Guest Editorial
Introduction to the Special Issue on Automatic Target Detection and Recognition

AUTOMATIC target recognition (ATR) generally refers to the autonomous or aided target detection and recognition by computer processing of data from a variety of sensors such as forward looking infrared (FLIR), synthetic aperture radar (SAR), inverse synthetic aperture radar (ISAR), laser radar (LADAR), millimeter wave (MMW) radar, multispectral/hyperspectral sensors, low-light television (LLTV), video, etc. It is an extremely important capability for targeting and surveillance missions of defense weapon systems operating from a variety of platforms.

ATR is aimed at reducing the workload for human operators (e.g., image analysts, pilots, tankers) who are tasked with a large scope of activities ranging from assessing the battlefield/battlespace situation over large areas and volumes to targeting individual targets on land, sea, or air. ATR is also used to reacquire targets when used on unmanned lethal weapon systems such as missiles. Its need is dictated by large volumes of data requiring analysis and by the short timelines required by target acquisition scenarios. Its successful application will greatly increase the effectiveness and efficiency of weapon systems.

ATR is a multidisciplinary field that requires diverse technology and expertise in sensors, processing algorithms, architectures, and evaluation of hardware and software systems. The major technical challenge for ATR is contending with the combinatorial explosion of target signature variations due to target configuration (e.g., stores, articulation, manufacturing, wear/tear), target/sensor acquisition parameters (e.g., aspect, depression, squint angles), target phenomenology (e.g., cavity responses, glints, infrared thermal behavior), and target/clutter interaction (e.g., foliage masking, camouflage). ATR systems must maintain low false alarm rates in the face of varying and complex backgrounds, and must operate in real time. Another extremely important challenge for ATR is the evaluation and prediction of ATR field performance given the practical limitation of data sets that cannot represent the extreme variability of the real world. The ability to rapidly insert new targets and to train algorithms on-the-fly in the field are important challenges to support flexible and sustained employment of ATR.

The ATR field has evolved from using statistical pattern recognition approaches to model-based vision and to knowledge-based systems. Currently, adaptive and learning systems, focused on parts of the ATR problem, are also being developed. Current research areas include knowledge-based and model-based techniques, and approaches based on using physical principles, detection theory, multiresolution processing, statistical techniques, neural nets, and genetic algorithms. However, no single approach is likely to be the solution to all ATR problems, but by applying the most useful techniques to each part of the problem, progress is accelerating. The most successful ATR systems will probably blend several algorithmic techniques to achieve satisfactory performance.

Papers in This Special Issue

The goal of this special issue is to provide an overview of the state of the art in this important field, and to collect significant research results about new developments. The special issue contains 15 papers. These papers use a variety of techniques for target detection and recognition. There are various possible ways in which these papers can be grouped. We have organized them according to the kind of techniques and principles that are used for target detection and recognition.

The first four papers use multiresolution processing for clutter modeling, target detection, and recognition.

In the first paper on multiscale segmentation and anomaly enhancement of SAR imagery, Fosgate *et al.* take advantage of the coherent nature of the SAR sensor and describe a statistical scale-autoregressive model for imagery. They apply this to pixel classification, boundary detection, and anomaly enhancement in SAR imagery. The authors construct a multiresolution (quadtree-based) statistical model for SAR imagery of grass and forest terrain types. These models are then used to label pixels and find boundaries between them. For anomaly detection, the authors use a multiscale statistic similar to the spatial template constant false-alarm rate (CFAR) statistic commonly used in SAR target detection. Results are shown using real SAR images.

Like the first paper, the second paper by Subotic *et al.* uses multiresolution processing in SAR images to exploit the signature differences between natural clutter and man-made objects to detect targets in SAR images. They develop statistical models for multiresolution SAR signatures of natural clutter and man-made objects. These models are then used to develop a variety of target detection methods to distinguish clutter from man-made objects using multiresolution SAR data. The detectors are tested on simulated and real SAR data to verify that multiresolution processing is indeed useful.

The next paper by Greer *et al.* develops a maximum-likelihood multiresolution-based approach to the laser radar image processing problem. The expectation-maximization (EM) algorithm is used for fitting a multiresolution Haar wavelet basis to laser radar range data to achieve a computationally efficient and numerically robust procedure. The approach provides quantitative information about the performance, which can be used in a model- based recognition system to characterize system performance. The results are presented on both simulated and real laser radar range data.

