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Clutter Metrics for Automated Target Recognition

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Metrics Induced by Empirical Covariance

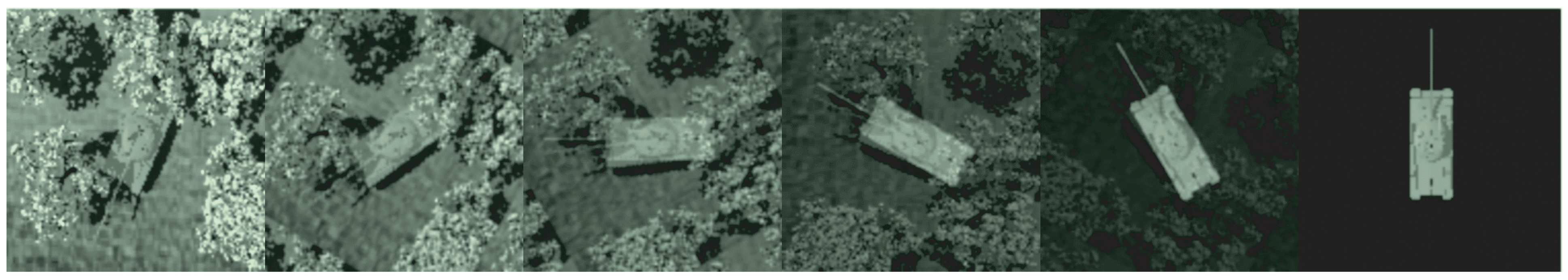
One of the central problems in Automatic Target Recognition (ATR) is to accommodate the infinite variety of clutter in real military environments. The model-based approach to this problem uses a variety of models to represent real-world scenes. However, object identification and classification rates are limited by the accuracy of the models, used and in heavily cluttered scenes, it is impractical to explicitly represent each object by a deterministic 3D model. Applying low-dimensional statistical descriptions of clutter may significantly improve the performance of an ATR system. The image on the right illustrates the problem. Model-based methods must be able to acquire pose and type of targets while, at the same time "seeing through" the confounding clutter.

