SCTransNet: Spatial-Channel Cross Transformer Network for Infrared Small Target Detection

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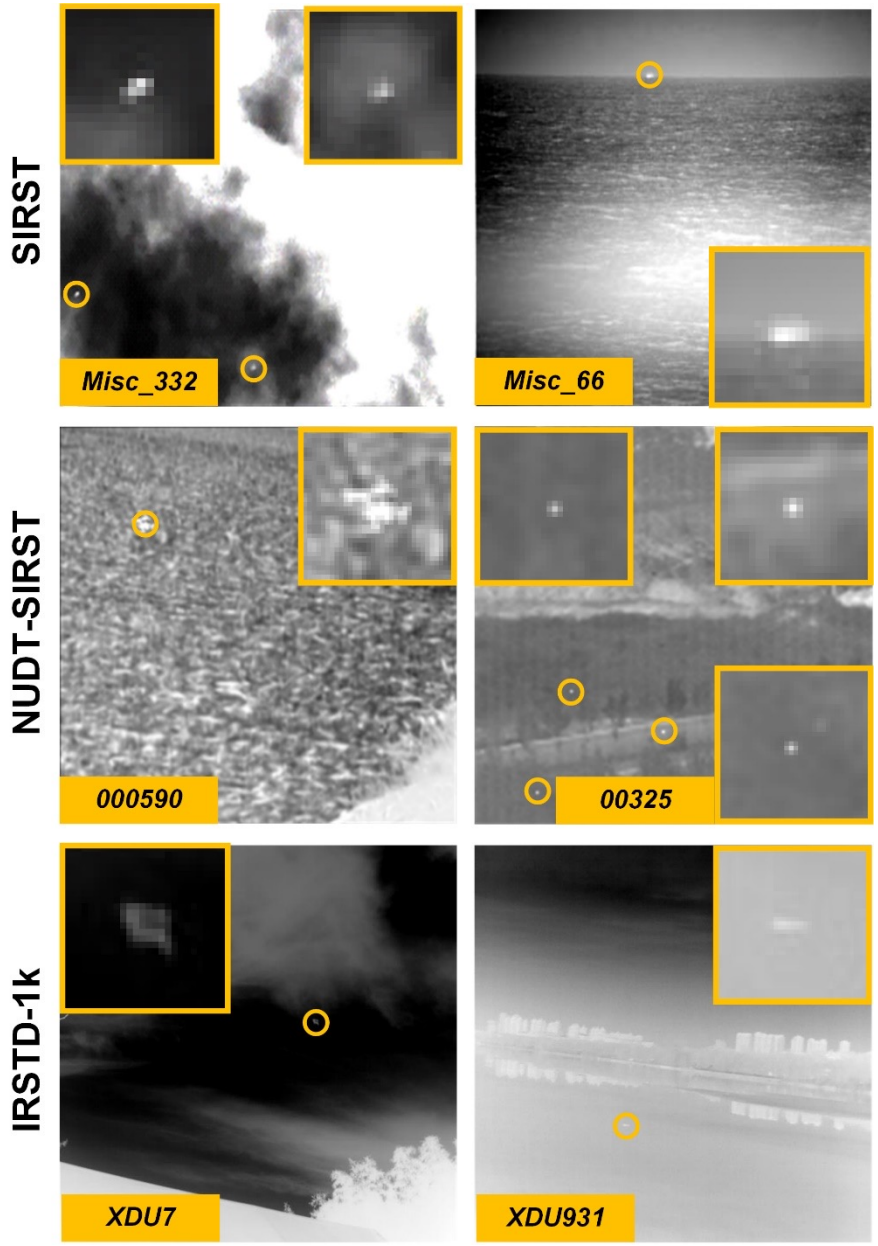
Infrared Small Target Detection (IRSTD)



1) Dim

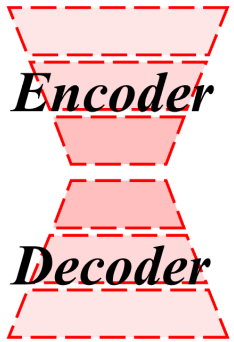
2) Small

3) Characterless

4) Uncertain shapes

Segmentation

Input:



1) Encoders

2) Decoders

3) Skip connection

4) Feature fusion

Label:

Challenges

① *Semantic interaction across full levels*

② *Information gap between encoders and decoders*

③ *Long-range contextual perception of targets and backgrounds in deeper layers*

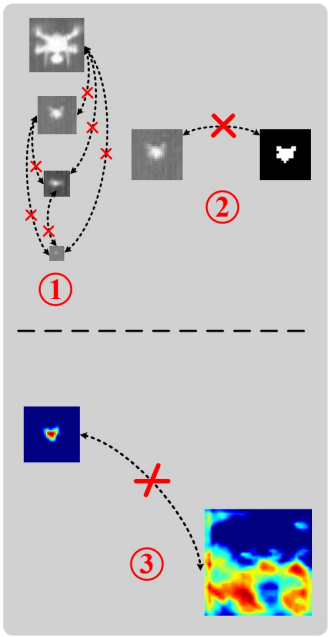
U-Net:

