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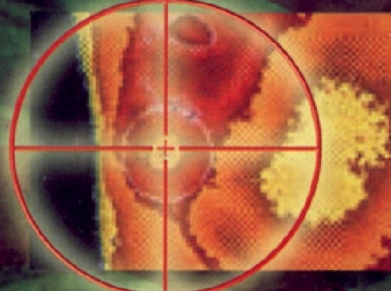
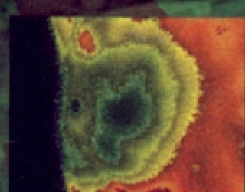


Infrared: From Tanks to Tumors



Military Technology Aids Medical Infrared Imaging in Targeting Tumors and Tracking Treatment

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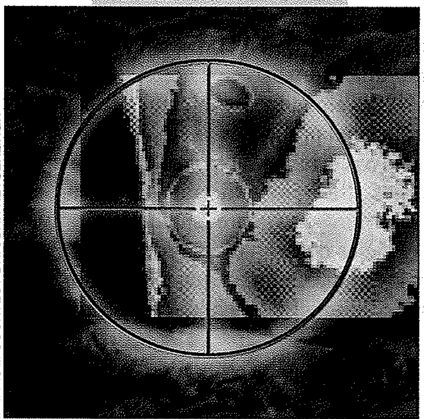

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From the Guest Editor

Advances in Medical Infrared Imaging

Nicholas A. Diakides
Advanced Concepts Analysis, Inc.

This is the third special issue on the use of infrared imaging in medicine, and it is with great pleasure that we are reporting the significant innovations in this field. The previous issues were well received by the medical and biomedical engineering community (*IEEE EMB Magazine*, July/August 1998 and May/June 2000). These two events coupled with the annual IEEE/EMBS conferences have helped create a unifying forum for forward-looking research world-wide.

A significant number of government-sponsored programs have been initiated in Europe, Japan, and the United States. The evolution of technological advances in infrared sensor technology, image processing, and smart algorithms and their integration led to new methods of research in medical infrared imaging. These were highlighted at the special event "From Tanks to Tumors: A Workshop on the Application of IR Imaging and Automatic Target Recognition (ATR) Image Processing for Early Detection of Breast Cancer," held in Arlington, Virginia, 4-6 December 2001. This workshop was sponsored by the Office of the Deputy Undersecretary of Defense (S&T—Sensor Systems), Office of the Deputy Assistant Secretary of the Army for Installations and Environment (Environmental Safety and Occupational Health), The Army Research Office (ARO), and the Defense Advanced Research Projects Agency (DARPA). Leaders in multidisciplinary fields presented plenary papers and participated in three working groups: Image Processing, Web-based Database, and Sensor Technology. The working group results were then presented to the attendees in a plenary session. These recommendations are being implemented in a highly leveraged, government-sponsored program to develop a "Web-based database" for the quantification of thermal signatures of the breast. This issue contains two articles highlighting the workshop and its findings.

Currently, there are several methods being used in medical infrared imaging. They are the following:
- static
- dynamic (DAT, subtraction, etc.)
- multispectral and hyperspectral
- thermal texture mapping
- multimodality
- sensor fusion
- infrared regulation imaging (IRI).

They are being used in a variety of applications including: oncology (breast, skin, etc.), pain, vascular disorders (diabetes, deep venous thrombosis), arthritis, rheumatism, surgery, tissue viability (burns, etc.), dermatological disorders, monitoring the efficacy of therapeutic drugs, etc., and sports medicine.

Articles have been contributed by experts with many years of experience in the use of this modality in universities, industry, government research, and clinical settings. There are two introductory articles: one by Jeff Paul and Jasper Lupo (United States) on the "Tanks to Tumors Workshop." It gives an overview of the workshop structure, its scope and intent, and its potential outcome with reference to the Web-based database initiative. The second is by John Irvine (USA), who explores the possibility of leveraging the experience and knowledge of the military automatic target recognition (ATR) community toward addressing the medical imaging problem. He makes a compelling case for this.

Bryan Jones (United Kingdom) and P. Plassmann present digital imaging of thermal radiation emanated from the human body and measured on the surface of the skin. His article also discusses its analysis and interpretation by image processing. Several medical applications are presented. Kimio Otsuka et al. (Japan) present a novel method and system for measuring emissivity, emissivity-corrected temperature, and thermal inertia simultaneously and highlight some interesting phenomena found by this technique. It not only provides precise temperature distribution of the skin but also allows speedy measurement of emissivity

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and inertia distribution. Ioannis Pavlidis et al. (United States) discuss a new method for scoring polygraph tests using thermal image analysis. It features three stages: image acquisition, physiological correlation, and pattern recognition. This approach achieved a correct classification rate of 84% on the population tested, and it demonstrates an enhancement in reliability and accuracy of traditional polygraph examinations.

