一种基于 DSmT 和 HMM 的序列飞机目标识别算法

李新德 [1] 潘锦东 [1] DEZERT Jean[2]

摘 要 , DSmT (Dezert-Smarandache theory) (Hidden Markov model, HMM) (Multiple features and sequential information fusion, MFSIF). . , , Hu ; , (Probabilistic neural networks, PNN) (Basic belief assignment, BBA); , DSmT , HMM ; , , , ; , , , , . , ¿ ≤ 6 , .

关键词 , , , DSmT , , ,

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A Target Recognition Algorithm for Sequential Aircraft Based on DSmT and HMM

LI Xin-De[1] PAN Jin-Dong[1] DEZERT Jean[2]

Abstract For the low rate problem of recognition of automatic target recognition of aircraft caused by the great change of posture, a target recognition algorithm based on DSmT (Dezert-Smarandache theory) and HMM (Hidden Markov model) is proposed by utilizing the fusion of multiple features and sequential information (i.e. MFSIF). The novelty of the algorithm is integrating the multiple feature fusion recognition with the sequential images fusion recognition. Firstly, the sequential images are preprocessed with the binarization method, then the features of Hu moments and partial singular values of outline are picked up. Secondly, the PNN (Probabilistic neural network) is used to construct the BBA (Basic belief assignment). After that, these different features from the same image are fused by DSmT in order to gain the observation sequence of HMM. Then, the sequential information is fused by utilizing HMM to finish the automatic recognition of aircraft with varied multiple postures by calculating the similarities between the observation sequence and each HMM. Finally, according to the simulation experiment results, this algorithm has a high exact recognition rate even for aircraft with greatly varied postures. Simultaneously, this algorithm can also satisfy the requirement of aircraft target recognition in real-time. In addition, this algorithm can also guarantee a high recognition rate of aircraft target when the number ¿ of consecutive occulted frames is less than or equal to six.

Key words Sequential aircrafts, target recognition, multiple features fusion, Dezert-Samarandache theory (DSmT), probabilistic neural network (PNN), sequential information fusion, hidden Markov model (HMM)

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(Automatic target recognition, ATR) , . (Automatic aircraft recognition, AAR) ATR

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1. 210096 2. F-91761
1. Key Laboratory of Measurement and Control of CSE of Ministry of Education, School of Automation, Southeast University, Nanjing 210096, China 2. The French Aerospace Lab, Palaiseau F-91761, France

, . , ATR [1 ¡ 3] [4 ¡ 7]. , [8] , BP . , , , . , , (Multiple features automatic target recognition, MF-ATR)[9 ¡ 13]. [12] BP DST (Dempster-Shafer theory) ; [13] Hu , (Probabilistic neural networks, PNN) DSmT (Dezert-Smarandache theory) . , . , , , , , . , , [14 ¡ 15]. [14] Hu , BP , DST . [15] Hu , BP DSmT . [14 ¡ 15] , , . , DSmT , , (Hu), DSmT PNN , , (Hidden Markov model, HMM) , HMM , HMM , . , , , , , , . : 1 , ( ) ; 2 , , ; 3 , ; , 4 .

1 序列飞机目标识别框架

DSmT HMM 1 . 1 , T . :

1) : Hu ;

2) : DSmT , PNN (Basic belief assignment, BBA). , DSmT , ;

3) : HMM , , .

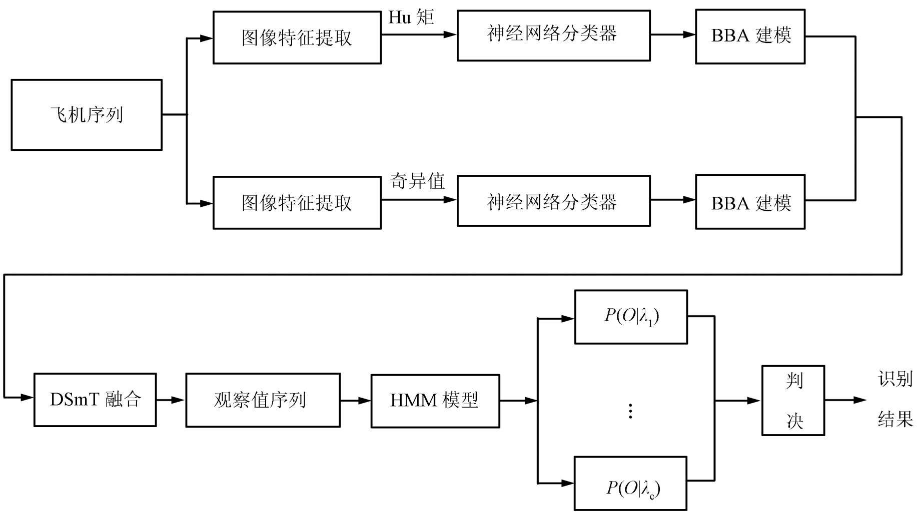
1.1 图像特征提取

, , . , : . Hu [7, 16]. [17].

