

An Infrared Small Target Detection System for UAVs

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A target is located within the red box.

- Unmanned Aerial Vehicle (UAV)-mounted infrared (IR) target detection system.
- Detect a missing victim's *heat signature*.
- Assist search & rescue missions.
- Reduce human errors.

INFRARED SMALL TARGET DETECTION

- Model-driven methods.
- Learning from data:
 - Convolutional Neural Networks.
 - Feature Pyramid Networks.
- Reduce downsampling [4].
- Low-rank & sparse matrix decomposition.
- Infrared Patch-Image (IPI) model [3].
- $\mathbf{D} = \mathbf{L} + \mathbf{S} + \mathbf{N}$.

The following problem needs to be solved [3]:

$$\min_{\mathbf{L}, \mathbf{S}} \left(\|\mathbf{L}\|_* + \lambda \|\mathbf{S}\|_1 + \frac{1}{2\mu} \|\mathbf{D} - \mathbf{L} - \mathbf{S}\|_F^2 \right).$$

DATASET

- Single-Frame IR Small Target (SIRST) dataset [1], [2].
 - ~ 400 SWIR & MWIR images.
 - No negative samples.
- Dataset after augmentation:
 - ~ 1100 images containing 1300 targets.
 - 210 negative samples.

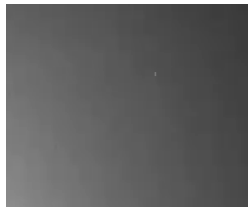
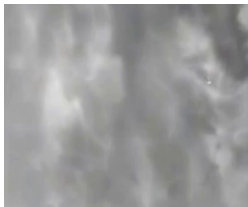


Image source [1]

- Residual Neural Network (ResNet)
 - Speed vs. accuracy.
 - ResNet with 50 layers.
 - Modified ResNet.
- CenterNet
 - Keypoint-based object detector.
 - Peaks in keypoint heatmap.
- Training the Data-driven Method
 - Trained from scratch.
 - Training loss.

MODEL-DRIVEN APPROACH

RPCA-PCP solved via the Inexact augmented Lagrangian method (IALM)

Require: Patch-image matrix $\mathbf{D} \in \mathbb{R}^{m \times n}$, $\lambda = 1/\sqrt{\max(m, n)}$.

1: $\mathbf{Y}_0 = \frac{\mathbf{D}}{J(\mathbf{D})}$; $\mathbf{S}_0 = 0$; $\mu_0 = \frac{1.25}{\|\mathbf{D}\|_2}$; $\bar{\mu} = 10^7$; $\rho = 1.6$;

2: **while** not converged **do**

3: $(\mathbf{U}, \Sigma, \mathbf{V}) = \text{svd}(\mathbf{D} - \mathbf{S}_k + \mu_k^{-1} \mathbf{Y}_k)$.

▷ svd is singular value decomposition

4: $\mathbf{L}_{k+1} = \mathbf{U} \mathcal{J}_{\mu_k^{-1}}[\Sigma] \mathbf{V}^*$.

5: $\mathbf{S}_{k+1} = \mathcal{J}_{\lambda \mu_k^{-1}}[\mathbf{D} - \mathbf{L}_{k+1} + \mu_k^{-1} \mathbf{Y}_k]$.

6: $\mathbf{Y}_{k+1} = \mathbf{Y}_k + \mu_k (\mathbf{D} - \mathbf{L}_{k+1} - \mathbf{S}_{k+1})$.

7: Update μ_k to μ_{k+1} .

▷ $\mu_{k+1} = \min(\rho \mu_k, \bar{\mu})$

8: $k \leftarrow k + 1$.

9: **end while**

10: **return** \mathbf{S}_k .

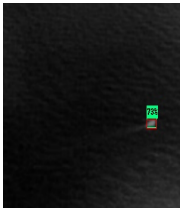
▷ Returning sparse matrix

Where $J(\mathbf{D}) = \max(\|\mathbf{D}\|_2, \lambda^{-1} \|\mathbf{D}\|_\infty)$, and

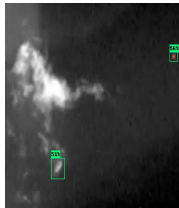
$$\mathcal{J}_\epsilon[x] \doteq \begin{cases} x - \epsilon, & \text{if } x > \epsilon, \\ x + \epsilon, & \text{if } x < -\epsilon, \\ 0, & \text{otherwise.} \end{cases}$$

TESTING

- Evaluation metrics
 - Matthews Correlation Coefficient (MCC).
 - F_{β} , precision, recall.
- Model-driven approach: patch size, stride, tolerance.
- Data-driven Approach: score threshold.



