

Diploma thesis final presentation

**Fast and efficient error correction
of electromagnetic tracking
and its application in prostate cancer treatment**

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Outline

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The Topic of this Diploma Thesis

- „Fast and efficient error correction of electromagnetic tracking . . . “

⇒ improve an existing algorithm for static error correction

- „. . . and its application in prostate cancer treatment“

⇒ with regard to the treatment of prostate cancer

Static and dynamic errors

(Only static error correction was treated in this thesis.)

Static Errors:

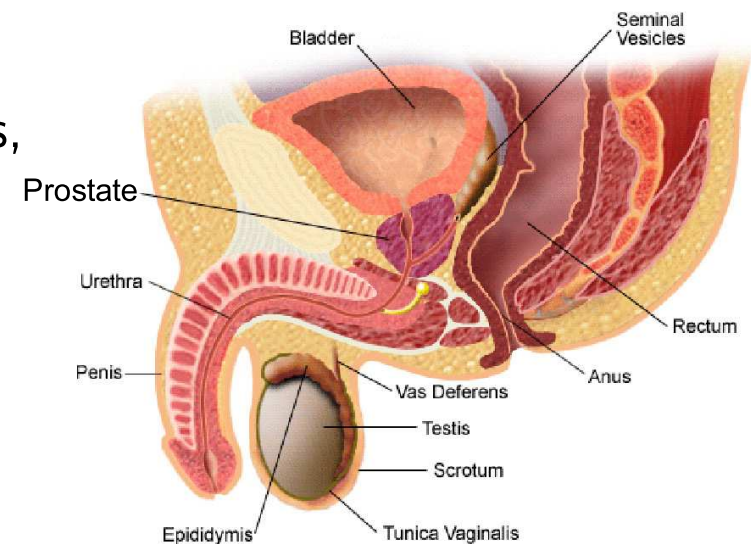
- caused by non-moving metallic objects in the working volume of the magnetic tracking system
- static over time \Rightarrow can be corrected

Dynamic Errors:

- caused by moving metallic objects in the working volume of the magnetic tracking system and the earth's magnetic field
- change over time

Prostate cancer

- prostate gland located underneath the bladder and in front of the rectum, it encloses the urethra
- prostate cancer occurs only in male patients, most of them are older



Source of the picture: http://mcghealth.org/greystone/images/ei_0327.gif

The Intended Medical Application

- natural organ movement: 10 to 15 mm
⇒ safety margins around the prostate during radiation
- The idea was to use magnetic tracking during external beam radiation for a better localization of the prostate cancer
⇒ position of the prostate cancer is known
- intended output, wished by the doctors:
„Please move the treatment table 3 cm to the left and 1 cm up to bring the prostate cancer into the isocenter of the linear accelerator.“

Preliminary Work at the chair

done by Suhkbansbir Kaur¹ in 2006



- implementation and comparison of different algorithms for static error correction for magnetic tracking (bilinear and trilinear interpolation, Hardy's multiquadric method)
- data collected by putting the sensor into 121 wholes of a polymer block
- collected tracking data was saved in a lookup-table as input for the algorithms

⇒ good results, but collecting data too time-consuming and too inconvenient

¹ „Error Correction for ElectroMagnetic Tracking“, Master thesis by Suhkbansbir Kaur, handed in 2006/04/28

Issues to be followed up

- collecting data for error correction algorithm shall be more convenient and less time-consuming
 - calibration between coordinate systems of the devices shall be done in distortion-free szenario instead of in the distorted szenario during online error correction
 - approach: using an additional optical tracking system with more accuracy
- ⇒ coregistration between optical and magnetic tracking needed

During **coregistration**, the transformation between the coordinate systems of the tracking systems is determined.

