Seminar#4
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Image registration by maximization of combined mutual information and gradient information

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Introduction

- Mutual Information is currently one of the most intensively researched measures. (intensity based measure)

- Retrospective Registration Evaluation Project (RREP), an international study comparing the accuracy of sixteen registration methods against a screw marker gold standard

- Mutual information registration function can be ill-defined, con- taining local maxima.

Introduction (2)

- Improvements of different aspects of the method have been suggested, such as **multiresolution** methods , a **different entropy** measure, **invariance with respect to overlap** , and ’**higher-order**’ mutual information, using co-occurrence matrices of neighbouring voxels’ intensities

- Combine mutual information with a gradient measure to provide spatial information. Image gradients by themselves have been shown to be useful registration criteria

Method

Mutual Information

$$I(A,B) = H(A) + H(B) - H(A,B).$$

$$\mathrm{H}(X) = \sum_{i=1}^{n} \mathrm{P}(x_i)\,\mathrm{I}(x_i) = -\sum_{i=1}^{n} \mathrm{P}(x_i)\log_b \mathrm{P}(x_i)$$

$$\mathrm{H}(X|Y) = \sum_{i,j} p(x_i, y_j)\log \frac{p(y_j)}{p(x_i, y_j)}$$

Method (2)

Normalized Mutual Information - sensitive to the amount of overlap between the images

Introduced by Studholme et al.

$$Y(A,B) = \frac{H(A) + H(B)}{H(A,B)}$$

Method (3)

The proposed registration measure

$$I_{new}(A, B) = G(A, B)\ I(A, B)$$

with

$$G(A, B) = \sum_{(\mathbf{x},\mathbf{x}')\in(A\cap B)} w(\alpha_{\mathbf{x},\mathbf{x}'}(\sigma))\ \min(|\nabla\mathbf{x}(\sigma)|, |\nabla\mathbf{x}'(\sigma)|).$$

$$\alpha_{\mathbf{x},\mathbf{x}'}(\sigma) = \arccos \frac{\nabla\mathbf{x}(\sigma)\cdot\nabla\mathbf{x}'(\sigma)}{|\nabla\mathbf{x}(\sigma)||\nabla\mathbf{x}'(\sigma)|}$$

RESULT

TABLE I

REGISTRATION RESULTS FOR MRI AND CT IMAGE PAIRS (IN MM)

	median				maximum				
	I	Y	I_{new}	Y_{new}	I	Y	I_{new}	Y_{new}	n
T1	1.07	0.84	1.21	1.37	2.23	2.08	2.23	2.91	7
PD	1.42	1.43	1.53	1.73	3.20	3.95	2.90	3.08	7
T2	1.48	1.51	1.29	1.63	8.79	3.02	3.16	3.01	7
T1rect	0.71	0.61	0.78	0.80	1.69	1.00	1.62	2.15	6
PDrect	0.68	0.71	0.69	0.87	1.49	1.19	1.67	2.40	7
T2rect	0.72	0.63	0.89	1.04	3.54	2.20	1.83	2.99	7

RESULT(2)

TABLE II

REGISTRATION RESULTS FOR MRI AND PET IMAGE PAIRS (IN MM)

	median				maximum				
	I	Y	I_{new}	Y_{new}	I	Y	I_{new}	Y_{new}	n
T1	2.37	1.90	2.46	2.43	38.91	74.74	6.65	8.78	7
PD	2.33	2.24	3.04	2.67	5.13	6.55	7.55	6.82	7
T2	2.51	2.40	3.13	2.27	7.24	5.38	6.05	7.91	7
T1rect	1.82	1.34	2.12	1.29	3.51	3.56	3.62	4.29	4
PDrect	2.72	2.88	2.07	2.97	6.00	3.78	6.29	6.44	5
T2rect	2.74	2.67	2.24	1.62	6.95	5.25	3.27	5.42	5

Multimodality Image Registration by Maximization of Mutual Information

IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 16, NO. 2, APRIL 1997

Introduction

- A new approach to the problem of multi- modality medical image registration is proposed.

- Mutual Information or relative entropy, as a new matching criterion

- To measure the statistical dependence or information redundancy between the image intensities of corresponding voxels in both images

Introduction (2)

- This paper expands on the ideas first presented by Collignon et al.

