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**Abstract**—Mutual information (MI) is a popular similarity measure for image registration, whereby good registration can be achieved by maximizing the compactness of the clusters in the joint histogram. However, MI is sensitive to the “outlier” objects that appear in one image but not the other, and also suffers from local and biased maxima. We propose a novel joint saliency map (JSM) to highlight the corresponding salient structures in the two images, and emphatically group those salient structures into the smoothed compact clusters in the weighted joint histogram. This strategy could solve both the outlier and the local maxima problems. Experimental results show that the JSM-MI based algorithm is not only accurate but also robust for registration of challenging image pairs with outliers.

**Index Terms**—Image registration, joint saliency map, mutual information, outliers, weighted joint histogram.

I. INTRODUCTION

IMAGE REGISTRATION is a fundamental task in many applications, such as medical image registration, remote sensing image registration, and video registration. Mutual information (MI) [1] is a popular similarity measure for image registration, whereby good registration can be achieved by maximizing the compactness of the clusters in the joint histogram. However, MI is sensitive to the “outlier” objects that appear in one image but not the other, and also suffers from local and biased maxima. We propose a novel joint saliency map (JSM) to highlight the corresponding salient structures in the two images, and emphatically group those salient structures into the smoothed compact clusters in the weighted joint histogram. This strategy could solve both the outlier and the local maxima problems. Experimental results show that the JSM-MI based algorithm is not only accurate but also robust for registration of challenging image pairs with outliers.

$$I(f, g) = -\sum_{r,f} p(r) \log p(r) - \sum_{r,g} p(r) \log p(r) + \sum_{r,f,g} p(r, f, g) \log p(r, f, g)$$

$$p(r) = \sum_f p(r, f)$$

$$p(f) = \sum_r p(r, f)$$

$$h(r, f) = p(r, f)$$

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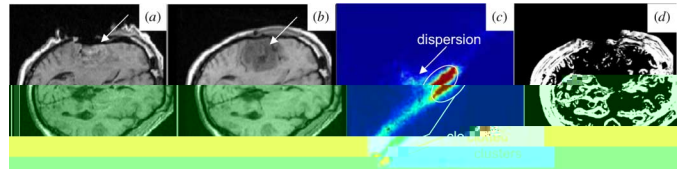


Fig. 1. (a) Original MR brain slices. (b) Joint histogram of the slices. (c) Joint Saliency Map (JSM) highlighting salient structures. (d) Weighted joint histogram with compact clusters.

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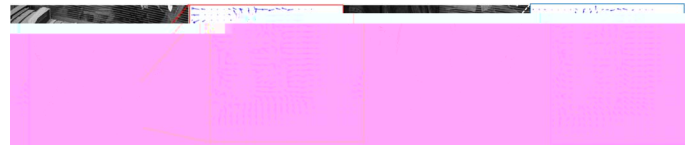


Fig. 2. ( ) ( ) RSV. 60 18

## II. METHODS

### A. Regional Saliency Vector

W

M

12, 13,

14. G

MI- 9, 11. H

L, 12

15

C

I, 16, 17

4

$$S_l(v) = \sum_{u \in N_v} (I_l(v) - I_l(u))^2 \quad (2)$$

$N_v = \{1, \dots, N_v\}$

$v = (x, y)$

$l, S_l(v)$

$I_l(v)$

$l, I_l(u)$

$I_l(v)$

$S(x, y)$

I

PAA

regional saliency

$$M = \begin{bmatrix} \mu_{20} & \mu_{11} \\ \mu_{11} & \mu_{02} \end{bmatrix} \quad (3)$$