Naoto Kakuta et al. (Japan) use a human thermal model with which IR images obtained under certain environmental conditions can be converted into images taken under other conditions. The modeling is based on numerical calculations of the bio-heat transfer equations that express heat transfer phenomena with the human body. Their research shows that this method is effective in eliminating the influence of the thermal environmental conditions. Arcangelo Merla et al. (Italy) present a novel approach for the evaluation of Raynaud's phenomenon based on infrared functional imaging. The results of this pilot study are encouraging. A larger study is underway. Jonathan Head and Robert Elliott (United States) review the past, present, and future applications of infrared imaging in medicine. They discuss predominant areas of interest, such as breast cancer, and other promising applications. Arcangelo Merla et al. (Italy) in their second article introduce the "Tau Image"—a new complementary imaging technique based on infrared functional imaging. The basic idea of this work was to identify the altered thermoregulatory properties associated with a specific disease in order to detect and classify the kind and the stage of the disease itself.

Articles have been contributed by experts with many years of experience in the use of this modality in universities, industry, government research, and clinical settings.

I would like to acknowledge the U.S. Department of Defense for developing the infrared technology and the Office of the Undersecretary of Defense for Science and Technology (ODUSD-S&T), the ARO, and DARPA for the continued support toward the transfer of this technology to medicine. Also, I would like to acknowledge the Office of the Deputy Assistant Secretary of the Army for Installations and Environment (Environmental Safety and Occupational Health) and the Office of Naval Research (ONR) for their support in the Web-based database initiative. I am indebted to John Enderle, editor-in-chief of this magazine, for his guidance, assistance, and advice in making this special issue possible. My appreciation and thanks also go to all the authors for their excellent contributions and the reviewers for their time and valuable comments.

Nicholas A. Diakides received a D.Sc. (1979) in electrical engineering (biomedical engineering) from George Washington University. He is president of Advanced Concepts Analysis, Inc. (1989-present), a small company dealing with advanced biomedical technology and innovative defense research on sensors. Currently, he is involved in analysis and assessment of sensor systems, biomedical technology, medical imaging, and bioinformatics for the Office of the Secretary of Defense (OSD-S&T, DARPA, ARO, and ONR). In addition, since 1994 he has led the effort to establish internationally the use of advanced digital infrared imaging in medicine. Previously, he was the director of the Survivability Enhancement Division, U.S. Army Laboratory Command (1984-1989).

From 1962-1983 he was program manager for various areas of IR technology and electro-optics at the Army Night Vision and Electro-Optics Laboratory. He has published more than 50 papers and one book chapter (invited) in the *Electronics Engineers Handbook*. Professional Activities: IEEE/EMBS, publicity chair and member of the conference and technical program committees in Baltimore (1994); organizer and chair of all infrared imaging activities (tracks, sessions, workshops and mini-symposia) for IEEE/EMBS International Conferences (1994-2002); member IEEE/USA member for the following committees: R&D Policy (1994-present) and Healthcare Engineering Policy (1989-1994); guest editor, *IEEE EMB Magazine* special issues on medical infrared imaging (July/August 1999 and May/June 2000). He is a Fellow of the American Institute of Medical and Biological Engineering and a member of the Executive Committee of the American Academy of Thermology (1998-present).

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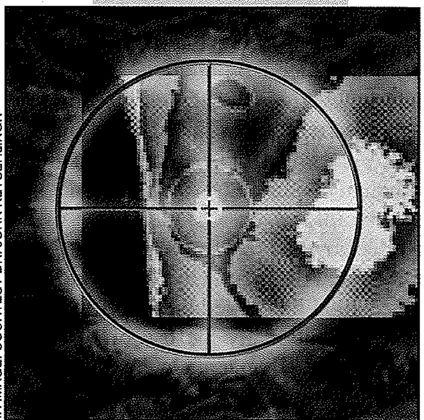

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From Tanks to Tumors

Applications of Infrared Imaging and Automatic Target Recognition Image Processing for Early Detection of Breast Cancer

Jeffrey L. Paul[1] and Jasper C. Lupo[2]
[1]Space and Sensor Technology, The Pentagon
[2]Applied Research Associates

This article summarizes proceedings of the "Tanks to Tumors" workshop that was held in Arlington, Virginia, 4-5 December 2001. The workshop was co-sponsored by the Office of the Director, Defense Research and Engineering, Space and Sensor Technology Directorate; the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health; the Defense Advanced Research Projects Agency; and the Army Research Office. The purpose was to explore means for exploiting the technological opportunities in the integration of image processing, Web-based database management and development, and infrared sensor technology for the early detection of breast cancer. A second objective was to provide guidance to a program sponsored by the Army, with help from the Office of Naval Researh (ONR) and Office of the Secretary of Defense (OSD). Significant military advances in thermal imaging and automatic target recognition coupled with the medical understanding of abnormal vascularity (angiogenesis) offer the prospect of automated detection from one to two years earlier than other, more costly and invasive screening methods.

