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. T CPD [7]

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SIFT fl [2] . M

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A ,

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I fi ,

. I

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T 38 . T , 2D , . T z . T S 2 S 3. T S 4.

## 2. Methods

### 2.1. C a e fi e . c e, a chi g ba ed b c , a chi g

T $I_M$ $I_R$ $\tau$ z t (x), x . T fi $I_M \circ \tau(x) = I_M(x + t(x))$. A fi z . T fi , fi 30 . T . F . 1 fi , . F , $I_M$ fi fi . T fi . S , JSS ( F . 1) fl , fi fi . A , fi . T fi fi fi . I fi , fi . A F . 1, , ( . ., F . 1) $I_M$ . T ( F . 1) (0.65) , . , fi , . T J . F , fi J 30 .

I , MI 39 . A , MI . T MI fi :

$$\mathrm{MI} = H(R) + H(M) - H(R,M)$$

$$= \sum_{i_R, i_M} p(i_R, i_M) \left( \frac{p(i_R, i_M)}{p(i_R)\,p(i_M)} \right) \quad (1)$$

$i_R$ $i_M$ . $H(I) = -\sum_i p(i)$ $p(i)$ $H(R,M) = -\sum_{i_R, i_M} p(i_R, i_M)$ $p(i_R, i_M)$ $I$ , $p(i)$ $p(i_R) = \sum_{i_R} p(i_R, i_M)$ $p(i_M) = \sum_{i_M} p(i_R, i_M)$, $p(i_R, i_M)$ (PDF) $h(i_R, i_M)$. MI $S_{\mathrm{MI}}$, fi $i_R, i_M$, MI :

$$\mathrm{MI} = \frac{1}{N} \sum_{i_R, i_M} S_{\mathrm{MI}}(i_R, i_M)$$

$$S_{\mathrm{MI}}(i_R, i_M) = \left( \frac{p(i_R, i_M)}{p(i_R)\,p(i_M)} \right) \quad (2)$$

$S_{\mathrm{MI}}$ PDF $N$ . F , PDF . T , PDF . T , fi , MI . T , MI fi . A , fi , . T , . T , JSS ( F . 1) fi fi : F , . B , , . T fi . S , . B , z JSS

Fig. 1. F fi . (F , .)

fi . D S 2.2 2.4. A fi , fi fi .

*2.2. Ke e eg e i ba ed ca def a i ec c i*

I 30,31 , z fi fi . S fi $\{y_i, x_i\}_{i=1}^{P}$

$$y_i = T(x_i) + \varepsilon_i, \quad x_i \in \Omega, \quad i = 1, \ldots, P \tag{3}$$

$y_i$ ( ) ( ) $x_i$, $T(\cdot)$ fi ( ) $\Omega$ z $\varepsilon_i = \varepsilon(x_i)$. I , $T(\cdot)$ y x, $T(x) = E\{y|x\}$. I , fi fi .

S x $x_i$, fi $T(x_i)$ T

$$T(x_i) \approx T(x) + \{\nabla T(x)\}^T (x_i - x) + \frac{1}{2}(x_i - x)^T \{H \quad T(x)\}^T \times (x_i - x) + \cdots \approx \beta_0 + \beta_1^T (x_i - x) + \beta_2^T \quad \{(x_i - x)(x_i - x)^T\} + \cdots \tag{4}$$

$(\cdot)$ z $\{\beta_0, \beta_1, \beta_2, \ldots, \beta_N\}$ $N+1$ . A 2D , x = $^T$,

$$\beta_0 = T(x)$$
$$\beta_1 = \left[\frac{\partial T(x)}{\partial x_1}, \frac{\partial T(x)}{\partial x_2}\right]^T \tag{5}$$
$$\beta_2 = \frac{1}{2}\left[\frac{\partial^2 T(x)}{\partial x_1^2}, \frac{\partial^2 T(x)}{\partial x_1 \partial x_2}, \frac{\partial^2 T(x)}{\partial x_2^2}\right]^T$$
$$\ldots$$

S $\{y_i\}_{i=1}^{P}$, $\{\beta_n\}_{n=0}^{N}$ fi :

$$\min_{\{\beta_0, \beta_1, \beta_2, \ldots\}} \sum_{i=1}^{P} \left[ y_i - \beta_0 - \beta_1^T (x_i - x) - \cdots \right]^2 K_H(x_i - x) \tag{6}$$

$K_H(\cdot)$ ( ), z x.