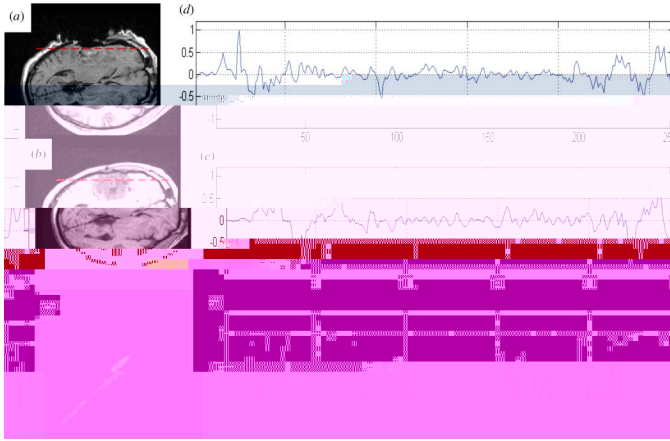


Fig. 3. (a) Original images. (b) Registration results for JSM. (c) Registration results for JSM-WJH. (d) Histograms for JSM. (e) Histograms for JSM-WJH. (f) MI map for JSM. (g) MI map for JSM-WJH. (h) MI map for JSM-WJH with a red line indicating a path. (i) MI map for JSM-WJH with a red line indicating a path.

### C. JSM-Weighted Joint Histogram

To improve registration accuracy, we propose a JSM-weighted joint histogram (JSM-WJH) method. In this method, the joint histogram is weighted by the JSM. The joint histogram is defined as follows:

$$H(r, f) = \sum_{v_r, v_f} w(v) \delta(r - v_r) \delta(f - v_f) \quad (1)$$

where  $w(v)$  is the JSM of the input images,  $v_r$  and  $v_f$  are the gray values of the reference and floating images, respectively.  $\delta(\cdot)$  is the Dirac delta function.  $I_R$  and  $I_F$  are the reference and floating images, respectively.  $P$  is the probability density function of the joint histogram. The registration cost function is defined as follows:

$$C = \int \int h(r, f) p(r, f) dr df \quad (2)$$

### D. Computational Complexity

The computational complexity of the JSM-WJH method is analyzed as follows. Let  $N$  be the number of pixels in the input images.

TABLE II  
COMPUTATION ITERATIONS AND RUNTIME IN SECONDS FOR FIG. 4.  
(MATLAB 6.5, SINGLE CORE INTEL CELERON 2.8 GH , RAM 2 GB)

	JMI	NMI	RMI	HMI	GMI	PMI
Iter.	64	41	45	46	50	29
Time	157.4	296.7	297.1	1060.1	329.1	3049.3

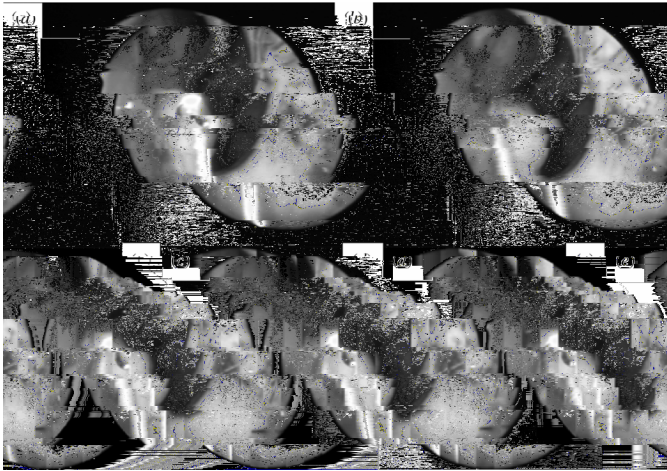


Fig. 5. (a) (c) (e) (g) (i) (k) Original images,  $(720 \times 572)$ . (b) (d) (f) (h) (j) (l) Reconstructed images after denoising.

JSM [12], NMI [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100].

IV. CONCLUSION

We proposed a novel denoising method based on JSM and MI. The method is effective in removing noise from brain MRI images while preserving the anatomical structure. The experimental results show that the proposed method outperforms other denoising methods in terms of PSNR and SSIM. The method is also computationally efficient and can be applied to other types of images.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (Grant No. 60773086), the Shanghai Leading Academic Local Project (Grant No. 10Y1101), and the Shanghai Leading Academic Local Project (Grant No. 10Y1101).

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