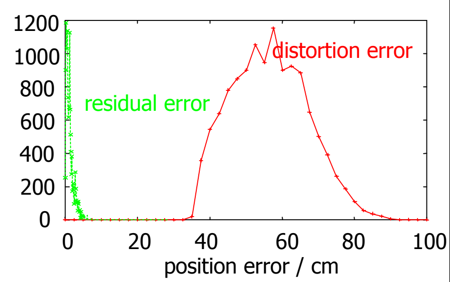


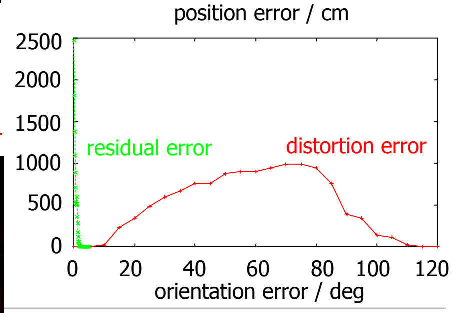
- Interpolation of orientations:
  - Quaternions $g : \mathbb{R}^3 \to \mathbb{R}^4$
  - 2 vectors $g : \mathbb{R}^3 \to \mathbb{R}^6$
- Normalize g(P)

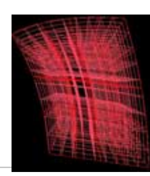
- The optimal R^2:
  - No theoretical results
  - My experience:
    [0.1,100] is good
    for enough points in 3D



- Performance of HMQ:
  - Model distortion by analytical functions
  - Compute HMQ
  - Plot error distribution of "distortion functions"
  - Plot error after correction with HMQ
  - More plots at http://web.informatik.uni-bonn.de/~zach/papers/diss.html







Advantages of HMQ

- Fast: ca. 0.5 millisec with 200 samples
- Arbitrary point clouds
  - Non-rectangular workspace (e.g., real mock-up plus VR didplay)
  - Semi-automatic calibration at run-time

Literature

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URLs

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- http://www.ncsa.uiuc.edu/~kindr/emtc.html
- http://www.polhemus.com/
- http://www.ascension-tech.com/