1.1.1 **Hu** 矩

$f(x,y)$, $(p+q)$ m_{pq} $(p+q)$ μ_{pq} :

$$m_{pq} = \sum_{m=1}^{M}\sum_{n=1}^{N} m^p n^q f(m,n) \tag{1}$$



1 DSmT HMM

Fig. 1 Target recognition algorithm of sequential aircrafts based on DSmT and HMM

$$\mu_{pq} = \sum_{m=1}^{M}\sum_{n=1}^{N}(m - \bar{x})^p(n - \bar{y})^q f(m,n) \quad (2)$$

, $(\bar{x}, \bar{y})$ $f(x,y)$.

η_{pq} :

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{0,0}^r}, r = \frac{p+q}{2}, p+q = 2,3,\cdots \quad (3)$$

Hu[18] 7

(4) :

$$\begin{aligned}
&\phi_1 = \eta_{20} + \eta_{02}\\
&\phi_2 = (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2\\
&\phi_3 = (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2\\
&\phi_4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2\\
&\phi_5 = (\eta_{30} - 3\eta_{21})(\eta_{30} - \eta_{21})[(\eta_{30} + \eta_{12})^2 -\\
&\quad 3(\eta_{21} + \eta_{03})^2] + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03}) \times\\
&\quad [3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]\\
&\phi_6 = (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] +\\
&\quad \eta_{11}(\eta_{30} + \eta_{12})(\eta_{03} + \eta_{21})\\
&\phi_7 = (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 -\\
&\quad 3(\eta_{03} + \eta_{21})^2] + (3\eta_{12} - \eta_{30})(\eta_{21} + \eta_{03}) \times\\
&\quad [3(\eta_{30} + \eta_{12})^2 - (\eta_{03} + \eta_{21})^2]
\end{aligned} \quad (4)$$

, Hu

ϕ, $\phi = [\phi_1, \phi_2, \phi_3, \phi_4]$.

1.1.2 轮廓局部奇异值

. :

定义 1. $A_{m \times n}$, U V :

$$U^{\mathrm{H}}AV = \begin{pmatrix} S & 0 \\ 0 & 0 \end{pmatrix} \quad (5)$$

, $S = \mathrm{diag}\{\sigma_1, \sigma_2, \cdots, \sigma_r\}$, σ_1 , σ_2 , $\cdots$, $\sigma_r > 0$, σ_i $(i = 1, 2, \cdots, r)$ A $A^{\mathrm{H}}A$ AA^{H} λ_i , $\sigma_i = \sqrt{\lambda_i}$.

, [19]

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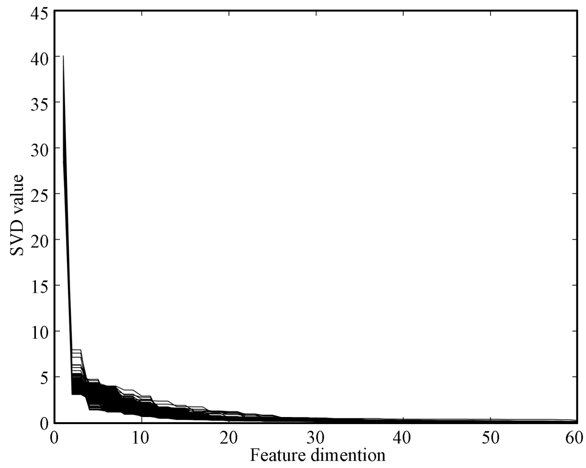
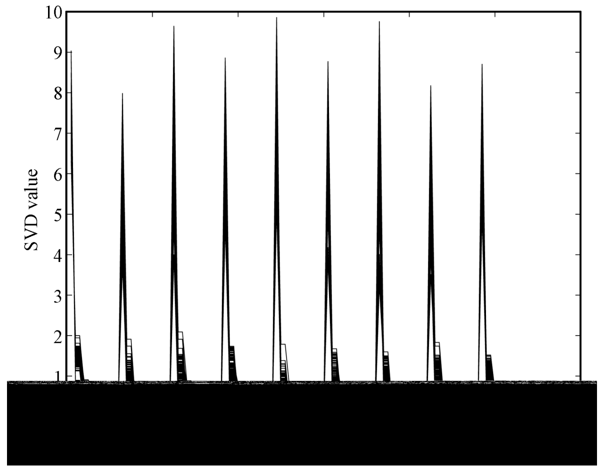