1) Encoders

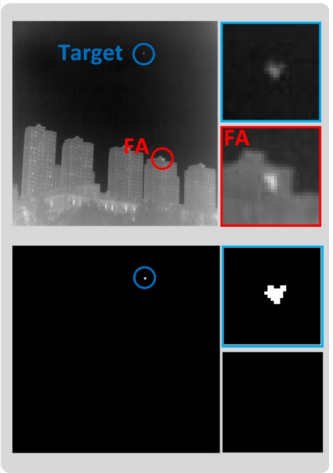
2) Decoders

3) Skip connection

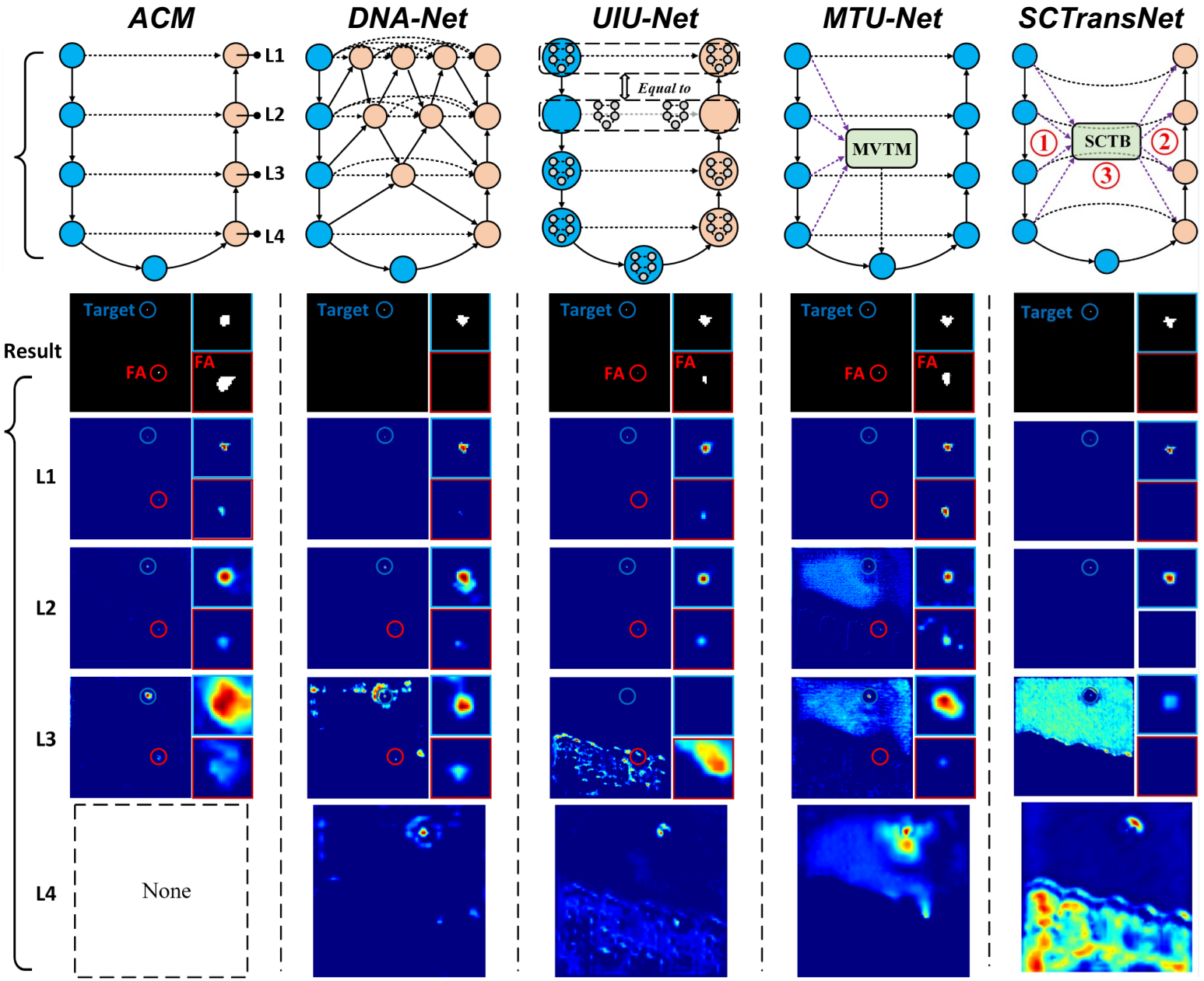
4) Feature fusion



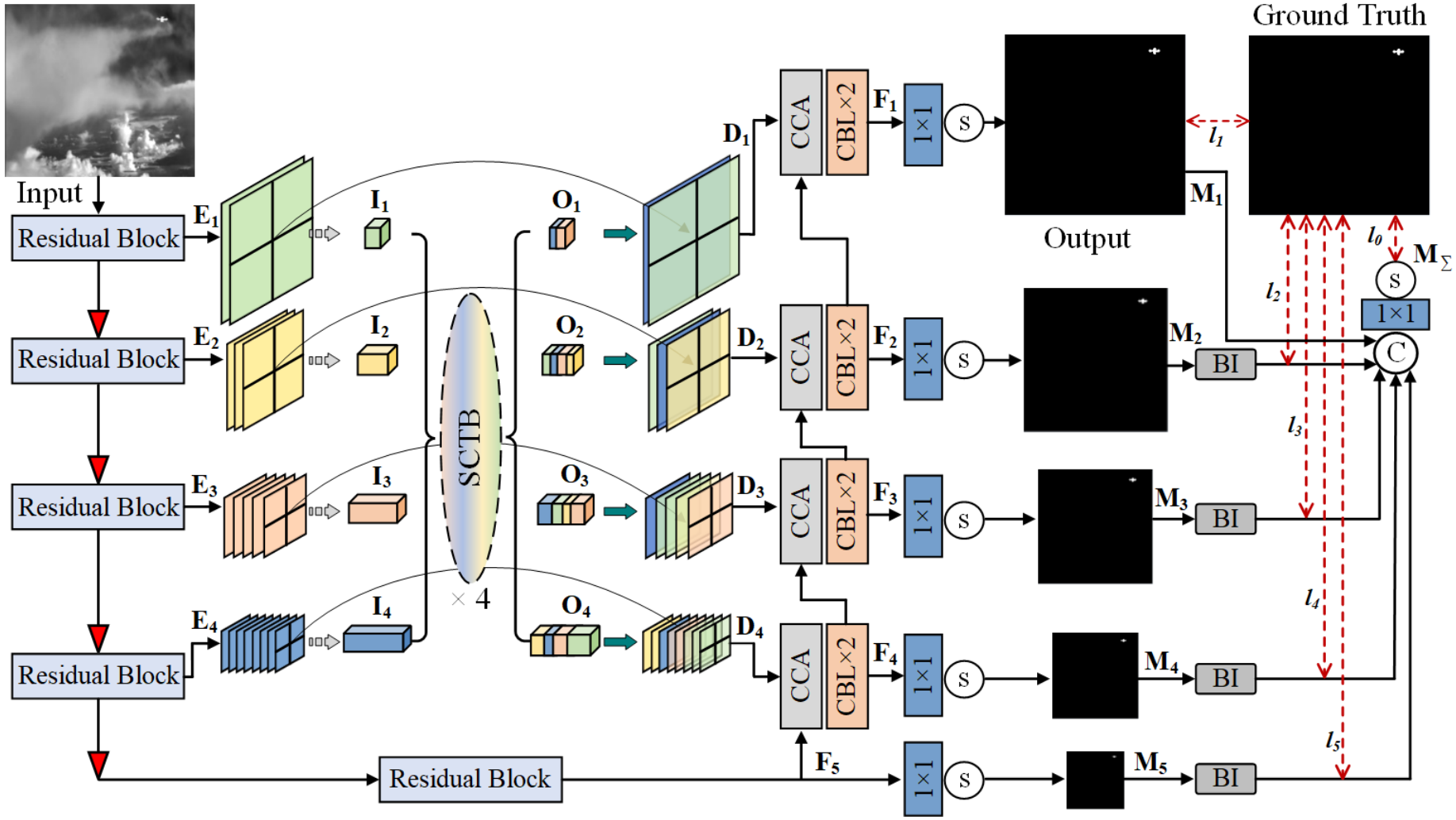
Three challenges



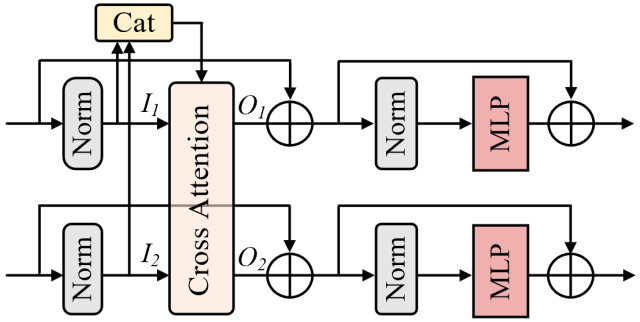
(b) Input image and GT



Framework


Input
Residual Block
Residual Block
Residual Block
Residual Block
Residual Block
SCTB
× 4
CCA
CBL×2
1×1
S
BI
C
Ground Truth
Output
Sigmoid Activation
Bilinear Interpolation
Channel Concatenate