Coregistration - Preliminary Work

Auer and Pinz² in 1999:

- HMD with two cameras and a magnetic sensor
- tracking of position and orientation
- tracking primitives: corners in the camera images
- optical tracking system computed position and orientation of the user
magnetic tracking system used to predict search areas on the images
optical tracking system used to detect misidentified features

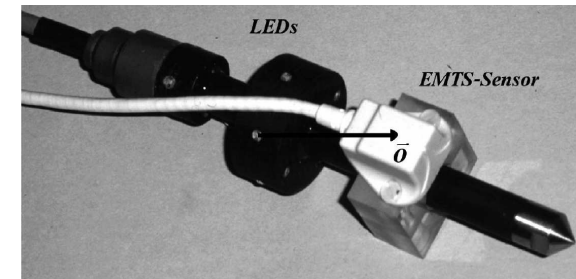


²„The integration of optical and magnetic tracking for multi-user augmented reality“ by T. Auer and A. Pinz, Computers & Graphics, 1999

Coregistration - Preliminary Work

Birkfellner³ in 2000:

- a stylus as magneto-optical probe with two magnetic sensors and active optical markers
- magnetic sensors attached to the stylus in a defined distance
- distance of the sensors was monitored
a deviation showed the distortion of the magnetic tracking system
⇒ discard the distorted data of the magnetic tracking system

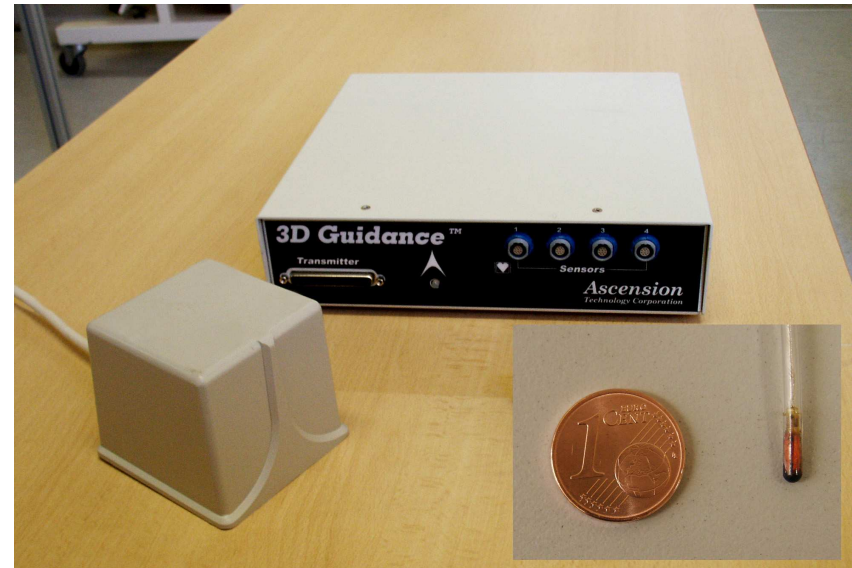


³ „Tracking Systems in Surgical Navigation“, Doktorarbeit by W. Birkfellner, 2000