2

Fig. 2 Distribution diagram of global singular values of outline



3

Fig. 3 Distribution diagram of partial singular values of outline

n ,

, ,

$[d_1, d_2, \cdots, d_n]$. , ,

w $[d_1, d_2, \cdots, d_n]$,

m,

.

n, l :

$$l = \frac{n - w}{w - m} + 1 \tag{6}$$

,

,

$l \times w$.

, 200 ,

3 .

3 , ,

,

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3 ,

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1.2 多特征融合

,

Hu

DSmT PNN ,

(Basic belief assignment, BBA), DSmT PCR5

,

. DSmT BBA PNN

.

1.2.1 DSmT 建模

DSmT Dezert Smarandache [20-23]

. DST ,

.

,

D^Θ ,

DSmT , $\theta_1, \theta_2, \cdots, \theta_n$

. 1 .

1 , , m_i

i (BBA),

$\theta_i, i = 1, \cdots, n$, $m_i(\theta_j)$

i j .

DSmT , S_1 S_2

(7) [24]:

$$\forall X \in D^\Theta,$$

$$m_{\mu^f(\Theta)}(X) \equiv m(X) = \sum_{\substack{\theta_i, \theta_j \in D^\Theta \\ \theta_i \cap \theta_j = X}} m_1(\theta_i) m_2(\theta_j) \tag{7}$$

(7) , ,

,

. PCR (Proportional conflict redistribution)[24]

,

. PCR , PCR6

. ,

, PCR6 PCR5,

:

1 DSmT

Table 1 The modeling of DSmT

	S_1	S_2	$\cdots$	S_k
θ_1	$m_1(\theta_1)$	$m_2(\theta_1)$	$\cdots$	$m_k(\theta_1)$
θ_2	$m_1(\theta_2)$	$m_2(\theta_2)$	$\cdots$	$m_k(\theta_2)$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
θ_n	$m_1(\theta_n)$	$m_2(\theta_n)$	$\cdots$	$m_k(\theta_n)$

$$\begin{cases} X=\emptyset, m_{PCR5}(X)=0 \\ \forall X\in D^{\Theta}\setminus\{\emptyset\}, m_{PCR5}(X)=m_{12}(X)+ \\ \sum\limits_{\substack{Y\in D^{\Theta}\setminus\{X\} \\ X\cap Y=\emptyset}}\left[\frac{m_1(X)^2m_2(Y)}{m_1(X)+m_2(Y)}+\frac{m_2(X)^2m_1(Y)}{m_2(X)+m_1(Y)}\right] \end{cases} \quad (8)$$

, $m_{12}(X) \equiv m_{\cap}(X)$, (7) ; (8) , , .

1.2.2 BBA 的 PNN 赋值

DSmT , . , . . , PNN Specht [25–26], . : . PNN , . , , . PNN . [13] , DSmT , PNN BBA. PNN BBA . c , k , y (DSmT), y , c .

1) , Hu .

2) , $c \le k$.

3) , y . Hu PNN , , . . , , (Learning vector quantization, LVQ) . , DSmT , . , , ; , , Bayesian BBA . :

$$m'_{ij}=\frac{m_{ij}}{\sum\limits_{j=1}^{y}m_{ij}},\quad i=1,2 \qquad (9)$$

(9) , DSmT PCR5 .

1.3 序列信息融合

, , , . , , . . . N , $S=\{s_1,s_2,\cdots,s_N\}$, , . $Q=(q_1,q_2,\cdots,q_T)$, S , t q_t. , t s_j $1,2,\cdots,t-1$. , , t q_t

$t-1$ q_{t-1} , :

$$P(q_t = s_j | q_{t-1} = s_i, q_{t-2} = s_k, \cdots) = P(q_t = s_j | q_{t-1} = s_i) \tag{10}$$

(Markov chain).