Convolution 1×1
Maxpooling
Patch Embedding
Feature Mapping
Channel-wise Cross Attention
Convolution + Batch Normalization + LeakyReLU
Spatial-embedded Channel-cross Transformer Block

Spatial-channel Cross Transformer Block (SCTB)



Inspirations:

SSCA: 1) ***Local spatial embedding***

2) ***Multi-head Cross Attention***

CFN: 3) ***Mixed modelling of spatial and channels***

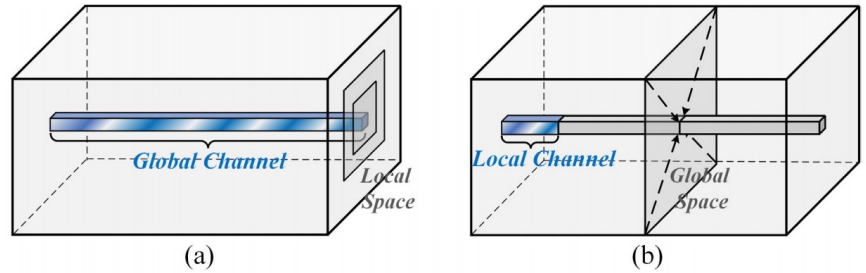
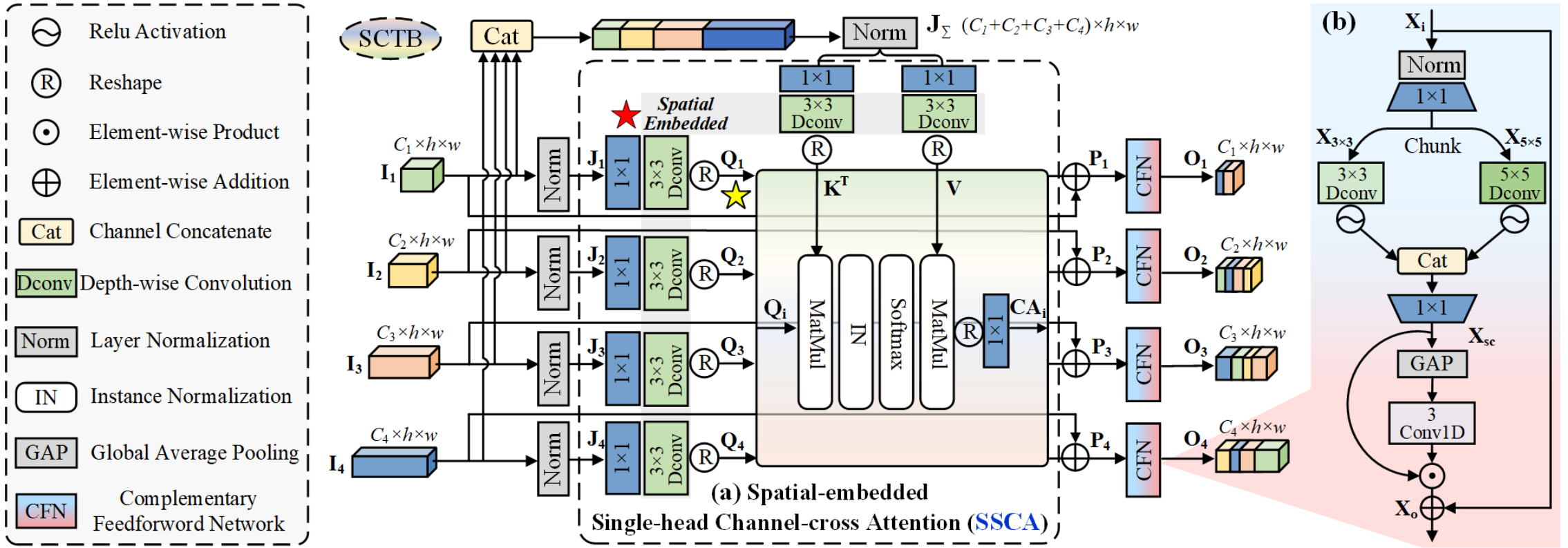