Used Hardware

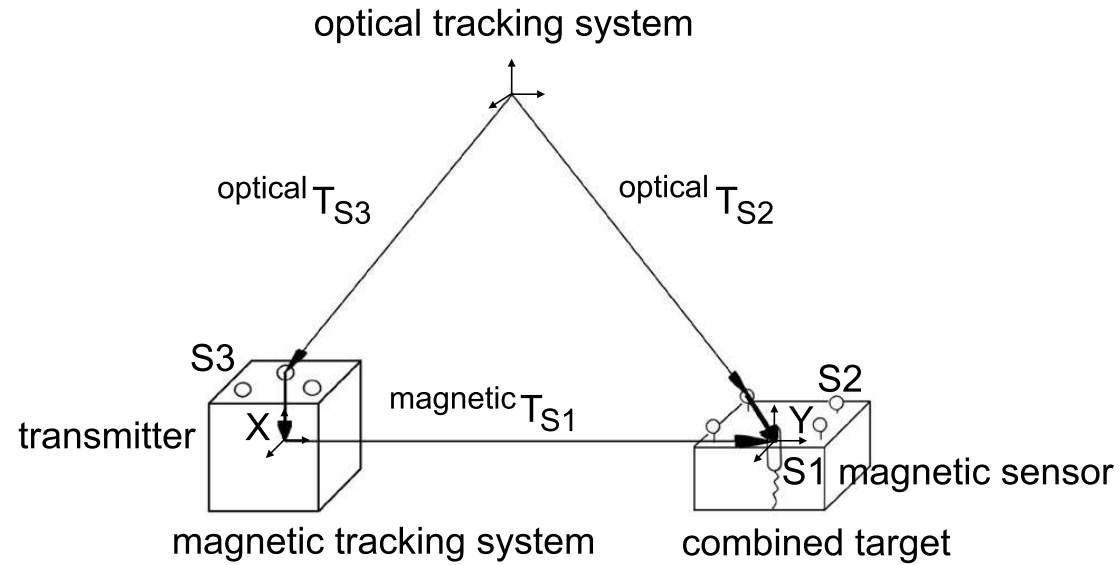


optical tracking system dtrack
with 4 cameras model ARTtrack2
by A.R.T.



magnetic tracking system
3D Guidance/Microbird
by Ascension Technologies

The Setup



The transformations are linked by this equation:

$${}^{AR}T_{S3} \cdot X \cdot {}^{MB}T_{S1} = {}^{AR}T_{S2} \cdot Y$$

Explanation of the picture

- top: the optical tracking system
- left: the field-generator of the magnetic tracking system with attached optical markers
- right: a device called „combined target“ with one magnetic sensor inside and optical markers attached on top (compare picture on slide 17)
- X = transformation inside the transmitter between the origin of the magnetic tracking system and the origin of the optical markers on the transmitter
- Y = transformation inside the combined target between the origin of the magnetic sensor and the origin of the optical marks on top

Background: Hand-Eye-Calibration (HEC)

- HEC⁴ used to find rigid transformation between magnetic sensor and optical markers inside the combined target (= Y from the picture)
- collecting 13 pairs of poses of the combined target:
optically determined pose of the sensor and the corresponding magnetically determined pose of the sensor
- motions between the poses taken as input for HEC
- EulerAngles computed as threshold during collecting poses to avoid poses that are too close
- I used an existing implementation of Daniilidis.

⁴ „Hand-Eye Calibration Using Dual Quaternions“ by K. Daniilidis, The International Journal of Robotics Research, 1999

Background: Hardy's Multiquadric Method (HMQ)

- global interpolation method, developed by Hardy in 1971 for topographic maps
Collected height informations were used to interpolate elevation informations for the whole surface.
- HMQ⁵ uses lookup-table (LUT) with two entries per line:
magnetically and optically measured poses of the magnetic sensor
- input: distorted value
output: interpolated undistorted value
- data for LUT collected with combined target in the working volume
- I used the existing implementation of Suhkbansbir Kaur.

⁵„Multiquadric equations of topography and other irregular surfaces“ by R. L. Hardy, Journal of Geophysical Research, 1971