, ,
. , ,
,
. ,
[27-33]. :

1) N: . N
$S = \{s_1, s_2, \cdots, s_N\}$, t
$q_t, 1 \le t \le T$, T
, $q_t \in S$.

2) Π: , $\Pi = \{\pi_1, \pi_2, \cdots, \pi_N\}$,

$$\pi_i = P(q_1 = s_i), \quad 1 \le i \le N \tag{11}$$

π_i q_1 s_i .

3) M: .
$V = \{v_1, v_2, \cdots, v_M\}$, t
o_t, $o_t \in V$.
$O = \{o_1, o_2, \cdots, o_T\}$.

4) A: , $A = \{a_{ij}\}_{N \times N}, 1 \le i, j \le N$,

$$a_{ij} = P(q_{t+1} = s_j | q_t = s_i) \tag{12}$$

a_{ij} s_i s_j .

5) B: (
), $B = \{b_{jk}\}, 1 \le j \le N, 1 \le k \le M$,

$$b_{jk} = P(o_t = v_k | q_t = s_j) \tag{13}$$

b_{jk} t s_j v_k .
:

$$\lambda = (A, B, \Pi) \tag{14}$$

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1) :
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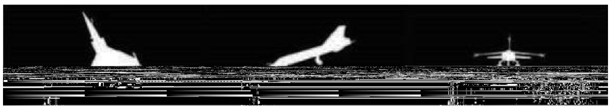


4

Fig. 4 The state of aircraft

2) : ,
,
. ,
,
. ,
, c ,
$3 \times c$.
b_{jk} s_j
$3 \times c$ v_k
.

1.2
, T ,
Hu ,
PNN
, $1 \times 3c$,
, Bayesian
. DSmT PCR5
, T
. 1.2.2 PNN
, y
, $y = 3 \times c$.
, HMM
,
.