Fig. 4. Information enhancement from different perspectives. (a) LSGC paradigms. (b) GSLC paradigms. Our CFN integrates both of these information enhancement methods internally.



Quantitative Results

TABLE I

COMPARISONS WITH SOTA METHODS ON NUAA-SIRST, NUDT-SIRST AND IRSTD-1K IN $IoU(\%)$, $nIoU(\%)$, $F\text{-}Measure(\%)$, $Pd(\%)$, $Fa(10^{-6})$

Method	NUAA-SIRST [14]					NUDT-SIRST [15]					IRSTD-1K [40]				
	mIoU	nIoU	F-measure	Pd	Fa	mIoU	nIoU	F-measure	Pd	Fa	mIoU	nIoU	F-measure	Pd	Fa
Top-Hat [5]	7.143	18.27	14.63	79.84	1012	20.72	28.98	33.52	78.41	166.7	10.06	7.438	16.02	75.11	1432
Max-Median [54]	4.172	12.31	10.67	69.20	55.33	4.197	3.674	7.635	58.41	36.89	6.998	3.051	8.152	65.21	59.73
WSLCM [55]	1.158	6.835	4.812	77.95	5446	2.283	3.865	5.987	56.82	1309	3.452	0.678	2.125	72.44	6619
TLLCM [56]	1.029	4.099	4.995	79.09	5899	2.176	4.315	7.225	62.01	1608	3.311	0.784	2.186	77.39	6738
IPI [9]	25.67	50.17	43.65	84.63	16.67	17.76	15.42	26.94	74.49	41.23	27.92	20.46	35.68	81.37	16.18
PSTNN [57]	30.30	33.67	39.16	72.80	48.99	14.85	23.57	35.63	66.13	44.17	24.57	17.93	37.18	71.99	35.26
MSLSTIPT [1]	10.30	15.93	18.83	82.13	1131	8.342	10.06	18.26	47.40	888.1	11.43	5.932	12.23	79.03	1524
ACM [14]	68.93	69.18	80.87	91.63	15.23	61.12	64.40	75.87	93.12	55.22	59.23	57.03	74.38	93.27	65.28
ALCNet [18]	70.83	71.05	82.92	94.30	36.15	64.74	67.20	78.59	94.18	34.61	60.60	57.14	75.47	92.98	58.80
RDIAN [39]	68.72	75.39	81.46	93.54	43.29	76.28	79.14	86.54	95.77	34.56	56.45	59.72	72.14	88.55	26.63
ISTDU [22]	75.52	79.73	86.06	96.58	14.54	89.55	90.48	94.49	97.67	13.44	66.36	63.86	79.58	93.60	53.10
MTU-Net [17]	74.78	78.27	85.37	93.54	22.36	74.85	77.54	84.47	93.97	46.95	66.11	63.24	79.26	93.27	36.80
IAANet [58]	74.22	75.58	85.02	93.53	22.70	90.22	92.04	94.88	97.26	8.32	66.25	65.77	78.34	93.15	14.20
AGPCNet [19]	75.69	76.60	85.26	96.48	14.99	88.87	90.64	93.88	97.20	10.02	66.29	65.23	79.58	92.83	13.12
DNA-Net [15]	75.80	79.20	86.24	95.82	**8.78**	88.19	88.58	93.73	**98.83**	9.00	65.90	66.38	79.44	90.91	12.24
UIU-Net [16]	76.91	79.99	86.95	95.82	14.13	93.48	93.89	96.63	98.31	7.79	66.15	66.66	79.63	**93.98**	22.07
SCTransNet	**77.50**	**81.08**	**87.32**	**96.95**	13.92	**94.09**	**94.38**	**96.95**	98.62	**4.29**	**68.03**	**68.15**	**80.96**	93.27	**10.74**