The Previous Method

1. Creating a Lookup-Table
⇒ time-consuming and not robust
2. Online Error Correction
⇒ works stable

The Method

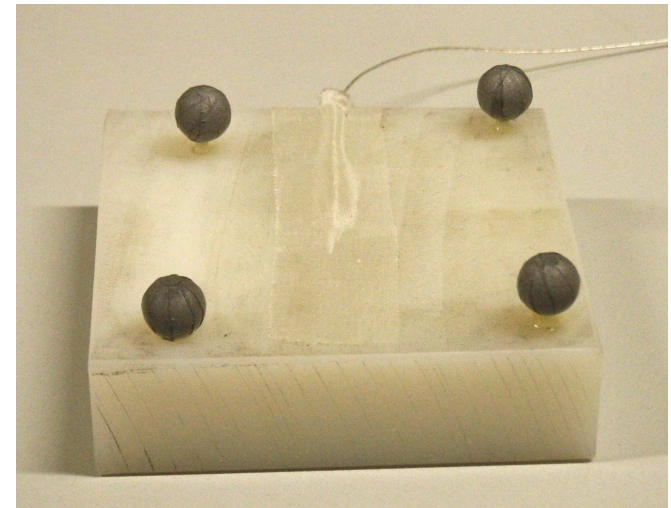
1. Device Calibration
2. Creating a Lookup-Table
3. Online Error Correction

Purpose:

online error correction for the sensor of a magnetic tracking system in a distorted setting

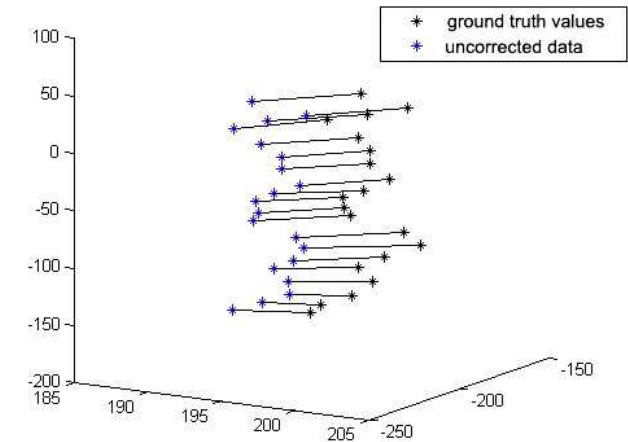
Step 1: Device Calibration

- purpose: compute spatial relationship between the coordinate systems of the magnetic and optical tracking systems (= coregistration)
- determine transformations X and Y to compute true position of the (distorted) magnetic sensor using optical tracking data
- needs to be done in an undistorted setting
- done using the „combined target“



Step 2: Creating a Lookup-Table (LUT)

- LUT needed as input for error correction algorithm
- reflects displacement vectors of the distortion field
- data collected using the combined target
- done in distorted setting
- procedure to collect LUT shall be convenient, quick and easy to integrate in medical workflow
- data should be recorded along a space-filling curve to collect data from the whole magnetic tracking volume, but mechanical solution not possible
⇒ Pacman-Game (on slide 20)