2 算法流程

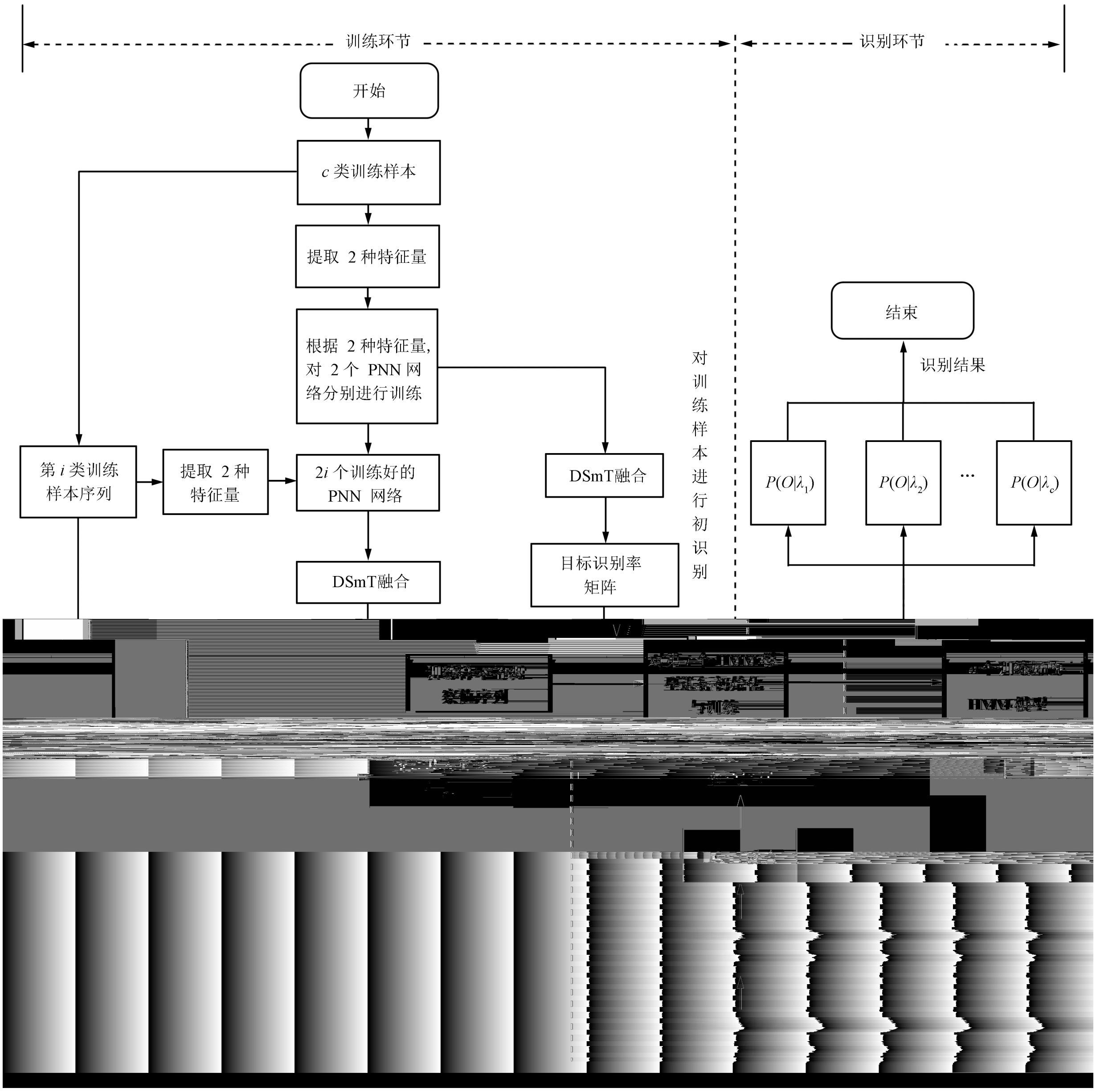
DSmT HMM

. 5 .
.
, c Hu
, PNN . ,
PNN DSmT HMM
, Baum-Welch
HMM . ,
, PNN DSmT
; ,
HMM , ,
. 5
.

2.1 HMM 模型训练

Baum-Welch HMM

HMM $\lambda = (A, B, ¦)$, , ,
HMM , Baum-Welch , , Baum-Welch
, , , $P(O|\lambda)$.
(Maximization)[34]. ,
, , :
, A B
,
. , Baum-Welch , ¦ .



5 DSmT HMM

Fig. 5 Flowchart of the target recognition of sequential aircrafts based on DSmT and HMM algorithm

1) A .

, ,

; , ; ; ½

$P(O_T|\lambda_i)$, $i = 1, \cdots c$. c HMM ( ). Bayesian , . :

$$class = \arg\max_{1 \le i \le c} \{P(O|\lambda_i)\} \quad (20)$$

3 实验结果与分析

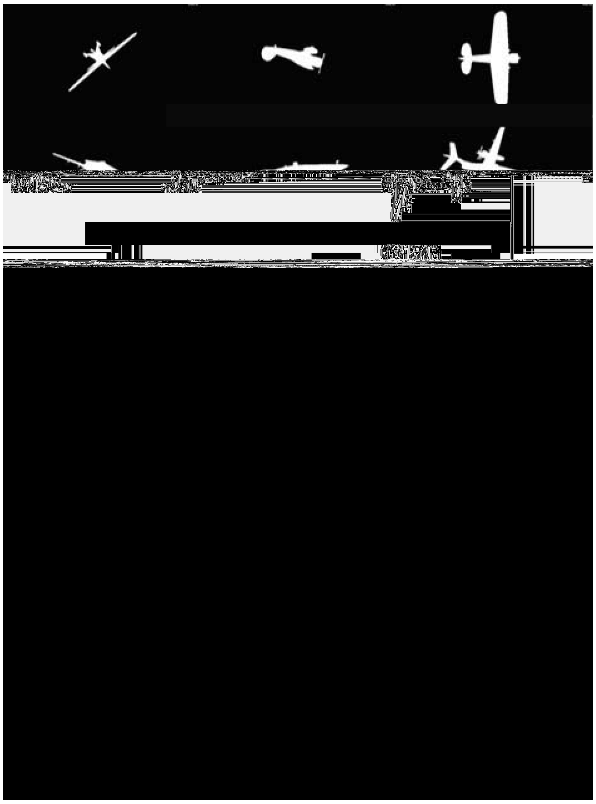
DELL OPTIPLEX380 PC Visual Studio 2008 , CPU: Pentium (R) Dual-Core E5500 @2.80 GHz 2.80 GHz, : 2 GB, : 32 Windows 7 . 7 , , 150 (1 200 × 702). , 7 , 6 . , . , 7 7 , 400 ∼ 500 . PNN 1.2.2 , y . PNN , 2 PNN , , , ( ) 0.1. , .