ROC

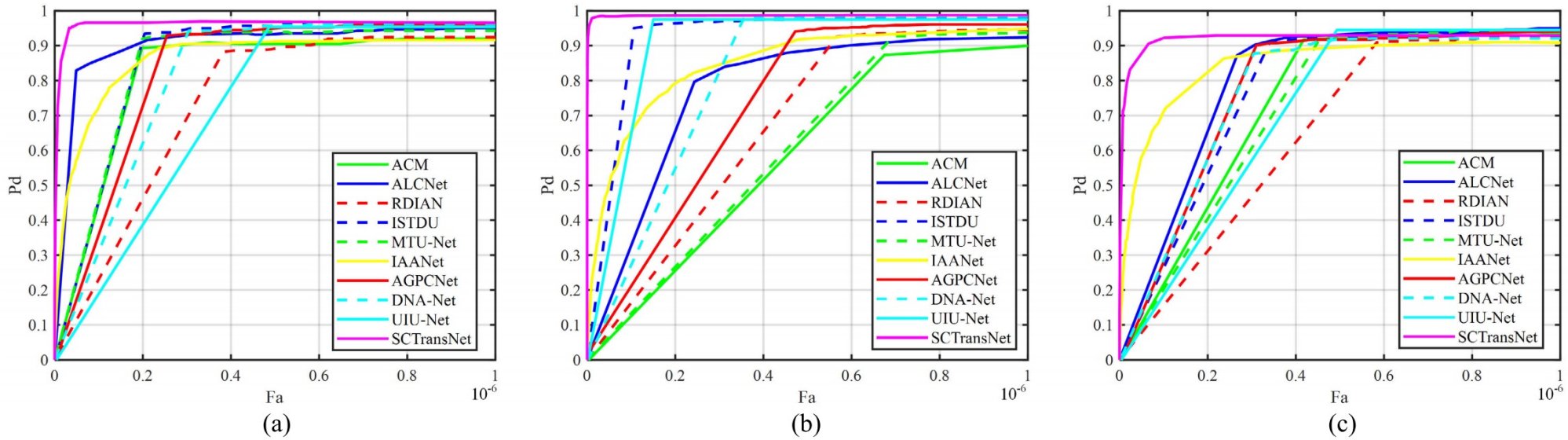


Fig. 5. ROC curves of different methods on the NUAA-SIRST, NUDT-SIRST, and IRSTD-1K dataset. Our SCTransNet can achieve the highest P_d at very low F_a. (a) NUAA-SIRST. (b) NUST-SIRST. (c) IRSTD-1K.

TABLE III

AUC WITH DIFFERENT THRESHOLDS OF THE SOTA METHODS ON THE NUAA-SIRST, NUDT-SIRST, AND IRSTD-1K DATASETS

Dataset	Index	ACM	ALCNet	RDIAN	ISTDU	MTU-Net	IAANet	AGPCNet	DNA-Net	UIU-Net	SCTransNet
NUAA-SIRST [14]	$AUC_{F_a=0.5}$	0.7223	<u>0.8618</u>	0.5461	0.7515	0.7457	0.8081	0.6953	0.6582	0.4854	**0.9539**
	$AUC_{F_a=1}$	0.8180	<u>0.9025</u>	0.7321	0.8579	0.8437	0.8614	0.8262	0.8098	0.7197	**0.9589**
NUDT-SIRST [15]	$AUC_{F_a=0.5}$	0.4392	0.6321	0.4630	<u>0.8635</u>	0.4640	0.7569	0.5038	0.6300	0.8275	**0.9853**
	$AUC_{F_a=1}$	0.5865	0.7716	0.6695	<u>0.9211</u>	0.6064	0.8463	0.7306	0.8072	0.9013	**0.9863**
IRSTD-1K [40]	$AUC_{F_a=0.5}$	0.5374	0.6606	0.4545	0.6014	0.5018	<u>0.7862</u>	0.6211	0.6162	0.4749	**0.9107**
	$AUC_{F_a=1}$	0.7366	0.8006	0.6480	0.7687	0.7198	<u>0.8456</u>	0.7752	0.7684	0.7099	**0.9200**

Ablation

Baselines Analysis

TABLE IV

BASED ON U-NET, ABLATION STUDY OF THE RBS, DEEP SUPERVISION (DS), SSCA, CFN, AND CCA MODULE IN AVERAGE *IoU*(%), *nIoU*(%), AND *F-Measure*(%) ON NUAA-SIRST, NUDT-SIRST, AND IRSTD-1K

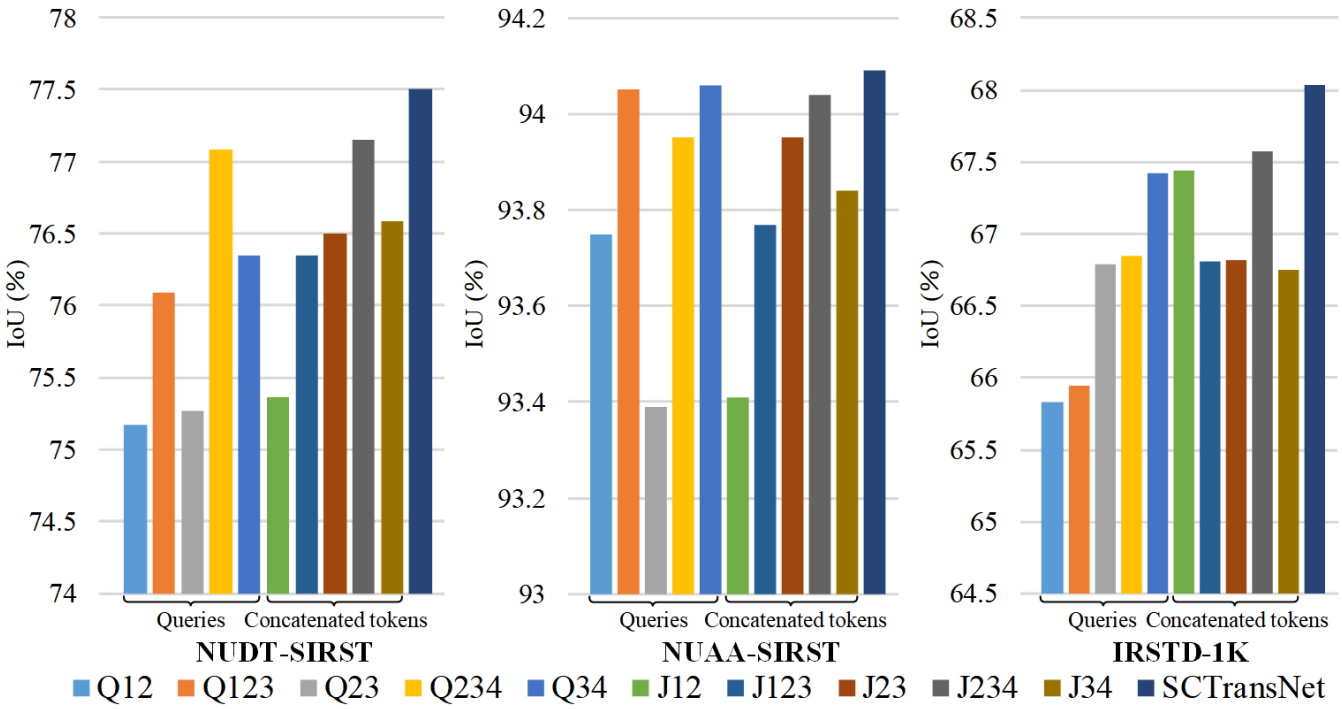
U-Net	+RBs	+DS	+SSCA	+CFN	+CCA	IoU	nIoU	F-measure
✓	✗	✗	✗	✗	✗	75.29	78.60	86.36
✓	✓	✗	✗	✗	✗	77.07	80.13	87.05
✓	✓	✓	✗	✗	✗	77.73	80.78	87.47
✓	✓	✓	✓	✗	✗	82.39	85.71	90.34
✓	✓	✓	✓	✓	✗	82.89	86.28	90.66
✓	✓	✓	✓	✓	✓	83.43	86.86	90.96