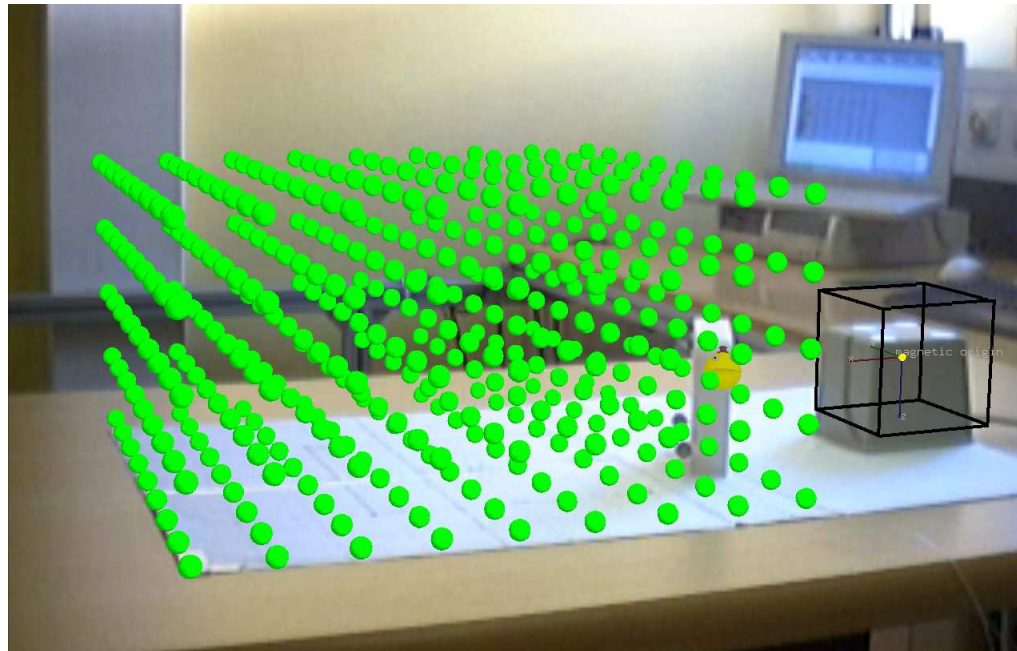


The Contents of the Lookup-Table (LUT)

$${}^{MB}T_{S1} = \underbrace{X^{-1} \cdot ({}^{ART}T_{S3})^{-1} \cdot {}^{ART}T_{S2} \cdot Y}_{\text{„ground truth values“}}$$

- equation derives from the equation on slide 11
- left side: pose of the magnetic sensor given by the magnetic tracking system
- right side: pose of the magnetic sensor given by the optical tracking system
- both sides of the equation may differ in a distorted setting as the magnetic pose may be distorted

Screenshot of the Pacman-Game



The black frame and the transmitter only differ because the magnetically tracked webcam was hold outside the magnetic tracking volume to take the picture.

The Pacman-Game

- visual help to collect data inside the *whole* magnetic tracking volume
- real scenario augmented with green spheres inside the volume
- magnetic sensor augmented by pacman-like character
- combined target used for collecting data
- a sphere disappears when the pacman (= magnetic sensor) comes close enough

Step 3: Online Error Correction⁶

- The current (distorted) position of the magnetic sensor is corrected by Hardy's multiquadric method⁷ using information from the recorded lookup-table.
- The setting may not change between the creation of the lookup-table and the online error correction. If it changes in between, the lookup-table is outdated and does not reflect the distortion field correctly.

⁶ „A survey of electromagnetic position tracker calibration techniques“ by V.V. Kindratenko, Virtual Reality, 2000

⁷ „Multiquadric equations of topography and other irregular surfaces“ by R. L. Hardy, Journal of Geophysical Research, 1971

Experiments & Results

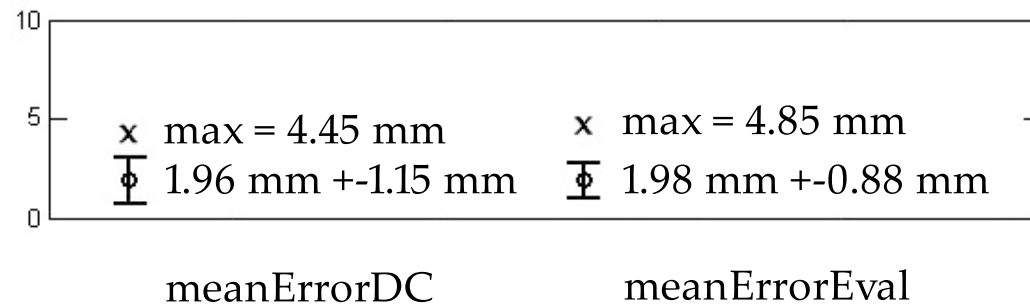
- two kinds of experiments:
evaluation of the device calibration (step 1) and
evaluation of the applied error correction (step 2 and 3)
- purpose of the experiments:
evaluate the benefit of the implemented method

Evaluation of the Device Calibration

- 13 poses taken for hand-eye calibration as usual
- additionally 50 points recorded in the magnetic volume for evaluation

Results of the Evaluation of the Device Calibration

- meanErrorDC = mean error during HandEye-Calibration between 13 X's from the poses and computed mean value for X
- meanErrorEval = mean error of the 50 evaluation points