- In radiotherapy planning, dose calculation is based on the **CT** data

- While tumor outlining is often better performed in the corresponding **MR** scan

- Functional information may be obtained from **PET** images

Method

Mutual Information

$$I(A,B) = H(A) + H(B) - H(A,B).$$

$$\mathrm{H}(X) = \sum_{i=1}^{n} \mathrm{P}(x_i)\,\mathrm{I}(x_i) = -\sum_{i=1}^{n} \mathrm{P}(x_i)\log_b \mathrm{P}(x_i)$$

$$\mathrm{H}(X|Y) = \sum_{i,j} p(x_i, y_j)\log \frac{p(y_j)}{p(x_i, y_j)}$$

Method

Mutual Information

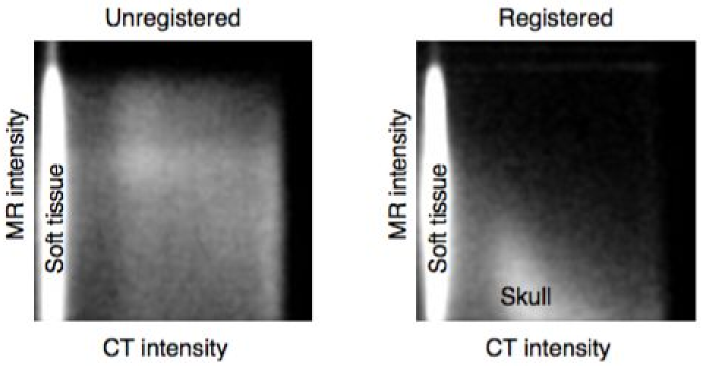
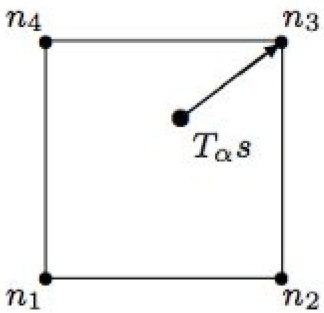


Fig. 1. Joint histogram of the overlapping volume of the CT and MR brain images of dataset A in tables II and III: a) initial position: $I(CT, MR) = 0.46$; b) registered position: $I(CT, MR) = 0.89$. Misregistration was about 20 mm and 10 degrees (see the parameters in table III).

Method

Criterion - Interpolation

NN:



$$\arg\min_{n_i} d(T_\alpha s, n_i) = n_3$$

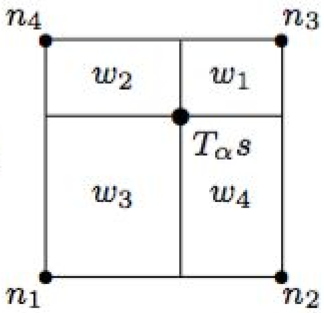
$$r(T_\alpha s) = r(n_3)$$

$$h_\alpha(f(s), r(T_\alpha s)) \mathrel{+}= 1$$

Method

Criterion - Interpolation(2)

TRI:

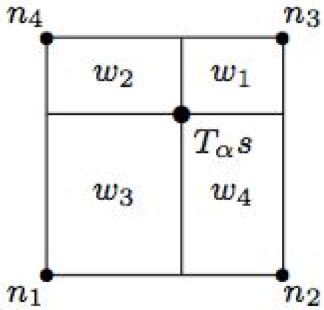


$$\sum_i w_i(T_\alpha s) = 1$$
$$r(T_\alpha s) = \sum_i w_i \,.\, r(n_i)$$
$$h_\alpha(f(s), r(T_\alpha s)) \mathrel{+}= 1$$

Method

Criterion - Interpolation(3)

PV:



$$\sum_i w_i(T_\alpha s) = 1$$
$$\forall i : h_\alpha(f(s), r(n_i)) \mathrel{+}= w_i$$

Experiments

DataSet

Set	Image	Size	Voxels (mm)	Range
A	MR	$256^2\times180$	$0.98^2\times1.00$	0×4094
	CT	$256^2\times100$	$0.94^2\times1.55$	0×4093
B	MR	$200^2\times45$	$1.25^2\times4.00$	38×2940
	CT	$192^2\times39$	$1.25^2\times4.00$	0×2713
C	MR	$256^2\times24$	$1.25^2\times4.00$	2×2087
	CT	$512^2\times29$	$0.65^2\times4.00$	0×2960
	PET	$128^2\times15$	$2.59^2\times8.00$	0×683
D	MR	$256^2\times30$	$1.33^2\times4.00$	2×3359