3.1 实验 1: 正确识别率与实时性

, , , 7 . : 7 , , , DSmT HMM , (Multiple features and sequential information fusion, MFSIF), , 7 , 93.5 % . , MFSIF . c , . ,

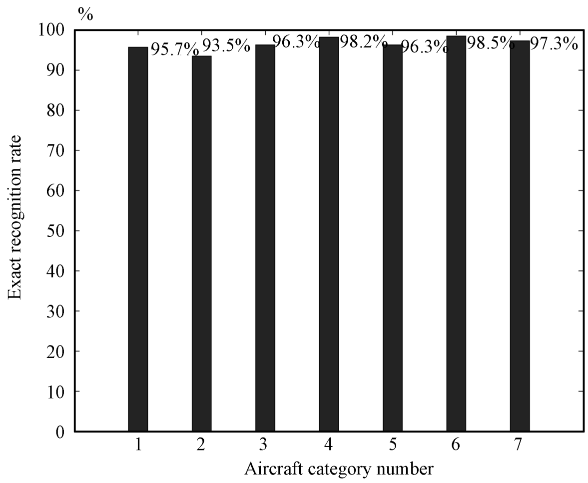
HMM O(c^2), HMM O(c^3). , MFSIF O(c^3) + O(c^2), , MFSIF O(c^3).

O(c^2).



6 7

Fig. 6 Observations of 7 classes of aircraft



7

Fig. 7 Exact recognition rate for every kind of aircraft

8 î•, ' ÓØE MFSIF ¥9Ø¯ ' L 1 ðØE (MFF1 aMFF2 aSF1 „ SF2) ÚB Ä, MYHWr qµt †®. ŒYVv L Vü, MFSIF ' Lvv 4Ú ØE¥ž ' MYq „ Zÿ Ÿ, OáÌ YVL ©k, ÿi žÄ–m^ ¥MYH W 5» 7ms - W, › †¡ @f "SMYØE¥ LHŸ1p.

3.2 L 2: • "3gMÄL

' L Ï, Þ " ' o„ ©k" ' oÐL 1 M]. ö1I ³ • "3gÉ MÄH MFSIF ØE ¥ž ' MYq. ¹ £• "ª ¤¥+˜´ ?÷ %Á¥í•}•, ƒ Ú×ß3gÉ m ¥| ´‹ ¾ {l¿• "3gÉ w. 6BZë, • "3gÉ ‹ û BçS¶=, y¹ ÂT• "3gÉ Vv, î4|¥ s´_ 5ö C" ¥, ´, •Á +˜ µr´, , í EW%¹ í•}• ' É. 7 • "3gVl, 5º ?í•%«+˜, 7 }•¥ œ8+˜ í•, . »y¹, }• † s´¥+ ˜´ Bî 6»[ªö áÎš h. î[, ' L Ï, • "3gÉ KlÊ 4¹ 6. V2ó ,]• "3 gÉ Ð×ß3gÉ 1´/ MFSIF ¥ž ' MY q.

L ²Ts : YVV2V[?C, ' • "3g v¿14 H, ž ' MYqÛ" • "3g¥9F)¿ /Á¥t]. ' • "3g9Fž 18 H÷FüA. î [, ' • "3g !çS¶6» 14 = H, ' ×ß3 g@ v¥f ƒ/, MFSIF ØE¥ž ' MYq, ù Ë¿• "3g¥MÄ.

3.3 L 3: j êbL

' L Ï, I ³ Û" "SêlH, MFSIF ØE^Ž?ž ' µr¥ "SÉ›MY, ' I ³ MFSIF ØE "SêlH¥ZÿŸ. Þ " ' oÐL 1 M], ©ko^ ðŸ©ko ¥ $, SBç1èêb, sYêl ÀðŸ 1/2 a1/4 a1/8 a1/16 a1/32 a1/64. I ³ NH" S¥ž ' MYq. MY² TÂm8î U.

L ²Ts : ®m8V[A , ' f "S ?3êbH, þËÏ ÄBË¥MYž ' qû Bç ¥– =?3l S¶œî, ' P"Sêl žðŸ¥ 1/8, 9V[£90%P·¥ž ' MYq, Vn " S Bçñ êlH, ' ZE9V[£"z¥ ZÿŸ. Œ' "Sêl žðS j¥1/16 H, ØE ¥ž ' MYq?3 1 üA¥/Á. 7 ' "SÉ B„êl ž 1/32 a1/64 H, K®MYqsY/† À36.70% „ 19.20%, NHØE ' >r.

