An X-Ray and CT based Registration Method for Patient to Beam Alignment designed for high Reliability despite of degraded X-Ray Image Quality

- **L**ocal **I**ntensity **M**aximum based **W**eighted **M**utual Information (LIMWMI) -

MEDCOM

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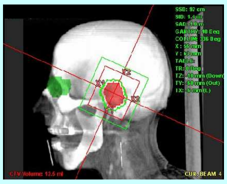
TUM PHOTOGRAMMETRY & REMOTE SENSING

1 BACKGROUND

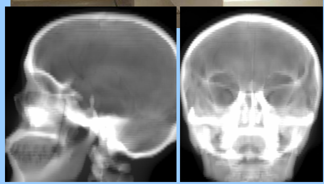
1.1 Motivation – Automatic Tumor Alignment

Planned alignment



Computed tomography and treatment plan.

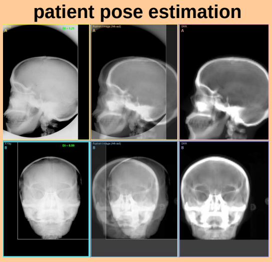
Real alignment



Stereoscopic X-ray images from within treatment device.

Automatic patient pose estimation

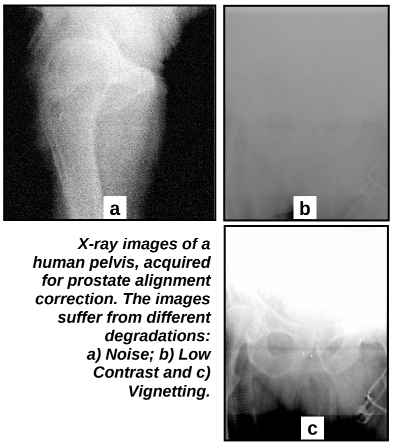
- Computation of a 6 DOF target alignment correction
- Intensity based 2D to 3D image registration
- Relative high registration reliability due to multi-modal registration approach - Mutual Information (MI)
- High accuracy (0.5 mm, 0.5°)



Display of mis-alignment - Left: DR images; Right: DRR images; Middle: Overlaid image display.

1.2 Problem – Varying Registration Quality

- **Reason 1: Low DR image quality due to**
  - → Noise
  - → Low contrast (Leads to same intensity for different materials)
  - → Vignetting (Leads to different intensities for same material)
- **Reason 2: Features and areas in DR that do not match the CT**
  - → Obstructing parts in the image
  - → Non-rigid transformations (e.g. movement of femurs, spine)
  - → Radiometric differences



X-ray images of a human pelvis, acquired for prostate alignment correction. The images suffer from different degradations: a) Noise; b) Low Contrast and c) Vignetting.

2 MATERIAL & METHODS

2.1 Image Preprocessing

2.1.1 Find areas with local intensity maxima

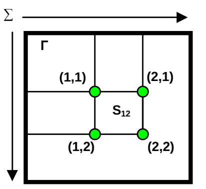
- Difference of means for small (S) and large (L) rectangle

$$I = \bar{S} - \bar{L}$$

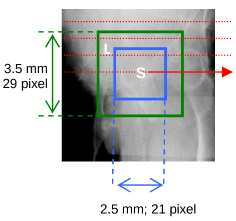
- High performance through summation over Integral Images

Integral Image $\Gamma_G(x,y) = \int_0^x \int_0^y G(x,y)\,dxdy$

(Images A, B; Transformation T)



$$S_{12} = \Gamma(x_2,y_2) + \Gamma(x_1,y_1) - \Gamma(x_1,y_2) - \Gamma(x_2,y_1)$$



Fast computation of the sum over a large portion of the image, using the Integral Image (left);
Finding areas of interest in the X-ray image of a human pelvis (right).

2.1.2 Weight areas of interest according neighboring points

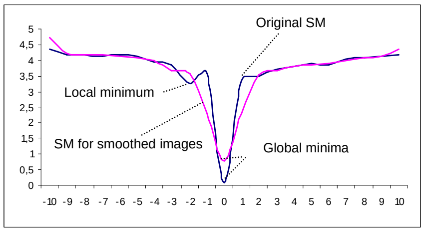
- Intensity scaling in a 2 pixel neighborhood to the range [0, 1] →

$$I(x,y) = \frac{I(x,y)}{\max\limits_{0 \le i < 5;\, 0 \le j < 5} \left(I(x-2+i,\, y-2+j)\right) + 1}$$

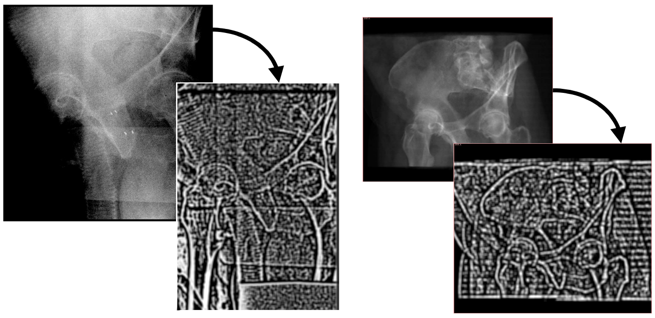
(Intensity I; Image coordinates x, y)

Blurring

- Smoothing of the areas of interest
  - → Reduction of local minima in the similarity function
  - → Broadening of the similarity functions global minimum (higher reliability, less accuracy)



Similarity measure (SM) for original images and for blurred images.



Original and preprocessed images – Left: DR Image of a human pelvis; Right: Digitally Reconstructed Radiography from a pelvis CT scan.

2.2 Registration & Similarity Measure

2.2.1 Intensity based similarity measure

- Mutual Information (MI)
- Minimization through Downhill Simplex →

$$MI(A,B,T) = \int\int P(a|Tb)\ln\left(P(a|Tb)\right)dbda - \int P(a)\ln P(a)da - \int P(Tb)\ln(Tb)db$$

(Images A, B with intensities a, b; Transformation T)

2.2.2 Improvement through Weighted Mutual Information

- Weighted Mutual Information (WMI)
- Weight with squared intensity differences →

$$WMI(A,B,T) = \frac{1}{(a-b)^2 + 1} * MI(A,B,T)$$

3 RESULTS

- 3 Types of DR images, categorized as high, medium and low quality have been tested
- Test 30 registrations for:
  - → Reliability in % of successful registrations (error < 3 mm)
  - → Accuracy in terms of the resolution of the used CT scan

Method	High Quality DR		Medium Quality DR		Low Quality DR	
	Reliability	Accuracy	Reliability	Accuracy	Reliability	Accuracy
MI	100%	0.5	80%	0.5	30%	1.5
LIMWMI	100%	0.8	90%	1.0	70%	1.4

Table of results: The LIMWMI approach is slightly less accurate that conventional MI if applied to high quality images, but performs much better on low quality DRs and is more reliable.

4 CONCLUSION

The proposed method provides:

- Higher reliability on low quality X-ray images than MI
- Only slightly reduced accuracy
- Slightly faster computation through faster convergence
- High tolerance regarding image quality

LIMWMI enables lower X-ray doses for verification images and allows automatic alignment where other approaches fail.