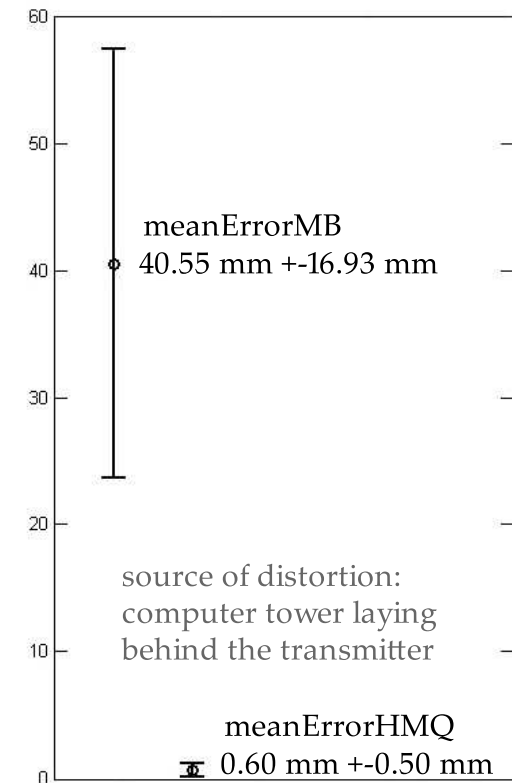
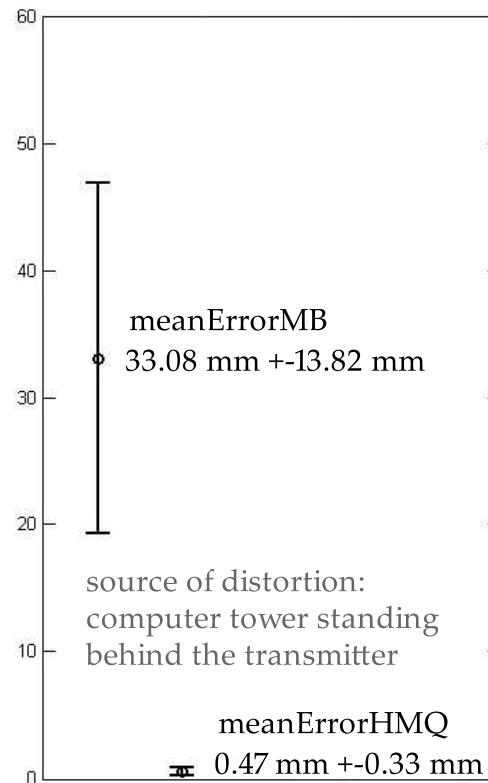


Evaluation of the Applied Error Correction

- LUT recorded in distorted setting as usual
- additional file recorded for evaluation (= contents of the LUT + HMQ)
- evaluation file has three entries per line:
 1. distorted position = magnetically reported position of the sensor
 2. ground truth value = optically reported position of the sensor
 3. interpolated value = corrected position of the sensor, interpolated using Hardys multiquadric method

Results of the Evaluation of the Applied Error Correction

- meanErrorMB = mean error for the distance between uncorrected values of the sensor and ground truth for all entries in the evaluation file
- meanErrorHMQ = mean distance between the uncorrected values and the corrected values of the sensor for all entries in the evaluation file



Future Work

- expand the system to detect dynamic field distortions
- solve the issue of insufficient synchronization between the optical and the magnetic tracking system
(timestamps taken at different moments in time: timestamp of the optical tracking system after picture was taken, timestamp of the magnetic tracking system taken *after* position of the sensor was computed)
- expand the application for the use in the radiation therapy room of a hospital
(registration between the magnetic tracking system, the patient, the treatment table and the patients' CT images)

Further Information

My diploma thesis is available online at

<http://campar.in.tum.de/Students/DaProstate>