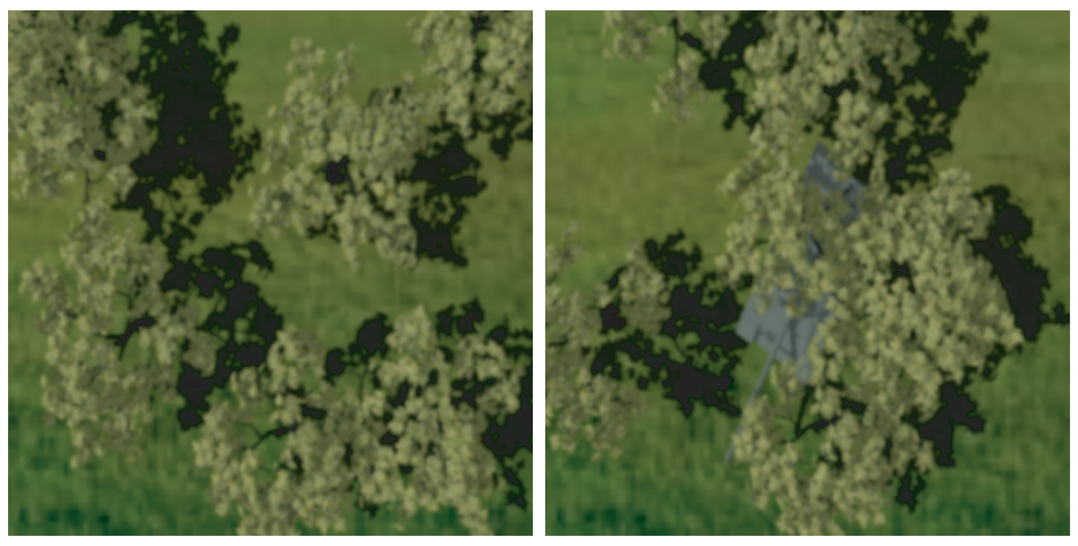
Courtesy of Dr. R. Sims

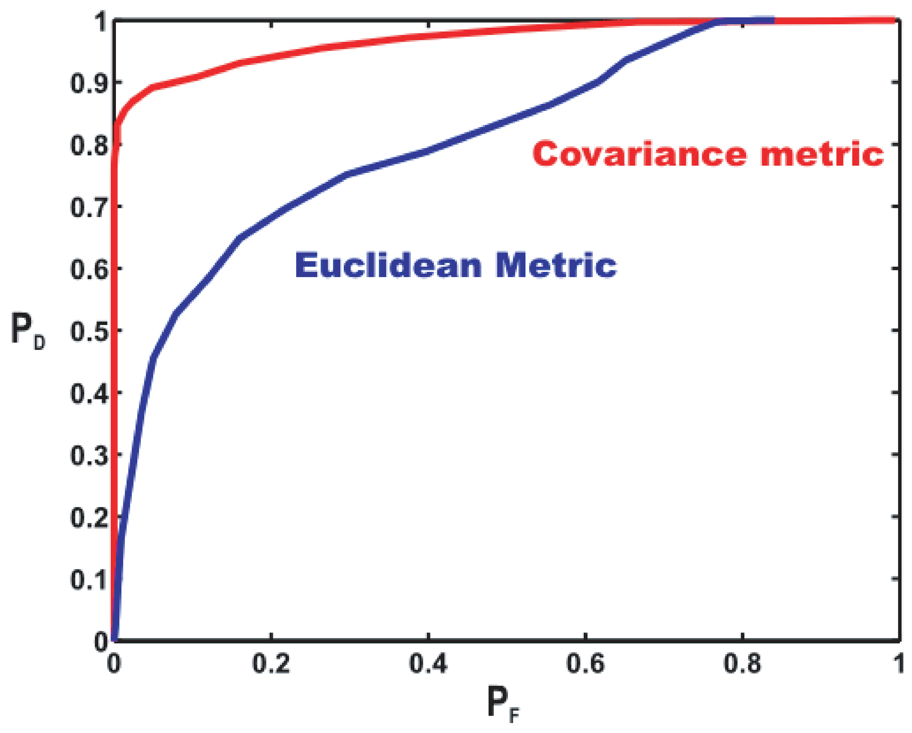
In this work, we construct robust deformable templates that accommodate both the variations of the target pose, represented by the group of rigid motions, and photometric variations associated with natural clutter. Photometric variations are modeled as elements of a Hilbert space H with a functional norm $\|\cdot\|_H$, induced by the empirical covariance kernel of clutter. To perform target detecting and identification, robust deformable templates are built into a metric-space structure, with the metric distance defined between templates and observed images. Constructing metric distances between images relies on concepts of differential geometry [1] and consists of defining the energy of paths connecting one image to the other. The metric distance is defined as the length of the minimum energy path between two images

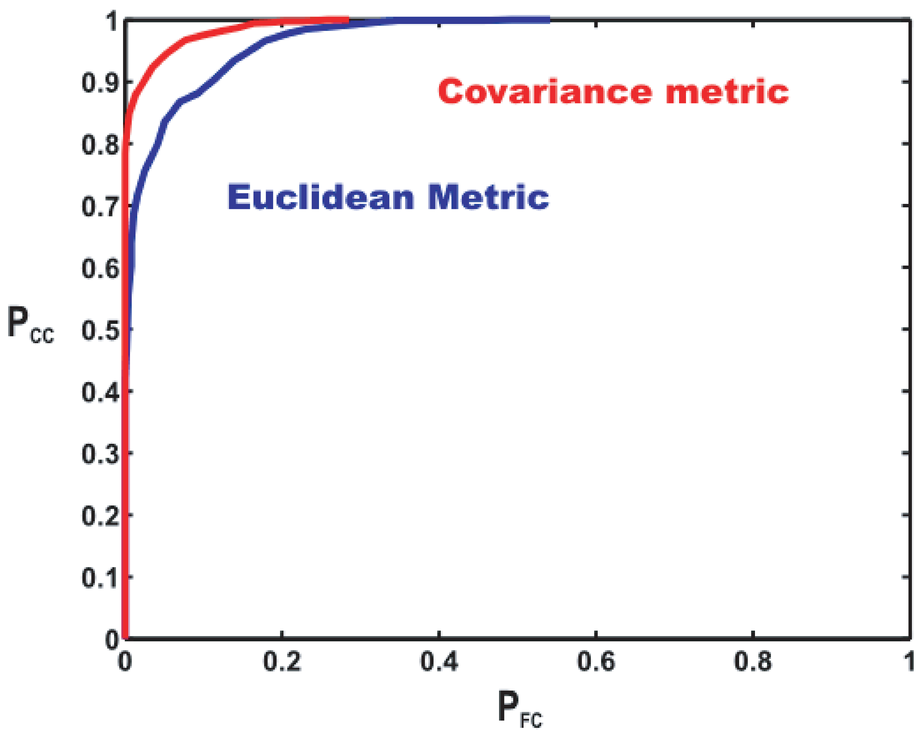
$$d(I_0, I_1) = \inf_{\substack{g(t):g(0)=id \\ I(t,\cdot):I(0,\cdot)=I_0,\, I(1,\cdot)=I_1 \circ g(1)}} \sqrt{\int_0^1 \left\| \frac{dI}{dt}(t, g^{-1}(t)) \right\|^2_{g^{-1}(t).H} dt}$$

We developed an efficient algorithm to compute these metric distances. The second and third sets of images show the minimum energy paths connecting images of a jeep and a tank in clutter to their templates.









Target Detection and Identification

In a Bayesian approach, target detection and identification are formulated as hypothesis testing problems. In binary settings, there are two target types associated with the hypotheses H_0 and H_1 . Generalized likelihood ratio decision rule is equivalent to comparing the metric distances from the observed image I_D to the templates, corresponding to hypotheses H_0 and H_1

$$d^2(I_D, I_{temp}^{(H_0)}) - d^2(I_D, I_{temp}^{(H_1)}) \underset{H_0}{\overset{H_1}{\gtrless}} \eta$$

The probability of detection/correct classification and the probability of false alarm are given by $P_D = P[H_1 | H_1]$ and $P_F = P[H_1 | H_0]$.

For the numerical experiments, a large dataset of targets in natural clutter was synthesized using ray tracing. Receiver Operating Characteristics (ROC) are used to analyze the performance of target detection and identification. Shown to the left are ROC curves, comparing the performance of the covariance metric distance to the Euclidean distance.

References:

[1] M. I. Miller and L. Younes, "Group Actions, homeomorphisms and matching: a general framework," International Journal of Computer Vision, vol. 41, pp. 61-84, 1999.

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