The workshop was motivated by: 1) recognition of breast cancer as a major occupational health issue by key personnel such as Raymond Fatz, Deputy Assistant Secretary of the Army for Installations and Environment; Environmental Safety and Occupational Health; 2) growing use of thermal imaging in military and civilian medicine (especially abroad); 3) maturation of military technology in automatic target recognition (ATR), ATR evaluation, and low-cost thermal imaging; and 4) emerging transfer opportunities to and from the military. In particular, ATR assessment technology has developed image data management, dissemination, collaboration, and assessment tools for use by government and industrial developers of ATR software used to find military targets in thermal imagery. Such tools seem naturally suited for adaptation to the creation and use of a national database for infrared breast cancer imagery and the evaluation of screening algorithms that would assist physicians in detecting the disease early. Finally, recent infrared theories developed by civilian physicians indicate that the abnormal vascularity (angiogenisis) associated with the formation of breast tumors may be detected easily by infrared cameras from one to five years before any other technique. Early detection has been shown to be the key to high survival probability.

Proceedings

We invited specialists and leaders from the military R&D, academic, and medical communities. Together they covered a multidisciplinary range of topics: military infrared sensor technology, ATR, smart image processing, database management, interactive Web-based data management, infrared imaging for screening of breast cancer, and related medical topics.

The workshop began with a set of plenary presentations to orient everyone. Following the presentations, the participants broke into three working groups: 1) Image Processing and Medical Applications; 2) Website and Database; 3) Sensor Technology for Medical Applications. A subject area expert led each working group. The deliberations of each group were presented in a briefing to the plenary session of the final day.

Working Group 1: Image Processing and Medical Applications

This group focused on the algorithms (ATR approaches) and how to evaluate and use them. This group advised that the

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clinical methods of collection must be able to support the most common ATR approaches; e.g., single frame, change detection, multilook, and anomaly detection. They also provided detailed draft guidelines for controlled problem sets for ATR evaluation. Although they thought a multisensor approach would pay dividends, they stressed the need to quantify algorithm performance in a methodical way, starting with approaches that work with single infrared images.

Working Group 2: Website and Database

This group concerned itself with the collection and management of an infrared image database for breast cancer. It looked particularly at issues of data standards and security. It concluded that the OSD-supported Virtual Distributed Laboratory (VDL), created within the OSD ATR Evaluation Program, is a very good model for the medical data repository to include collaborative software, image management software, evaluation concepts, data standards, security, bandwidth, and storage capacity. It also advised that camera calibration concepts and phantom targets be provided to help baseline performance and eliminate unknowns. It noted that privacy regulations would have to be dealt with in order to post the human data but suggested that this would complicate but not impede the formation of the database.

Working Group 3: Sensor Technology fo Medical Applications

The sensor panel started by pointing out that if angiogenesis is a reliable early indicator of risk, then thermal imaging is ideally suited to detection at that stage. Current sensor performance is fully adequate for this task. The group discussed calibration issues associated with hardware design and concluded that internal reference is desirable to insure that temperature differences are being measured accurately. However, they questioned the need for absolute temperature measurement; the plenary group offered no counter to this. This group also looked at the economics of thermal imaging and concluded that recent military developments in uncooled thermal imaging systems at DARPA and the Army Night Vision and Electronic Sensing Division would allow the proliferation of infrared cameras costing at most a few thousand dollars each. They cited China's installation of over 60 such cameras. They challenged the ATR and algorithm people to look at methods they could use to help simplify the sensor hardware; e.g., stabilization.

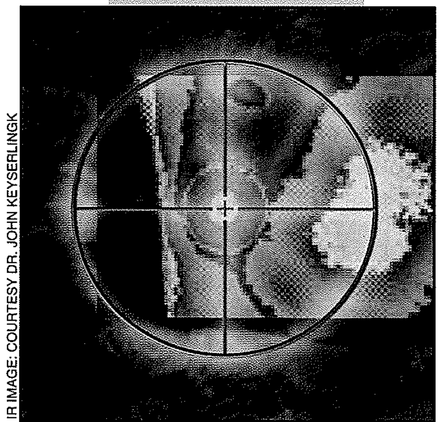
> **The panel recommendations will serve to guide the transition of military technology developments in ATR, the VDL, and IR sensors to the civilian medical community.**

Summary

"Tanks to Tumors" succeeded in bringing several different communities together—medical, military, academic, industrial, and engineering. They worked together in panels to determine how the United States might adopt thermal imaging diagnostic technology in an orderly and demonstrable way for the early detection of breast cancer and other conditions. The panel recommendations will serve to guide the transition of military technology developments in ATR, the VDL, and IR sensors to the civilian medical community. The result will be a new tool in the war against breast cancer—a major benefit to the military and civilian population. A CD of the workshop proceedings is available at no cost through Advanced Concepts Analysis, Falls Church, Virginia; +1 703 914 9237; e-mail: diakides@erols.com.

Jeffrey L. Paul has over 33 years of experience in the technical pursuit and management of science and technology within the Department of Defense and the aerospace industry, with emphasis on space, sensor, and electronics technology. From June 2001 to June 2002 he served as the Acting Director for Space and Sensor Technology in the Office of the Deputy Undersecretary of Defense for Science and Technology. Prior to this, he worked nearly five years as Staff Specialist for Sensors, ODUSD (S&T), providing technical leadership, management oversight, policy guidance, and coordination for the science and technology programs in the military services and defense agencies related to sensor technology, accounting for over $2 billion in Department of Defense investment. Before coming to OSD, he spent 11 years managing advanced technology efforts at Hughes Aircraft Company, El Segundo, California.