TABLE V

BASED ON UCTRANSNET, ABLATION STUDY OF THE RBS, DS, SKS AND SCTB, REPORTING AVERAGE *IoU*(%), *nIoU*(%), AND *F-Measure*(%) ON NUAA-SIRST, NUDT-SIRST, AND IRSTD-1K. NOTE THAT, WE REPLACE THE CCT IN UCTRANSNET USING THE PROPOSED SCTB

UCTransNet	+RBs	+DS	+SKs	SCTB r/ CCT	IoU	nIoU	F-measure
✓	✗	✗	✗	✗	78.78	81.56	87.80
✓	✓	✗	✗	✗	79.95	82.97	88.45
✓	✓	✓	✗	✗	81.47	83.89	88.92
✓	✓	✓	✓	✗	82.03	84.98	89.54
✓	✓	✓	✓	✓	83.43	86.86	90.66

Full Level Feature Interaction



Ablation

TABLE VI

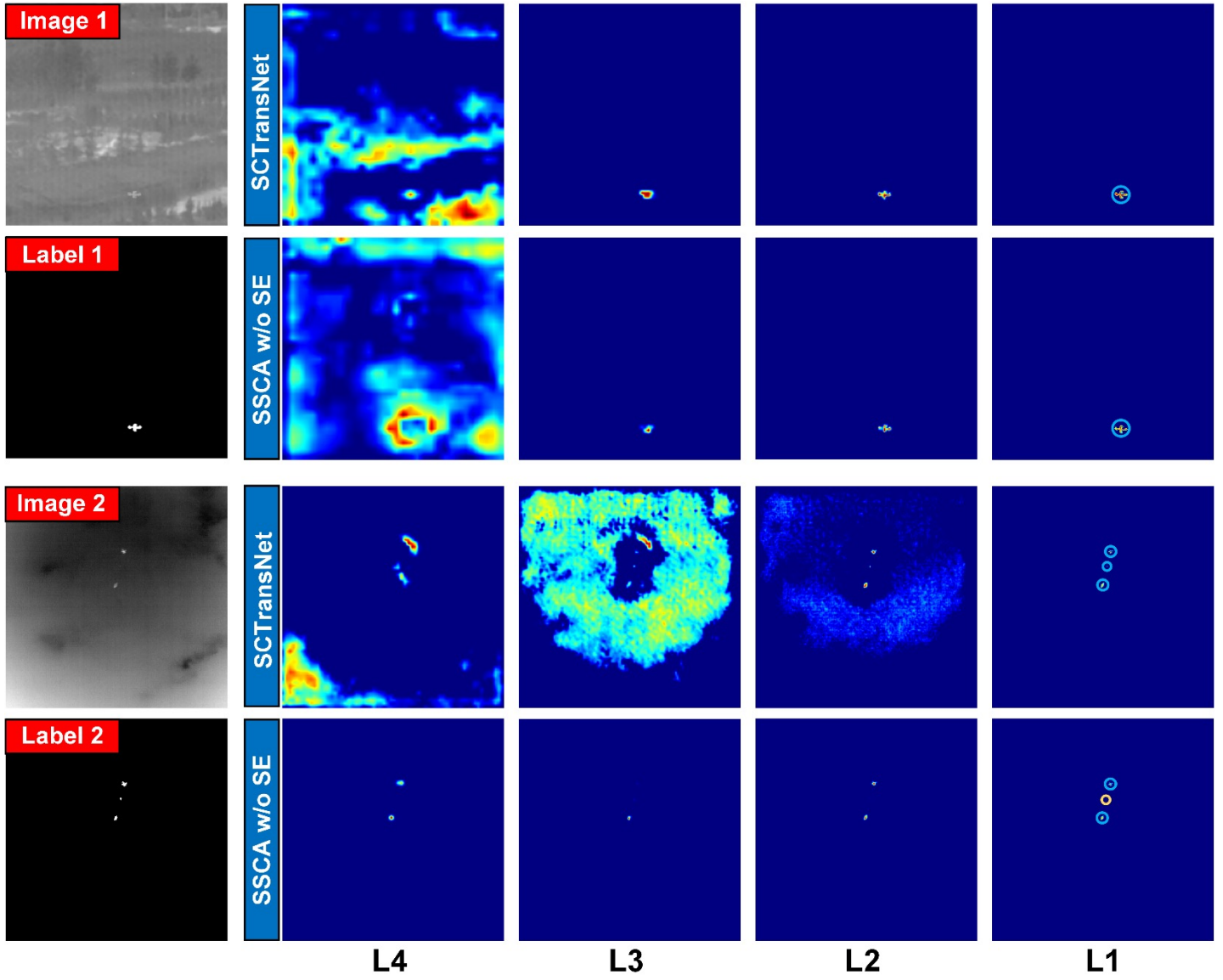
IoU(%)/nIoU(%)/F-Measure(%) Values Achieved by Variants of SSCA and MCA on NUAA-SIRST, NUDT-SIRST, and IRSTD-1K