3.4 L 4: "S¿ML

É›f MYH, î³1MY¥"SV? öy¹ HW¥ wMað"S$`î©", yÍ 7? 3¿M, ' Ó4 MFSIF ØE" ¿+˜• ¥µ†-", Î ¿½ • ¥µ†É›"SMY, î[1 £' î MY"S?3¿MH, ^Žy¹ V¿G ¿½ • 7•ÁvS¶¥MYp . ' L ¥Þ " ' oÐL 1 M], ©k" ' o•¨ ñ©k" ' ½ . ©k" ' ½ A ^®2ñË Yf Fî¥ †ËY¥©k" ' ½ . ©k" ' ½ A ®857 f mËFî. ÏËY1¥ f mËFî - 475 m, ËY2f mËFîª 382 . ©k" ' ½ B ^®3Ëf Fî¥ Ë ËY©k" ' ½ . ©k" ' ½ B ©k" ' ½ A¥ $ @F BËf Fî¥•¥©k" ' ½ , ' ®1340 mËFî, - 475 ®ËY1 ¥f mËFî, Ï W¥ 382 mË®ËY2¥f mËFî, ª 487 mË®ËY3¥f mËF î. d9ƒ ñ©k" ' " †Nka NàËË îÆ7•Ñ>9TJF1 10.5

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Fig. 8 Exact recognition rate when images zoom out

3 A (%)

Table 3 The exact recognition rate of test sample sequence A and the composite type (%)

	1	2	
	98.5	96.3	97.3

4 B (%)

Table 4 The exact recognition rate of test sample sequence B and the composite type (%)

	1	2	3	
	98.5	96.3	96.3	96.8

: 3 4 , A, MFSIF 97.3 %. 98.5 % 96.3 %. A 97.5 %. B, MFSIF 96.8 %.

98.5 % 96.3 % 96.3 %. B 97.1 %. A B . MFSIF , , .

3.5 实验 5: 与基于多特征融合算法对比试验

, MFSIF , MFSIF Hu (Normalized moment of inertia, NMI) , PNN DSmT [13] (1-MFF1) Hu NMI , BP DST [12] (2-MFF2) . MFF1 PNN , , , . MFF2 BP 3 , S , 1 000 , Levenberg-Marquardt , 0.05, $nodes = \sqrt{ts} + d, 1 \le d \le 10$, t , s . 1 , 9 .

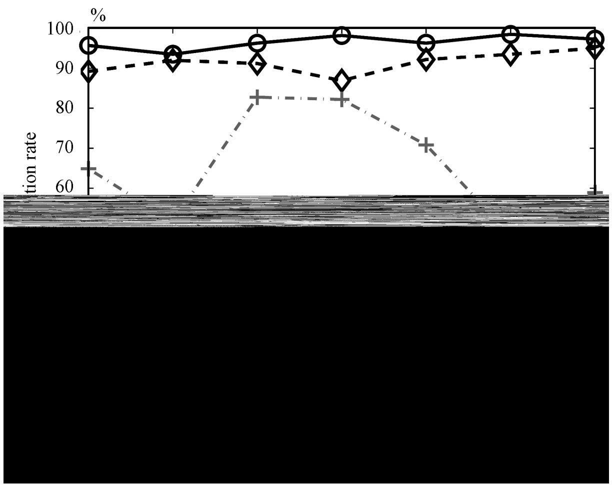

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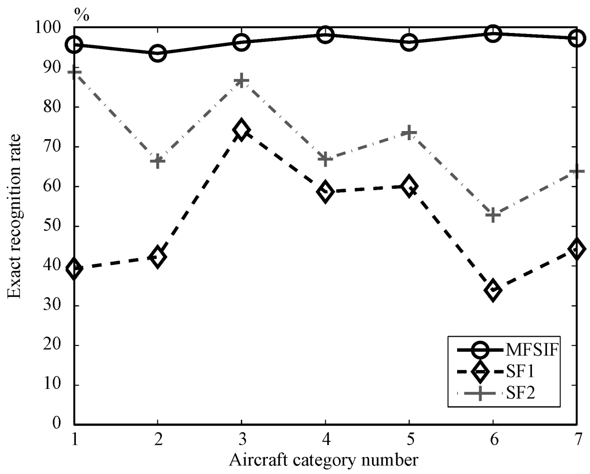
Fig. 9 Comparison of exact recognition rate with multiple features fusion algorithms

: , , , . , MFSIF , , , 93.5 %, MFF1 MFF2 , , 9

, MFSIF , 7
, . BP
, ,
, BP MFF2
7 , 48.3 %, 82.75 %,
60 % .