Jasper C. Lupo is a senior technologist with over 35 years of experience in conducting and leading defense research and development, from the laboratory to the Office of Secretary of Defense. Prior to joining Applied Research Associates in Alexandria, Virginia, as principal scientist in 2002, he served four years as the Director for Sensor Systems and four years as Director for Research in the Office of the Director, Defense Research and Engineering. From 1982 to 1992 he worked at DARPA. He has a Ph.D. in physics from Georgetown University.



Targeting Breast Cancer Detection with Military Technology

Applicability of Automated Target Recognition Technology to Early Screening for Breast Cancer

John M. Irvine
Science Applications International Corporation

Automated target recognition (ATR) technology encompasses a range of image processing tools and techniques designed to detect, locate, identify, and characterize military targets in imagery. ATR methods can be employed in weapon systems or for intelligence, surveillance, and reconnaissance (ISR) applications. In a weapon system, ATR is designed to operate autonomously by detecting and locating the target to be attacked. For ISR applications, ATR assists the image analyst by focusing attention on specific regions of an image or indicating the likely class or identity of a target. In this case, the final decision about target detection and identification remains with the human, but the ATR should assist the analyst.

Despite ongoing investment by the U.S. Department of Defense in ATR research and development, there are not many operational ATR systems today. The ATR community has learned that automated target detection and recognition is a very challenging problem. Several factors have led to progress: advances in computing power, detailed modeling of the physics that underlies target sensing, careful characterization and understanding of specific missions for the ATR, and a considerable investment in data collection and analysis. Nevertheless, general solutions remain elusive.

The medical application under consideration here is very specific: Can thermal IR imagery provide valuable first phase screening for early detection of breast cancer? For this well-defined application, the methods and experience from the ATR world may provide some benefit. This article presents a brief overview of ATR methods, examines the relationship between ATR techniques and the medical application, and offers recommended areas for further investigation, based on the experience of the ATR community.

Overview of ATR Technology

The typical processing strategy for ATR operating on a single frame of imagery is to perform the target detection and recognition tasks sequentially (Figure 1) (see [5]). Initially, a "detector" (sometimes called a "focus of attention") assesses local information in the image and flags a set of regions of interest (ROI), which are candidate targets. After some additional processing to eliminate false alarms, the set of candidates are offered up by the ATR as "detections." At this stage, the ATR has judged these objects to be military targets, but no further identification has been made. The second major stage of processing compares these candidate targets to known characteristics about a set of possible targets. If the candidate detection closely resembles the characteristics of one of these known targets, the ATR declares that candidate to be from the same class of objects. In this manner, the target is "recognized."

A common approach to the identification step is to construct a library of known templates for the targets of interest. The objects flagged by the detector are compared to each template and, based on some figure of merit, the object is classified. The set of templates could be derived empirically by repeated imaging of the targets of interest or a model-based approach could be used to predict the signature for each target. Regardless of the source of the templates, some rule for matching detected objects to the templates is critical. Several approaches can be used for matching the detected target to the library

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of possible targets. The comparison can be performed with the actual image chips or, more often, with a set of features extracted from the imagery.

For early detection of breast cancer, the goal of processing the thermal imagery is to assist the physician in the diagnosis. Because the final decision rests with the human, this problem most closely resembles the ISR applications for ATR technology. Automated processing should be used to detect and locate suspicious features or anomalies in the thermal image. The physician would then examine the highlighted area to determine the next course of action.

The automated processing should cue a physician's attention to anomalies in the image that are genuine concerns, while avoiding spurious or irrelevant features. Incorrect decisions by the automated processing will lead to certain costs. A missed detection implies a failure to flag a condition that warrants further investigation—a potentially costly error. Conversely, a false alarm means that a subject is unnecessarily flagged for additional testing, which may be a less costly error. The Receiver Operator Characteristic (ROC) curve quantifies the tradeoff between missed detections and false alarms (see [7], [8], [15]). These relative costs imply an optimal position on the ROC curve.

Experience from the ATR community indicates that successful use of the automated cueing relies on more than simply finding the optimal operating point on the ROC curve. Because the human is the final decision maker, the interaction between the user and the automated cueing system complicates the process substantially. For the user, both missed detections and false alarms can undermine the credibility of the automated system, leading him or her to distrust or ignore the cues provided. In general, an automated cueing system provides benefits only if it improves the physician's performance in some significant way, such as reducing the probability of incorrect decisions or reducing workloads.