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The focus of the next paper by Wu and Bhanu is the use of the multiscale Gabor wavelet representation for three-dimensional (3-D) object recognition. They use magnitude, phase, and frequency of the Gabor representation in a flexible matching approach for recognition of targets in infrared images, where targets undergo rotation, translation, scale, occlusion, and aspect variations under changing environmental conditions. Flexible matching between the model and the image minimizes a cost function based on local similarity and geometric distortion of the Gabor grid, which is a topology-preserving map that efficiently encodes both signal energy and structural information of an object in a multiscale representation. Grid erosion and repairing is performed whenever a grid collapses due to object occlusion. Results are presented for both simulated and real infrared images with and without occlusion.

The next two papers use physics-based processing for target detection, recognition, and change detection.

The paper by Nandhakumar *et al.* presents an approach to computing thermophysical invariant features from infrared images by using principles of algebraic invariance theory. The approach is an extension of their previous work that required calibrated imagery for which the relationship between the sensed gray values and the actual temperature of the imaged object is assumed known. The new approach allows the use of uncalibrated imagery and does not require any knowledge of the ambient conditions of the scene. The authors use the new approach for hypothesis verification in a hypothesize-test method of model-based object recognition and for automatic change detection for site analysis using infrared images. The results are presented using long-wave infrared imagery.

In the next paper, Potter and Moses present physics-based parametric scattering models derived using the geometrical theory of diffraction. The attributes of a scattering center are estimated as parameters in a model of radar scattering. The attributes for each scattering center provided by these scattering models include location, amplitude, scattering geometry, and polarimetric properties. Further statistical analysis also provides the attribute uncertainty that may be used to characterize the performance of an ATR system. The results are demonstrated using SAR and ISAR images.

The next two papers use geometrical approaches to target detection and recognition.

The paper by Der and Chellappa presents a probe-based approach to target recognition in infrared images. A probe is based on the differences in gray levels along the silhouette of the hypothesized target. The target shape (silhouette) information is obtained from a 3-D computer-aided design (CAD) model of a target at a given range. The probability density function of the probe values (for target and background) is obtained from local regions of an image. The generalized likelihood ratio test between a target hypothesis and a background hypothesis is used to accept the input as one of the target poses or the background. Experimental results are presented using both synthetic and real images.

The next paper by Olson and Huttenlocher develops an approach for recognizing targets using both the location and direction of edges. Both the models and objects are represented in this manner. The 3-D target models are represented by their two-dimensional (2-D) viewer-centered representations. Target location hypotheses are generated using a modified Hausdorff distance measure that accounts for both the position of edge pixels and their direction. To speed up the process, hierarchical cell decomposition of the transformation space is used. The authors discuss ways to make their approach more efficient and to estimate the probability of a false alarm at run-time. As expected, experiments confirm that the use of edge direction, in addition to edge location information, reduces the number of false alarms. Results are presented using visible and infrared imagery.

The next three papers use sensor fusion and multisensor and multispectral processing for target detection and recognition.

The paper by Casasent and Ye presents Gabor basis function (GBF) and morphological wavelet transform (MWT) based detection algorithms and their fusion for target detection in infrared images. The GBF algorithm locates objects by combining Gabor basis functions for different training set images. The MWT algorithm combines morphological and wavelet filter outputs to locate targets and to remove clutter. Since a single algorithm may not provide high detection probability with a low false alarm rate, the authors fuse the outputs of these algorithms by using various ("binary," "analog," and "hierarchical") fusion algorithms to reduce false alarms while keeping the probability of detection high. The results are shown using terrain board imagery.

In the next paper, Stevens and Beveridge present a target recognition system that uses multisensor data for precise 3-D model matching. First, the targets are detected using color imagery. Next, the target type and pose hypothesis is generated using a boundary template matching algorithm that uses range images and the target CAD model. Finally, for each hypothesized target, multisensor (FLIR, color and range) matching uses an iterative optimization algorithm (a variant on Tabu search) to develop a best match between predicted target features computed on-line and the features extracted from multisensor imagery. The final step refines the model pose for each of the three sensors simultaneously. As the pose is being refined, image registration between sensors is also being corrected. The matching algorithm operates in a 3-D scene coordinate system within which it adjusts 3-D relationships between the sensors and the target.

The next paper by Yu *et al.* addresses the target detection and recognition problem using very-high-resolution spectral data in hyperspectral imagery. The authors use a two-stage processing scheme where the first stage is used to detect spectral anomalies caused by man-made objects and the second stage is used to recognize if the spectral anomaly is caused by known or partially known spectral features of a target or other man-made objects. The targets are detected using a generalized likelihood ratio test with unknown clutter spectral covariance and unknown image intensity in each band. The multiband data is partitioned into two groups, one corresponds to natural clutter from vegetation and the other to man-made objects. No known target spectral features are utilized in the detection phase, only known spectral features or *a priori* knowledge is required by the recognizer. The results are shown using images in the infrared spectrum and evaluated by finding the gain of the SNR needed for detection as well as the gain required for separability between the target classes to be recognized.