Experiments

MI Registration Parameters

Set	F/R		Rotation (degrees)			Translation (mm)			Difference (mm)		
			x	y	z	x	y	z	x	y	z
A	Reference [25]		9.62	-3.13	2.01	7.00	1.14	18.15			
	CT/MR	NN	10.23	-3.23	2.10	6.98	1.00	18.24	0.09 (0.18)	0.40 (0.79)	0.63 (0.84)
		TRI	10.24	-3.21	2.08	6.97	1.05	18.22	0.08 (0.16)	0.40 (0.72)	0.63 (0.80)
		PV	10.36	-3.17	2.09	6.94	1.15	18.20	0.08 (0.17)	0.48 (0.76)	0.76 (0.89)
	MR/CT	NN	10.24	-3.17	2.09	6.95	1.04	18.18	0.08 (0.16)	0.41 (0.74)	0.64 (0.74)
		TRI	10.24	-3.15	2.07	6.92	1.00	18.23	0.08 (0.15)	0.41 (0.76)	0.64 (0.80)
		PV	10.39	-3.14	2.09	6.90	1.15	18.18	0.10 (0.18)	0.51 (0.77)	0.79 (0.94)
B	Reference [25]		9.62	-3.13	2.01	7.00	1.14	18.15			
	CT/MR	NN	10.02	-3.42	2.25	6.63	0.34	18.28	0.40 (0.83)	0.80 (1.45)	0.43 (0.84)
		TRI	10.27	-3.11	2.05	6.53	0.54	18.34	0.48 (0.54)	0.61 (1.22)	0.67 (0.99)
		PV	10.57	-3.17	2.11	6.60	0.62	18.36	0.40 (0.53)	0.68 (1.47)	0.97 (1.32)
	MR/CT	NN	10.17	-3.06	2.25	6.47	0.30	17.90	0.54 (0.84)	0.84 (1.57)	0.57 (1.03)
		TRI	10.03	-3.05	2.22	6.44	0.37	18.19	0.56 (0.84)	0.77 (1.34)	0.42 (0.64)
		PV	10.29	-3.16	2.08	6.48	0.33	17.95	0.52 (0.61)	0.81 (1.48)	0.69 (0.98)

Experiments

MI Registration Parameters(2)

C	Reference [10]		-0.63	0.05	4.74	26.15	-41.08	-12.35			
	CT/MR	NN	0.87	0.05	4.84	26.70	-40.67	-9.92	0.54 (0.70)	0.74 (1.33)	2.43 (4.80)
		TRI	1.21	-1.94	3.67	29.51	-39.78	43.61	-	-	-
		PV	-0.00	0.00	4.95	26.57	-40.72	-10.00	0.41 (0.77)	0.49 (1.00)	2.35 (3.28)
	MR/CT	NN	-0.21	0.00	4.95	26.56	-41.27	-12.01	0.41 (0.76)	0.35 (0.71)	0.62 (0.98)
		TRI	-0.51	0.25	5.03	26.35	-40.80	-11.84	0.42 (0.75)	0.43 (0.79)	0.51 (0.95)
		PV	-1.58	0.13	4.97	26.48	-41.39	-12.18	0.35 (0.73)	0.56 (1.18)	1.38 (1.57)
C	Reference [10]		1.52	-1.17	4.22	27.62	-2.60	-4.46			
	PET/MR	NN	0.70	0.26	5.20	27.57	-0.74	-5.08	1.40 (2.28)	1.82 (3.66)	1.97 (3.91)
		TRI	0.38	0.01	5.25	27.50	-1.29	-1.37	1.47 (2.31)	1.62 (3.34)	3.22 (6.46)
		PV	1.63	0.18	4.98	27.65	-0.46	-4.94	1.09 (1.83)	2.14 (3.32)	1.97 (2.46)
	MR/PET	NN	0.42	0.14	5.04	27.93	-1.28	-5.03	1.17 (2.16)	1.47 (3.00)	2.00 (4.03)
		TRI	0.16	-0.11	4.90	27.99	-1.60	-4.27	0.98 (1.90)	1.27 (2.59)	2.05 (3.66)
		PV	1.46	-0.34	4.71	27.94	-0.85	-4.49	0.72 (1.44)	1.74 (2.49)	1.19 (1.37)

Conclusion

- Estimations of the image intensity distributions were obtained by simple normalization of the joint histogram.

- fixed number of bins of 256×256

- Finally, other registration criteria can be derived from the one presented here, using alternative information measures applied on different features.