Studies where ATR assists the imagery analyst have shown that an ineffective ATR or an ATR used inappropriately can actually degrade overall performance (see [12] and [6]). Understanding the interactions between the human and the ATR system is critical. Factors that can contribute to the problem include:

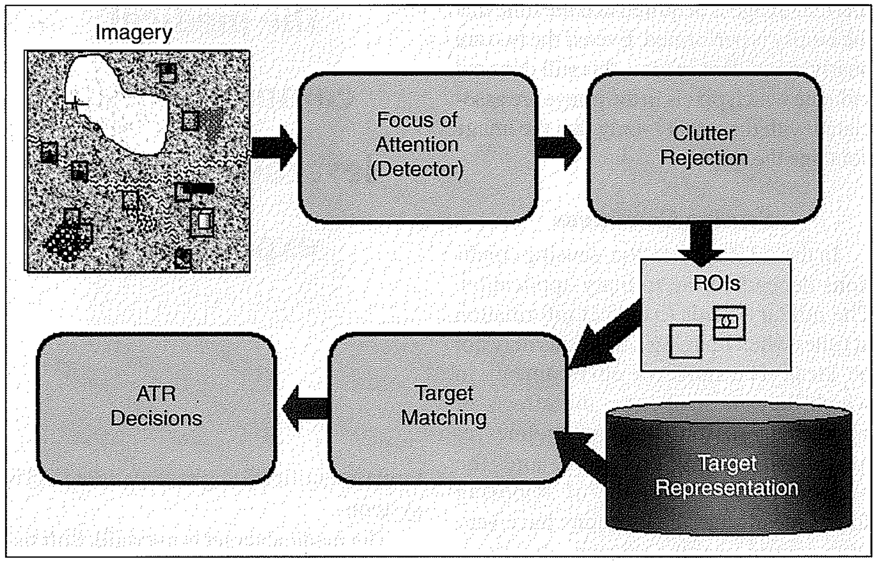
- excessive false alarms, which divert the analyst's attention, increase the time required for analysis, and affect vigilance
- training and familiarity with the system
- the human computer interface, including the visualization of ATR results and a clear understanding of the information conveyed by the ATR.

Parallels to the Cancer Screening Problem

Identifying the similarities and differences between the ATR problem and the medical one will indicate the ways in which the medical community can leverage the ATR experience (Table 1). Four areas of comparison are explored here: image truth, sensing conditions, the nature of the target, and the environment around the target. For this discussion, the term "target" in the medical context refers to the tumor and associated structure.

Image Truth

In the ideal situation, image truth would indicate with absolute certainty the location and identification of every target contained in the imagery. In practice, the quality of the image truth depends on the type of collateral data available and the ability to correlate the collateral data with the actual imagery. In the ATR problem,



1. Overview of ATR processing.

Table 1. Relationship between ATR and medical application.

Issue	ATR Application	Medical Application	Comments
Gold standard	Image Truth – often derived from GPS and ground measurements	Patient history, pathology, other diagnostic tests	Incomplete understanding of missed detections
Sensing conditions	Limited control over collection conditions (weather, time of day, range to target)	Good control of environment and subject. Protocol determines sensing conditions.	Need to develop standard protocols to maximize the information derived from thermal imagery
Targets	Rigid structures and defined shapes (vehicles). Amenable to CAD modeling	Target shapes and sizes vary. Target may grow over time	Modeling the target signature is challenging
Environment	Heterogeneous background and clutter. Camouflage, target obscuration	Depth of target — target is below the surface. Complexity of surrounding tissue	Need to understand interaction between target and surrounding tissue

the imagery used for system development and testing often comes from staged data collections in which known targets are placed in predefined positions and imaged according to some collection plan. Uncertainty enters the problem through the process of registering the imagery to the ground coordinates, so that specific pixels can be associated with the targets.

The medical application does not enjoy this level of control over the content of the imagery. For patients who are diagnosed with breast cancer, the pathology provides the best information about the target. Nevertheless, the nature and extent of the target could change between the time a specific thermal image is acquired and the time that the biopsy is performed. Even if the two are nearly coincident in time, this still does not indicate which pixels in the image are associated with the target—only that the image contains the target.

Sensing Conditions

In the ATR application, sensing conditions depend on the military application. The military needs to collect information at times when imaging conditions may not be ideal. The range of environments in which they must operate, the effects of weather and season, the short timelines required for many missions, and the noncooperative behavior of opposing forces means that the user may have very little control over the sensing conditions. In the medical setting, however, there is far more control over the data collection. There is control over the temperature in the room and the orientation of the patient with respect to the sensor. For medical diagnosis, we should expect high-quality imagery of the region of interest.

Target Conditions

For the ATR problem, the targets are military vehicles; i.e., rigid physical structures. The target signature can vary in several ways that pose a challenge for ATR. Target components can move; e.g., tank turrets can rotate, gun barrels can be elevated, etc. A class of targets may include model variants that alter the target signature. For thermal imagery, the target history, including exposure to sunlight and engine activity, can alter the signature. The physical principles related to the target signature can be studied and modeled in an effort to improve ATR performance. In this way, model-based vision techniques have been incorporated into the

Identifying the similarities and differences between the ATR problem and the medical one will indicate ways in which the medical community can leverage the ATR experience.

target identification phase of some ATR systems.

The medical target is not rigid. Soft tissue may change shape easily. The size, shape, and orientation of the target can vary over time. Modeling the target signature requires understanding of the biological processes related to tumor growth, microcalcification, and angiogenesis. Research that aids in understanding and modeling the signature of the target will be more challenging for this medical problem.

Environment Around the Target

The ability of ATR to detect and identify a military target depends on the degree to which the target differs from the surrounding environment. Complex clutter, including vegetation, rugged terrain, and various man-made objects, can exhibit features that resemble the target of interest. Thus, the environment surrounding the target significantly affects the performance of ATR. ATR systems should perform well when targets are in the open and the environment is benign. As the complexity of the surrounding clutter increases, ATR performance degrades.