The next three papers use model-based processing of image sequences for target motion detection, recognition, tracking and change detection for wide area surveillance.

The paper by Miller *et al.* presents a method for fusion of multisensor data (low resolution radar, optical, FLIR and high-resolution radar) to achieve simultaneous target detection, recognition, and tracking. The problem is formulated using the Bayesian paradigm with aircraft dynamics and known target templates used as a priors. The true priors are estimated using the data by maximizing *a posteriori* probabilities. The search for the solution is organized via the jump-diffusion algorithm, a Monte Carlo method related to simulated annealing. Results using simulated data are presented.

The paper by Serra and Berthod describes a system to solve the problem of 3-D model localization in a 3-D scene using a sequence of monocular images with known motion parameters of the sensor. The 3-D reconstruction of a scene is obtained by using a subpixel accurate contour matching algorithm to achieve complete 3-D contours. To achieve higher localization precision and robust 3-D scene reconstruction, 3-D contours obtained from a pair of images are fused in a Kalman filter. Once the 3-D contours are obtained, corners are detected in these contours for model matching in a hypothesize-test paradigm with suitable techniques for selecting the best hypothesis. Results are presented using infrared images obtained at different resolutions.

The next paper by Carlotto addresses the change detection and wide-area surveillance problem using multiband Landsat Thematic Mapper (TM) imagery, especially for situations when site model may not yet exist. The paper presents linear and nonlinear filtering techniques for modeling and detecting general patterns of change observed over multiple images associated with construction or similar activities. Patterns of change are expressed in terms of relative values of image properties over time, which are further used to describe changes in terms of general trends by performing temporal segmentation and filtering operations. The linear filtering technique provides information relating to the kind of changes that have occurred. Its performance depends critically on the thresholds that are used. The nonlinear technique may use the input from an image analyst or the input from the linear filtering step to emphasize a specific pattern of change. As expected, there is a reduction in false alarms as the number of images used for processing increases.

The last paper by Perlovsky *et al.* describes a model-based neural network approach and applies it to several target detection/segmentation problems. The basic neural network architecture consists of an association subsystem that computes weights that associate data with models. The modeling subsystem estimates parameters of the models. The general idea is to estimate the clutter model parameters for each image independently, and to classify those pixels with smallest likelihood of belonging to the clutter model (i.e., the outliers) as targets. The approach combines *a priori* knowledge (physical laws of electromagnetic scattering) with adaptations to the actual environment. The results are presented using SAR images.

The Future

The future of ATR is exciting and challenging. It is exciting since it involves so many technical disciplines and has so many practical (defense and nondefense) applications. It is challenging since we need to develop reliable and robust algorithms that can effectively work in the varying multiscenarios involved in practical missions.

It is generally agreed that significant progress has been made in the development of sensors and processing hardware systems. Great progress is being made in the development of algorithms using a variety of techniques, some of which are represented in this special issue. We expect to see useful ATR systems for practical applications while advanced research is attempting to solve difficult problems.

The challenging frontier for research is to develop sound theory for clutter and target characterization from physical principles, effective use of context and multisensor/multisource information that will result in reliable systems and, ultimately, transform the ATR field from an art to a science. This will allow a given set of ATR algorithms to predict performance, an essential element of a scientific field. In the future, we hope to have adaptive and learning-based ATR systems that will detect and recognize targets under varying environmental conditions and which will adapt to varying sensors, processing, and deployment conditions.

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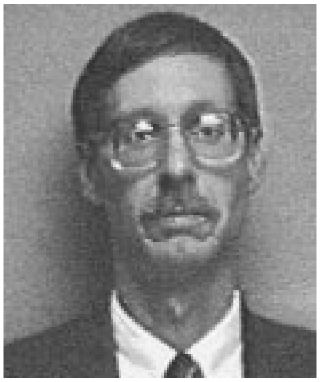

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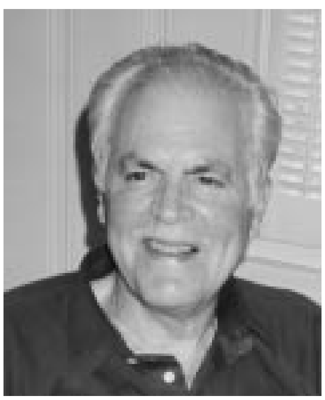

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