Model	Dataset		
	NUAA-SIRST	NUDT-SIRST	IRSTD-1K
MCA [27]	74.72/78.35/85.53	93.07/93.61/96.41	65.60/66.57/79.22
SSCA w PE	77.10/79.88/87.07	94.03/94.25/96.93	66.01/65.29/79.52
SSCA w MH	76.35/79.56/86.59	93.72/94.13/96.76	67.08/67.55/80.30
SSCA w/o SE	76.40/79.19/86.62	93.23/93.49/96.50	66.10/65.48/79.59
SSCA	**77.50/81.08/87.32**	**94.09/94.38/96.95**	**68.03/68.15/80.96**

SSCA w PE: Incorporate positional encoding during the patch embedding stage.

SSCA w MH: Use a typical multi-head cross-attention mechanism to replace the single-head cross attention mechanism in SSCA.

SSCA w/o SE: To validate the effectiveness of local spatial information coding, we eliminate the depth-wise convolution in the QKV matrix generation process in SCTB.



Ablation

TABLE VII

IoU(%)/nIoU(%) Values Achieved by the Representative FFNs and the Variants of CFN on NUAA-SIRST and NUDT-SIRST

Model	Params(M)	Flops(G)	Dataset	
			NUAA-SIRST	NUDT-SIRST
FFN [41]	**11.0292**	**20.1474**	76.87/80.08	93.58/93.85
LeFF [32]	11.1312	20.1944	76.49/80.21	93.92/94.07
GDFN [30]	10.1841	19.7210	75.48/79.32	93.40/93.64
MSFN [31]	11.7107	20.5026	77.35/79.89	93.88/94.24
CFN w/o GSLC	11.1905	20.2362	76.54/80.56	93.95/94.18
CFN	11.1905	20.2372	**77.50/81.08**	**94.09/94.38**

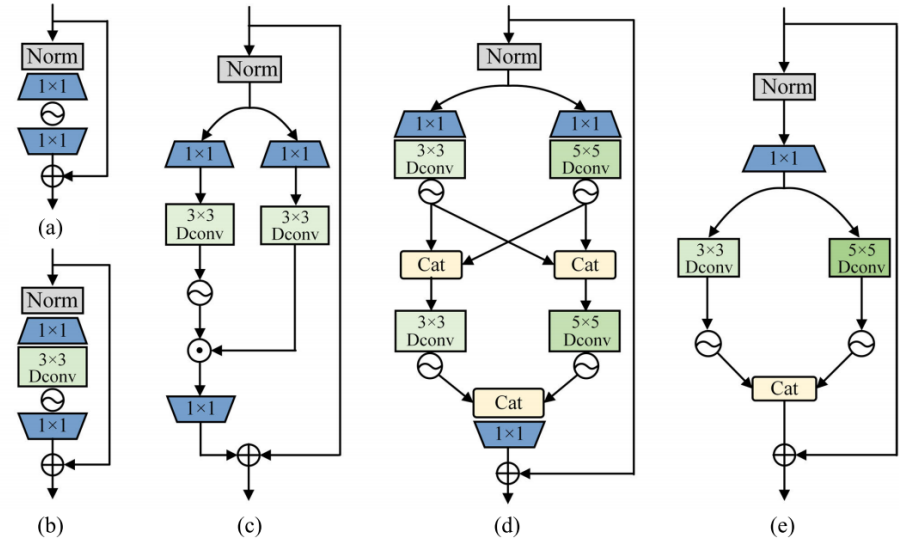
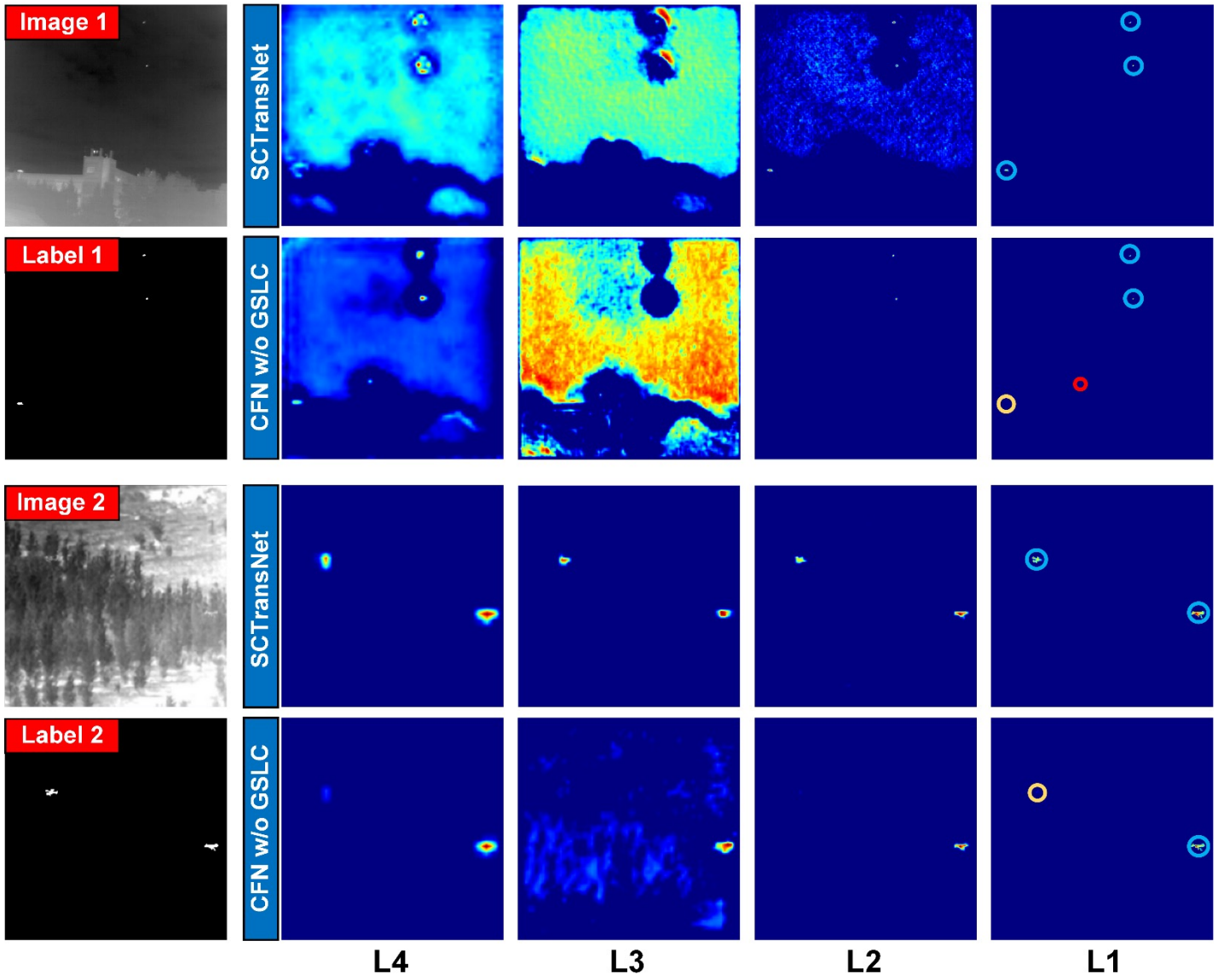