The major challenge for the medical application is that the target is never imaged directly. The thermal imagery indicates the radiance at the skin surface, which depends on the emissivity and the temperature of the skin. If the tumor gives rise to phenomena that are manifested at the surface, then detection may be possible. Once angiogenesis begins, the temperature differential attributed to the blood flow may give rise to the thermal signature that has been observed. To better understand this signature, investigation should focus on the relationship between the signature and key factors such as tumor depth, age of the tumor, room temperature, and the local heat transfer processes in the breast tissue.

Recommendations for Future Investigation

ATR remains a challenging problem, even after years of research. By analogy, it is naive to think that we will soon have an automated system for the early detection of breast cancer based on thermal imagery. Nevertheless, automated processing of thermal imagery holds the promise of assisting the physician in early detection of breast cancer and several areas on investigation could bring that promise closer to realization.

Characterization of the Test Problem

ATR performance depends on a complex set of conditions that affect the quality of the imagery-derived information and the relationship between training and testing conditions. The full set of operating conditions defines a multidimensional space in which the ATR problem resides [13], [16]. For simplicity, it is useful to group these dimensions into three broad categories: sensors, environment, and targets (Figure 2). Values close to the origin in this space of operating conditions represent the simple or nominal conditions for ATR. Often, these conditions resemble the training data for ATR or laboratory data used in ATR development. Moving away from the origin corresponds to increasing the complexity of the problem faced by ATR. The description of the operating conditions for a particular data set indicates whether ATR is confronting an "easy" problem or a "hard" one. The operating conditions provide a natural way to classify various tests of ATR performance and set the results into a meaningful context.

The operating conditions that characterize the medical application will differ in some respects from the ATR problem. The importance of enumerating the operating conditions is to characterize the problem, as a step toward understanding the performance of a processing algorithm. Consider, for example, an algorithm that has been developed from thermal imagery of an older woman. A fundamental question is how will this algorithm perform on imagery of younger women with firmer breast tissue? The explicit identification of the relevant operating conditions provides a framework for addressing these types of questions. By relating performance to the operating conditions, it is possible to assess progress in the development of an algorithm and identify areas where additional work is needed.

Problem Sets

In November of 2000, the Deputy Under Secretary of Defense for Science and Technology Sensor Systems (DUSD (S&T/SS)) chartered the ATR Working Group (ATRWG) to develop guidelines for sanctioned problem sets. Such problem sets are intended for development and testing of ATR algorithms (see [17]). A problem set is more than just data. It includes:

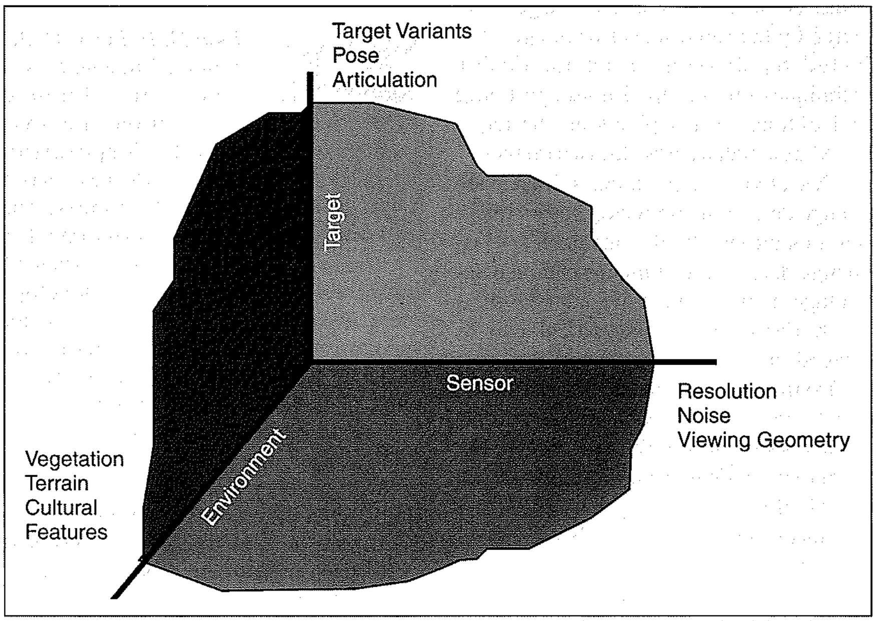
- imagery data
- associated image truth
- meta-data about the imagery collection
- description of the operating conditions encompassed by the data
- recommended experiments that the problem set can support, including the division of data into training and testing sets
- recommended performance measures and analyses.

By using problem sets in the manner envisioned by ATRWG, multiple ATR developers can compare and contrast their results. In some cases, problem sets could also include a sequestered test set, which a government organization could use for impartial testing of algorithms. The value of the problem set is the ability to compare results in meaningful ways. The current efforts to collect and analyze thermal imagery for breast cancer screening can provide the building blocks for one or more problem sets.