I , y = y1, y2, ..., yP T, b = $\beta_0, \beta_1^T, \ldots, \beta_N^T$ T, K = $K_H(x_1 - x)$, $K_H(x_2 - x)$, ..., $K_H(x - x)$, z

$$b = \underset{b}{} (y - Xb)^T K (y - Xb) \tag{7}$$

$$X = \begin{pmatrix} 1 & (x_1 - x) & {}^T\{(x_1 - x)(x_1 - x)^T\} & \cdots \\ 1 & (x_2 - x) & {}^T\{(x_2 - x)(x_2 - x)^T\} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ 1 & (x_p - x) & {}^T\{(x_p - x)(x_p - x)^T\} & \cdots \end{pmatrix}$$

$$b = (X^T K X)^{-1} X^T K y \tag{8}$$

B z T *Nada a Wa* fi , fi x

$$T(x) = \beta_0 = \frac{\sum_{i=1}^{P} K_H(x_i - x) y_i}{\sum_{i=1}^{P} K_H(x_i - x)} \tag{9}$$

S , . T , ( ) $c_i$ E . (9)

$$\begin{aligned} T(x) = \beta_0 &= \frac{\sum_{i=1}^{P} K_H(x_i - x) \cdot (y_i \cdot c_i)}{\sum_{i=1}^{P} K_H(x_i - x) \cdot c_i} \\ &= \frac{K \otimes (y \cdot c)}{K \otimes c} \end{aligned} \tag{10}$$

T E . (10) z 30 , ⊗ F . 2 . B , . A , fl ( F . 2( )) fi . T fl , . F , fl F . 2( ), N , .

### 2.3. L ca . c e ada i e e e f c i

A , ( ) . I , G . H , G fi fi . B , G fi

. T . T , P . 40 . A , T . 41 z , . I , .

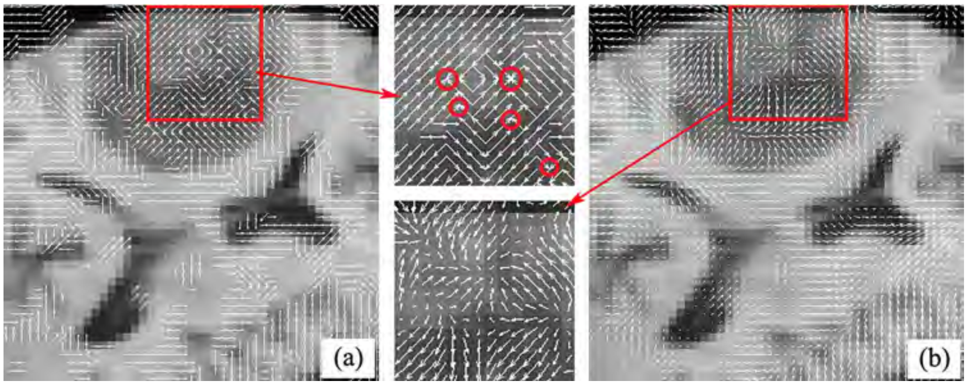


Fig. 2. A fi . ( ) T fl . ( ) T fl ( ) . (F , .)