Fig. 10. Structure of representative FFNs and CFN w/o GSLC. (a) FFN. (b) LeFF. (c) GDFN. (d) MSFN. (e) CFN w/o GSLC.

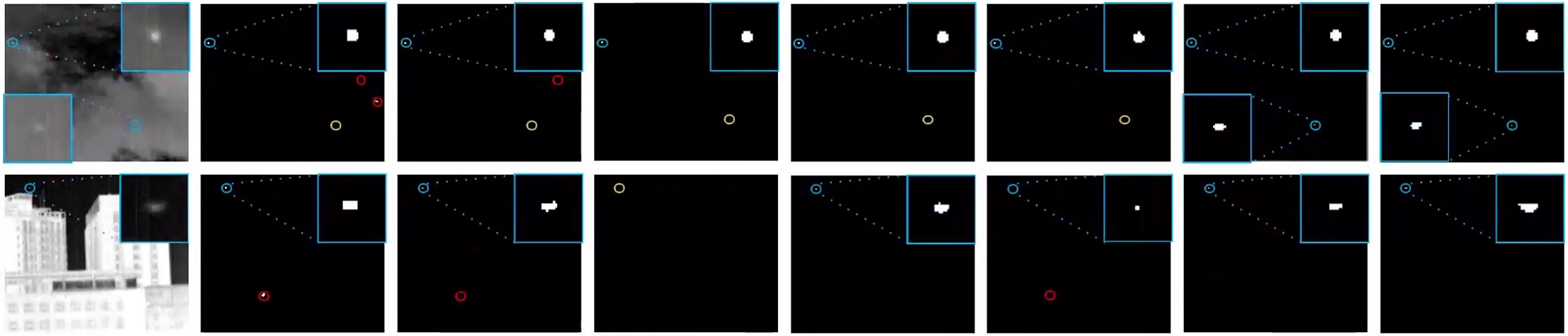


Ablation

TABLE VIII

IoU(%)/nIoU(%) Values Achieved by the Different Cross-Layer Feature Fusing Modules on NUAA-SIRST and NUDT-SIRST

Dataset								
✗	✗	✗	✗	82.29	85.77	90.26	20.0212	11.1462
✓	✗	✗	✗	82.33	85.89	90.31	20.0967	11.1484
✓	✓	✗	✗	82.49	86.11	90.40	20.1680	11.1569
✓	✓	✓	✗	82.95	86.27	90.68	20.2372	11.1905
✓	✓	✓	✓	83.43	86.86	90.96	20.2372	11.1905



(a) Stripy (b) ACM (c) RDIAN (d) DNA-Net (e) UIU-Net (f) MTU-Net (g) SCTransNet (h) GT

TABLE X

Hyperparameter Study of the Number of SCTBs, the Channel Expansion Factor of CFN, and the Basic Width of the Model in Average IoU(%), nIoU(%), *F*-Measure(%) on NUAA-SIRST, NUDT-SIRST, and IRSTD-1K

Hyper-param	IoU	nIoU	F-measure	Params(M)	Flops(G)
η = 3.00	83.24	86.69	90.84	20.4938	11.6917
η = 3.99	83.10	86.60	90.77	21.2306	13.1307
The basic width of the model					
W = 8	77.52	80.55	87.33	1.3321	0.7468
W = 16	81.02	84.50	89.51	5.1488	2.8609
W = 32	83.43	86.86	90.96	20.2372	11.1905
W = 48	82.95	86.48	90.60	45.2687	24.994

Summary

SCTransNet: Spatial-Channel Cross Transformer Network for Infrared Small Target Detection

Thanks

Project code is available at:
https://github.com/xdFai/SCTransNet

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