Modeling and Signature Development

A thermal image of the breast could contain "bright spots" for a variety of reasons, including the presence of a tumor. The challenge for both the human observer and the image-processing algorithm is to distinguish between the target of interest and other anomalies in the image. ATR developers have explored physics-based models of target signatures to develop greater understanding of the phenomena underlying the observed imagery. Similar investigations could enhance our understanding of the medical application and aid in developing rules for distinguishing tumors from other features in the image.

The fact that the target is below the surface of the skin raises some interesting challenges for characterizing the signature. An analogous military application that is related to ATR is the detection of buried land mines. Thermal imagery can be used to examine surface phenomena that indicate the presence of the subsurface target (see [2], [3], and [12]). For the detection of buried land mines using thermal imagery, empirical methods have provided information about the signatures. Laboratory measurements have



2. The space of operating conditions for ATR evaluation.

Table 2. Operating conditions for the ATR and medical applications.

Class of Conditions	ATR Application	Medical Application
Sensor	Sensing modality Resolution Viewing geometry Image chain	Waveband, spatial and spectral resolution, calibration, viewing geometry, monitor/display, ambient lighting
Target	Target types, model variants, pose, articulation, obscuration	Size, depth, tumor shape, vasculation
Environment	Vegetation Season Terrain Weather Cultural features Confuser targets	Age Pre- or post-menopause Time of day, month Breast size and density Temperature: body, room, time in room Family history and genetics Medications, alcohol, tobacco

been validated with field collections of thermal imagery, and statistical methods provide a characterization of the target signature. Again, analogous methods could be employed for the medical application.

Registration, Change Detection, and Data Fusion

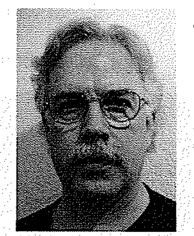
The term "fusion" implies different things to different users [9], [4]. For purposes of this discussion, fusion-based ATR encompasses algorithms that operate on two or more frames of imagery to detect, locate, and recognize military targets. The multiple frames of imagery could come from multiple images collected by the same sensor or images collected by different sensors. Fusion techniques rely on good image-to-image registration, so that pixels on the target can be associated across the two images.

Two obvious applications of fusion are change detection and fusion across imaging modalities. In the medical setting, change detection techniques can take advantage of the control over the environment. For example, the patient can be imaged once when introduced to a cool environment and imaged again after the skin temperature has changed. The differential cooling of some regions will be immediately evident from a comparison of the two images.

Fusion across modalities is more challenging. It is likely that the thermal image and a mammogram provide complementary information. Automated detection of a tumor might be enhanced if these two data sources are exploited synergistically. The challenge of co-registering the data, however, is significant. Not only are the viewing geometries different, the mammography procedure affects the shape of the tissue itself. Simple affine transformations will not be adequate for matching the two data sources and more general techniques must be developed. Registration techniques based on mutual information that permit nonlinear, continuous transformations should be considered.

Conclusions

The lessons learned from the ATR community underscore the importance of developing a clear understanding of the problem and characterizing the conditions under which various approaches succeed or fail. There is no magic answer to automatically extracting information from imagery, but progress is possible through a consistent, well-formulated research effort. The medical community will benefit from the establishment of standard problem sets and the development of a common framework for characterizing the problem. Specific areas of research that hold promise include better understanding of the underlying phenomenology that drives the target signature and exploration of fusion-based methods for data acquisition and analysis.



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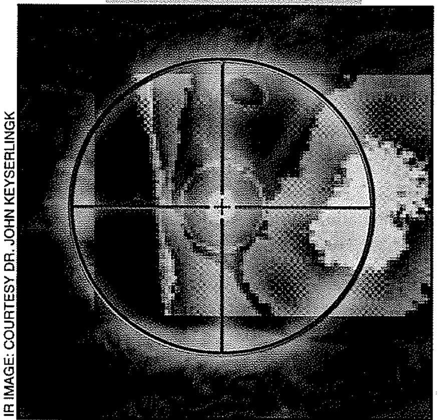

IR IMAGE: COURTESY DR. JOHN KEYSERLINGK

Infrared Imaging: Making Progress in Fulfilling Its Medical Promise

Past, Present, and Future Applications of Infrared Imaging in Medicine

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Infrared imaging in medicine has been around since the early 1970s, but its utility for any medical application has not been clearly demonstrated. Therefore, infrared technology is not widely accepted in medicine. Over the past ten years improvements in infrared systems (including staring array sensors, true digital output, sophisticated image processing, and analysis using target recognition software) have allowed objective analysis of digital radiometric information for a variety of medical applications.

Current medical applications that have supporting documentation in the peer-reviewed medical literature include breast cancer risk assessment and prognosis, analysis of burn trauma, and battlefield application of a helmet-mounted infrared imager for use by medics. Other promising areas for medical application of infrared imaging in medicine include coronary artery bypass surgery, diabetes, deep vein thrombosis, and areas involving angiogenesis (wound healing and microsurgery). However, some classic uses of infrared imaging that have achieved some amount of widespread use, such as pain management, probably will not survive rigorous scientific scrutiny. This article looks at where current applications of medical imaging started and promising future uses as the technology improves.