{ , }, G 2D

$$a( ,x_0) = \frac{1}{2\pi\sigma_u\sigma_v} \left[ - \left( \frac{d_u^2}{2\sigma_u} + \frac{d_v^2}{2\sigma_v} \right) \right] \quad (13)$$

$d_u = \langle d, u\rangle, \quad d_v = \langle d, v\rangle, \quad d = x - x_0$

d $x_0$ x, $\{d_u, d_v\}$ d { , }, G $\{\sigma_u, \sigma_v\}$ $A$ :

$$\sigma_u = \frac{\alpha}{\alpha + A}\sigma_c, \quad \sigma_v = \frac{\alpha + A}{\alpha}\sigma_c \quad (14)$$

$A = (\lambda_u - \lambda_v)/(\lambda_u + \lambda_v)$ . T G $\alpha > 0$ $\sigma_c$. S fi , $\alpha$ $\sigma_c$ . F , z . T , z $\alpha = 0.5$ $\sigma_c = 1.5$ z $3 \times 3$ .

T F . 3, ( ). I F . 3, G ( F . 3( ) F . 3( )). T .

F . 4 . T . T ( 5 ) fl . T fl , . F , F . 4( ) fl F . 4( ). C , , fl F . 4( ) F . 4( ). (10 F . 4( ) ) ,

. O , . H , , fi F . 4( ).

### 2.4. R b eigh i g echa i i g JSM

I , $c(x)$, 0 1, fi ( ) x . , z fi fi 28,29 . S fl , S z . 30 . H , , . T , S z . T . z , JSM JSS . T JSS

Fig. 3. G . ( ) T ( ). ( ) T G K . ( ) G . ( ) G . (F , .)

Fig. 4. C .( ) ( )T . ( ) ( ) I ( ) , . ( ) ( ) I fl fi , fl . ( ) ( ) I , . (F , .)

$x_0$ $\Omega$, $S(x_0)$ $x_0$

$$S(x_0) = \text{avg} \sum_{x \in \Omega} \|\text{LST}(x) - \text{LST}(x_0)\|_D \qquad (15)$$

$\|\cdot\|_D$ fi LST , . T avg $\Omega$ $x_0$. T (FA) fi .

F , .

I 44 , . , fi

$$\|T_1 - T_2\|_D = \sqrt{\frac{8\pi}{15}\left(\|T_1 - T_2\|_C^2 - \frac{1}{3}\text{Tr}^2(T_1 - T_2)\right)} \qquad (16)$$

$\|T_1 - T_2\|_C = \sqrt{\text{Tr}(T_1 - T_2)^2}$ E $\{T_1, T_2\}$, Tr .

I , .

L

LST . A z , JSM . G $x_R$ $x_M$ , JSM fi

$$JS(x_R, x_M) = \{S_R(x_R), S_M(x_M)\}\frac{A \cdot B}{B + \|\text{LST}(x_R) - \text{LST}(x_M)\|_D} \qquad (17)$$

$\{S_R(\cdot), S_M(\cdot)\}$ , . T $A$ $B$ z JSM fi 0 1 fi $c(x)$. I , $A = 10$ $B = \frac{1}{2}$ $(\|\text{LST}(x_R) - \text{LST}(x_M)\|_D)$, $B$ LST . I

, . T , LST($x_R$) LST($x_M$) E . (17).

F . 5 z JSM . T JSS . O , JSM ,

Fig. 5. JSM E . E . T . T JSM . (F , .)

Fig. 6. T . ( ) ( ) G fi , fi GST fi GST fi LST ( ). ( ) ( ). ( ) JSM fi ( ) ( ). (F fi GST LST, JSM . ( ) ( ) T fi LST ( ). ( ) ( ) G ( ). ( ) (†) S fi ( ) , .)