3.6 实验 6: 与基于单一特征的序列融合算法对比试验

, MFSIF
, MFSIF
Hu , BP DST
[14] (1-SF1) Hu ,
PNN DSmT (
2-SF2) , BP
3 BP .
1 ,
10 .



10
Fig. 10 Comparison of exact recognition rate with sequential fusion algorithms

: ,
,
. MFSIF
, ,
SF1 SF2 ,
.

3.7 实验 7: 遮挡实验

,
,
,
. , L_s = 475

, ,
, L_w = 7 .
(Monte-Carlo simulation) ,
τ • 6 ,
N = 500 ,
.
( ) 11 ,
$\tau(\tau$ • 6) .
, N
T_w ,
T_o T_n,
T_a,
( ) AR_o
AR_n. :

$$T_w = T_o + T_n \tag{21}$$

$$T_a = \frac{T_w}{N} \tag{22}$$

$$AR_o = 1 - \frac{L_w + T_a}{L_s} \tag{23}$$

$$AR_n = 1 - \frac{T_a}{(L_s - L_w)} \tag{24}$$

5 , 1 » 6 ,
, , MF-SIF , 6
, AR_o = 98.13 %
AR_n = 99.60 %,
.

4 结束语

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, DSmT HMM
MFSIF . ,
MFSIF
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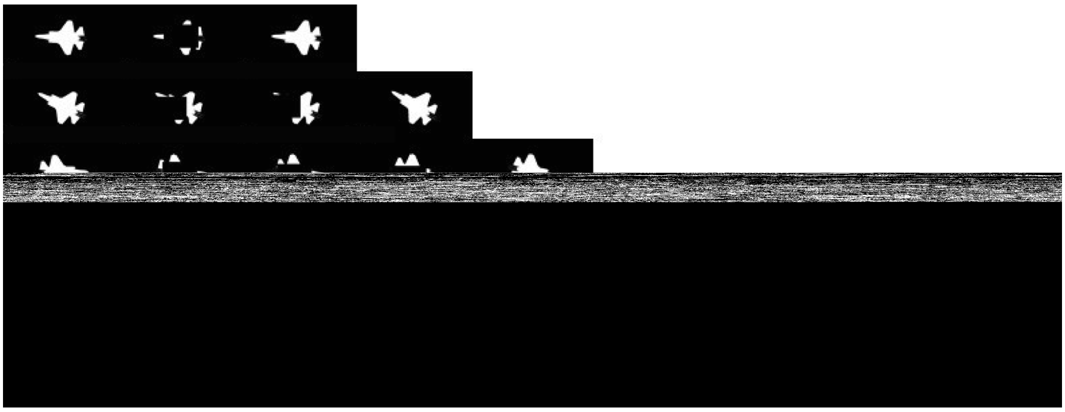

11

Fig. 11 Partial occlusion of aircrafts

5

Table 5 Test results under different occulted conditions

	T_o	T_n	T_w	T_a	AR_o	AR_n
1	0	0	0	0	98.53 %	100 %
2	84	9	93	0.186	98.49 %	99.96 %
3	248	24	272	0.544	98.41 %	99.88 %
4	383	48	431	0.862	98.34 %	99.82 %
5	593	74	667	1.334	98.25 %	99.71 %
6	819	127	946	1.892	98.13 %	99.60 %

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李新德 .
, ,
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. .
E-mail: xindeli@seu.edu.cn
(**LI Xin-De** Associate professor at the School of Automation, Southeast University. His research interest covers intelligent robot, human-robot interaction, robot perception, information fusion, reasoning under uncertainty, and machine vision. Corresponding author of this paper.)

潘锦东 .
2014 .
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E-mail: panjindong1989@163.com
(**PAN Jin-Dong** Master student at the School of Automation, Southeast University. He received his master degree from Southeast University in 2014. His research interest covers information fusion and image processing.)

DEZERT Jean
. ,
,
. E-mail: jdezert@gmail.com
(**DEZERT Jean** Senior scientist in ONERA (The French Aerospace Lab). His research interest covers information fusion, reasoning under uncertainty, auto navigation, multi-sensor and multi-object tracking.)