True positive



False positive



True negative

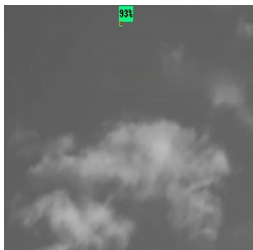


False negative

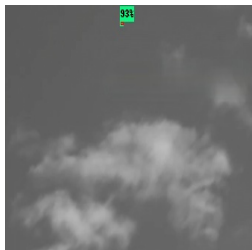
TEST RESULTS

	MD-v1	MD-v2	DD-v2-03	DD-v2-05	DD-v1-03	DD-v1-05
Recall	0.610	0.711	0.885	0.722	0.904	0.800
Precision	0.585	0.345	0.966	0.990	0.926	0.963
<i>MCC</i>	0.224	-0.024	0.842	0.720	0.817	0.760
F_β	0.604	0.586	0.900	0.763	0.908	0.828
FPS	0.2	0.2	1.2	1.3	4.2	4.8

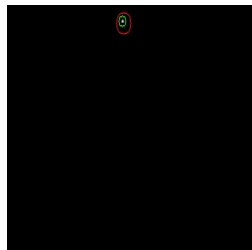
- **MD-v1**: Model-driven method w/ tolerance = 0.1.
- **MD-v2**: Model-driven method w/ tolerance = 0.01.
- **DD-v1-{0.3, 0.5}**: Data-driven based on original ResNet. Score threshold of 0.3 or 0.5.
- **DD-v2-{0.3, 0.5}**: Data-driven based on modified ResNet. Score threshold of 0.3 or 0.5.



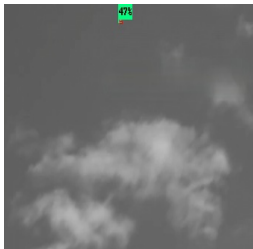
DD-v1-03



DD-v1-05



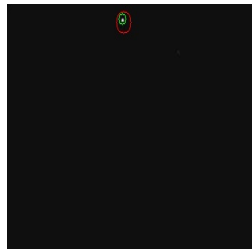
MD-v1



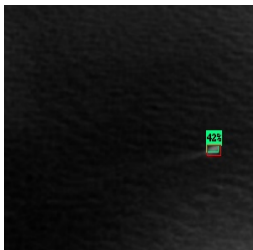
DD-v2-03



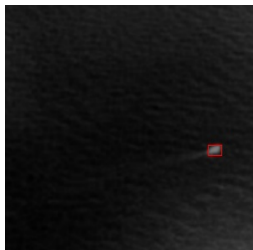
DD-v2-05



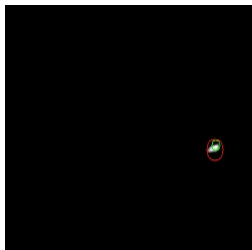
MD-v2



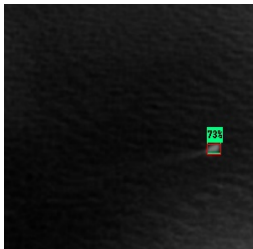
DD-v1-03



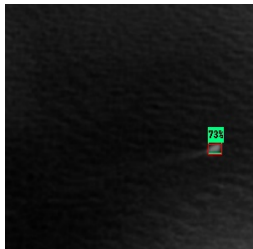
DD-v1-05



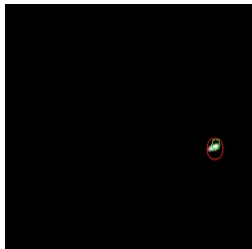
MD-v1



DD-v2-03

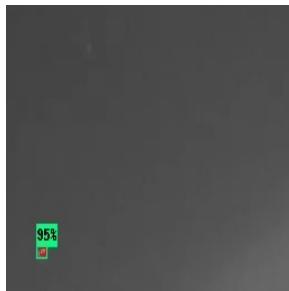


DD-v2-05



MD-v2

- Data-driven approach:
 - Could be faster.
 - High accuracy.
- Model-driven approach:
 - Slow.
 - *Too* thorough.
 - Good at extracting targets.



DD-v1-03



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