Applications

Breast Cancer

Initial studies of the application of infrared imaging to breast cancer concentrated on trying to use breast infrared imaging (contact or telethermography) as a stand-alone technology for the detection of breast cancer in a screening environment. The early Breast Cancer Detection and Demonstration Projects (BCDDP), which were done between 1973 and 1981 by the American Cancer Society and National Cancer Institute of the United States, clearly demonstrated the shortcomings of both mammography and infrared imaging of the breast but also showed that mammography was a superior stand-alone detection technology, if only because it localized a lesion that could be then surgically resected and examined by the pathologist to determine if the patient had breast cancer. In other words, even if infrared imaging was able to tell the surgeon that the patient was very likely to have breast cancer, its inability to tell the surgeon where the lesion was, because it is a physiological measurement and not a physical view as in mammography, made it unacceptable as a stand-alone detection device.

The ability of infrared imaging to be used in a multimodality-screening environment has not received the attention that it deserves. Although physical exam and ultrasound examination are widely accepted as techniques that complement mammography and are routinely used in the differential detection/diagnosis of breast cancer, this has not happened with breast infrared imaging. This is despite support for this concept by physicians who routinely use infrared technology. Recently Keyserlingk et al. [1] have shown that in their hands infrared imaging can help confirm the diagnosis of breast cancer, but larger studies are needed to determine if the false positive rate of 66 to 80% in the present clinical setting (physical exam, mammography and/or ultrasound) [2] can be reduced by integrating routine infrared imaging into breast cancer screening programs.

An application of infrared imaging in breast cancer that has been extensively studied with very positive results is the use of breast infrared imaging in risk assessment (determining whether a female is at average or high risk of getting breast cancer during her lifetime). Other imaging technologies (such as mammography, breast ultrasound, magnetic resonance imaging (MRI), and positron emission tomography (PET) scans) have not been found to be useful for predicting whether a woman will develop breast cancer in her lifetime. In addition, infrared imaging was not studied during the Breast Cancer Detection and Demonstration Projects to determine its ability to define a subgroup of women at increased risk of developing breast cancer, as this was not considered important. However, in more recent times intervention or prevention trials have become a reality, specifically the use of the anti-estrogen tamoxifen in patients who have not been diagnosed with breast cancer but are believed to be at a higher than normal risk of getting breast cancer due to their genetic makeup and/or environmental factors. Presently, the Gail Model is used to determine if a woman is at increased risk of getting breast cancer. This model uses age, age at first menstrual period, number of first-degree relatives who have had breast cancer, whether the woman had a previous breast biopsy (number and presence of atypical hyperplasia), and race to determine the risk of getting breast cancer for a woman who has received regular clinical breast exams and screening mammography. This risk assessment model does not apply to genetically predisposed women or women who have previously had a biopsy that contained DCIS (ductal carcinoma in situ) or LCIS (lobular carcinoma in situ). However, even by combining all these factors, less than half of the women at risk of getting breast cancer can be identified, and the women at increased risk only have about a two- to four-fold increase.

Several studies have shown that infrared imaging is a good, and perhaps the best, method for risk assessment in breast cancer. Gautherie and Gros [3] demonstrated in a prospective study of 58,000 women being screened for breast cancer that there were 784 patients that had an abnormal asymmetric infrared image of their breasts with normal physical exams, mammograms, and ultrasounds, and that 298 (38%) of these 784 patients were diagnosed with breast cancer within four years. This is in contrast to expecting only 1-2% of women from the general population being diagnosed with breast cancer in a four-year period, and thus the presence of an abnormal asymmetric infrared heat pattern of the breasts probably increases a woman's risk of getting breast cancer at least ten-fold. In a second study Stark [4] followed 11,249 women who were being screened for breast cancer and found that 1,499, or about 15%, of the women had abnormal asymmetric heat patterns of their breasts. Stark further found that in the next ten years 346, or 23%, of the women with abnormal asymmetric infrared images of their breasts were diagnosed with breast cancer. Stark further found that only 8.1% of women who had not had any children and 8.6% of women with one or two first-degree relatives who had breast cancer (family history) developed breast cancer during the same period of time. Therefore, two of the major criteria used to enroll patients in the tamoxifen prevention trial were poorer risk assessment tools than the presence of an abnormal asymmetric breast infrared image. The presence of atypical hyperplasia in a biopsy sample was found by Stark to result in 30 to 50% of these patients being diagnosed with breast cancer, but only 34 women had this risk marker, and this is too small a proportion of the overall population to be a significant risk assessment tool. In our own studies [5]-[10], we have found that approximately 28% of women have abnormal asymmetric breast infrared patterns (Figure 1) and are therefore at increased risk of getting breast cancer, and this is supported by the fact that a much higher proportion (65%) of breast cancer patients at presentation have an abnormal asymmetric breast infrared pattern (Table 1).

1. A patient with an abnormal asymmetric breast infrared image.

Table 1. Infrared results from normal, cancer, and deceased cancer patients.			
Infrared Results	Patients		
	Normal	Cancer	Deceased
Normal	72 72%	35 35%	15 12%
Abnormal	28 28%	65 65%	111 88%
p < 0.0001, chi-square analysis for independence			

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