. T JSS JSM , JSS . T JSM . H , . F . 6 , GST LST , JSM fi (F . 6( ) ( )). F , F . 6( ) ( ) 0, 1 . A F . 6, F . 6( ) F . 6( ) . T GST (F . 6( ) ( )) LST (F . 6( ) ( )). T F . 6( ) (†) LST E . (15). M , E . (15). A , JSM (F . 6( )) JSS . T , JSM fi F . 6. B , fi . T JSS fi , . ., . D , JSM ,

JSM . F . 7 fi . T JSM JSS F . 7( ) ( ) . JSM , (5 ) fl ( F . 7( )) ( F . 7( )). D JSM ( F . 7( )), ( F . 7( )) ( F . 7( )). C (10 ) F . 7( ), F . 7( ) JSM .

## 3. Experimental results

T [3] , 2D , . ANT [4] z (S ) MI (AGS1) 45 , ANT

[3] :// . . / / / .
[4] :// . . . /ANT

Fig. 7. M JSM . ( ) ( ) T . ( ) ( ) T fl

0.571Ti524prea1_0 1converg1 Tf 0.0002 0 0 -0.0002 194.6897 533.5539 Tm212.354/GS24prea1_0 1 Tf 6.3761 0 0 6.3761 182.0849 533.5539 Tm215539 67524

Fig. 8. C . O , AGS2 F NI . ( ) ( ) T , ( ) , ( ) AGS1, ( ) AGS2, ( ) AMI, ( ) DDD, ( ) BMI, ( ) AMM, (†) EPPM, ( ) LDOF, ( ) F NI. (F , .)

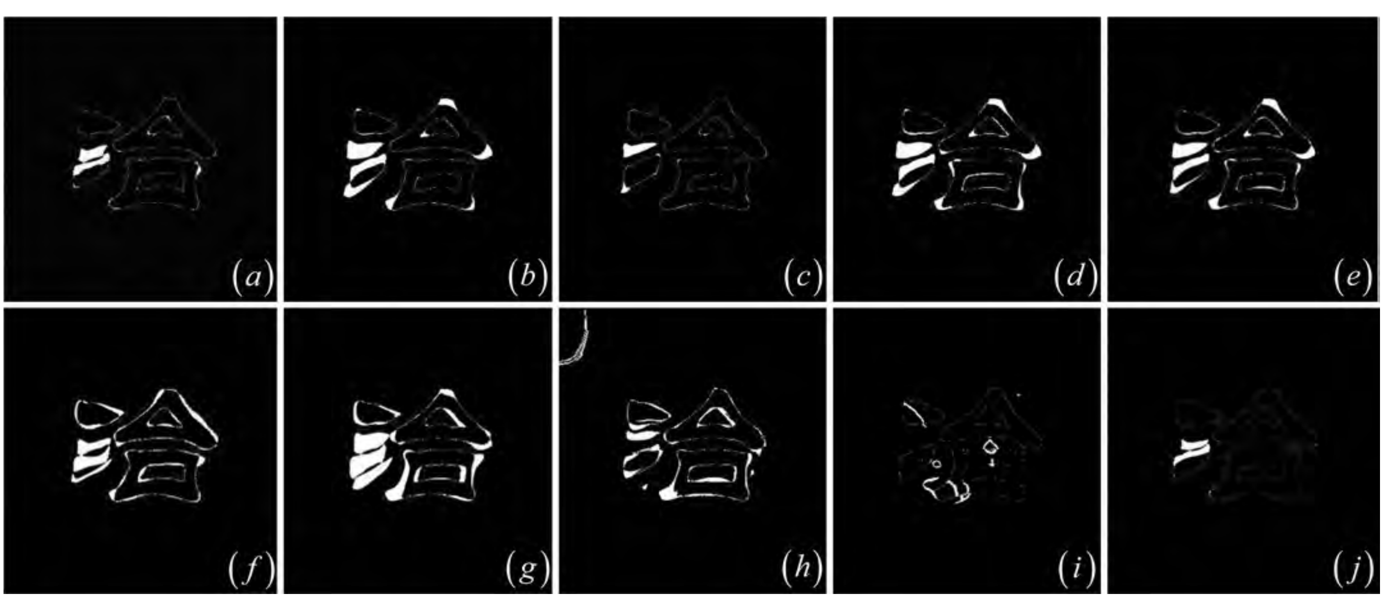


Fig. 9. D C 10 . ( ) O , ( ) AGS1, ( ) AGS2, ( ) AMI, ( ) DDD, ( ) BMI, ( ) AMM, ( ) EPPM, ( ) LDOF, (†) F NI.

Fig. 10. M L . ( ) ( ) T fi C , M , fl . ( ) ( ) T
M , fl . (F
, .)

( )
( F . 8( ) ( )). M ,
. T

Fig. 11. M . T F NI . ( ) ( ) T , ( ) , ( ) AGS1, ( ) AGS2, ( ) AMI, ( ) DDD, ( ) BMI, ( ) AMM, (‡) EPPM, ( ) LDOF, ( ) F NI. (F , .)

. A

( F . 12) .

Fig. 12. B . T AMI . ( ) ( ) T , ( ) , ( ) AGS1, ( ) AGS2, ( ) AMI, ( ) DDD, ( ) BMI, ( ) AMM, (†) EPPM, ( ) LDOF, ( ) F NI. (F , .)

DDD BMI (F . 13( ) ( )), . T EPPM (F . 13(†)) .

T MRE SD (F . 10( ) ( )) 10 T 1. B EPPM fi , EPPM T 1. T F NI M 1.27 ± 3.09 1.76 ± 2.96 , , AGS1, AGS2, AMI, DDD, BMI, AMM, LDOF 1.87 ± 3.11 . T .

A , fi

Fig. 13. F . T , F NI AMM . ( ) ( ) T , ( ) , ( ) AGS1, ( ) AGS2, ( ) AMI, ( ) DDD, ( ) BMI, ( ) AMM, (*) EPPM, ( ) LDOF, ( ) F NI. (F , .)

. z : fi , z , , fl fi F NI, (LDDMM) AGS1 AGS2 B (FFD) BMI, . H , LDDMM AGS1 AGS2 FFD BMI z z . S , AGS2 F NI . T . G , fi . A , fi z , fi .

T , z AGS2 C . S fi , , C , AGS2 ( F . 8( )) . T z , . T , fi z ( ) z . F ,

Table 2
C 10 (I (R) C (TM) 5 4460 Q C 3.2 GHz CP , RAM 4.0 GB).

| C | O | AGS1 | AGS2 | AMI | DDD | BMI | AMM | EPPM | LDOF | F NI |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 17.67 | 3563 | 30.67 | 13.99 | 4.42 | 11.41 | 13.99 | 0.79 | 41.23 | 4.02 |
| 2 | 18.83 | 3521.5 | 54.64 | 21.52 | 4.99 | 16.14 | 17.29 | 0.90 | 55 | 2.99 |
| 3 | 35.86 | 3761.5 | 33.88 | 15.69 | 8.97 | 32 | 14.94 | 0.90 | 84.43 | 4.53 |
| 4 | 14.67 | 3271.3 | 26.16 | 8.56 | 4.08 | 30.57 | 2.85 | 0.74 | 68.48 | 2.82 |

P , . F z AMM .

H , fi .

T 2 10 ,

1 3 372 × 392 , 4 384 × 288 . A 10 PC I C 5 4460 Q C 3.2 GHz CP 4 GB .

## 4. Conclusion and discussion

I , JSM . T JSM fi . T JSS . T .

N , . F , S 2.3 (1.5) G . A , , ( F . 7) . T I , ( ) . T fi fi . A . T , S , 45,48 , . M , ,

. H , . H , z fi JSS . A , 3D . A , 3D 3D . T 3D DIR L 50 [10] POPI 51 ,[11] . T 3D 3D fl : (1) ; (2) fi , fi .

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10 :// . . /
11 :// . . . / / /

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