Interactive Imagery Exploitation

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ABSTRACT

The vast increase in the amount of imagery to be exploited has led the intelligence community to look for techniques to increase the efficiency of the image analysts, who are also dwindling in number. One approach has been automatic target recognition (ATR). Although ATR has made considerable advancement in recent years it is not yet at the point where automatic recognition is sufficiently robust for general operational use. One hybrid approach being investigated is computer assisted ATR using man in the loop interactive exploitation.

The Interactive Imagery Exploitation (INIMEX) program sponsored by DARPA ISO is one approach to the problem. INIMEX is combining ATR algorithms from DARPA's MSTAR and Image Understanding (IU) programs with a new Human Computer Interface (HCI) paradigm in an attempt to greatly improve exploitation throughput. The HCI is based on the Pad++ Zoomable User Interface (ZUI) software developed by NYU, the University of New Mexico, the University of Maryland, and UCSD. Pad++ uses zooming as a primary method of manipulating data, which gives the exploiter a 3rd dimension to work in as opposed to the 2 dimensions in the past. However, navigation principally involves familiar 2-dimensional concepts. The Pad++ space is conceptually infinite in 3 dimensions and is ideally suited for implementing the electronic sandbox concept. Using this concept, multiple data types are organized in a layered format in which all data types are co-registered.

Lockheed Martin Astronautics is currently implementing a system that incorporates traditional Electronic Light Table (ELT) functions within a ZUI. MSTAR ATR and IU functions, such as target recognition and temporal analysis, are integrated into the system using Pad++'s lens concept. A critical aspect of the program is user involvement. A spiral development approach is being taken with periodic "Mockups" being delivered for evaluation by image analysts and feedback to the developers. INIMEX will be provided to an operational organization for a period of time for evaluation and feedback.

Keywords: automatic target recognition, synthetic aperture radar, interactive imagery exploitation, zoomable user interface

1. BACKGROUND

With the end of the Cold War the Joint Chiefs of Staff (JCS) commissioned a study to define the nature of U.S. Forces and the steps required to achieve this goal in the year 2010. The result of the effort was a document called Joint Vision 2010. "JV 2010 begins by addressing the expected continuities and changes in the strategic environment, including technology trends and their implications for our Armed Forces. It recognizes the crucial importance of our current high quality, highly trained forces and provides the basis for their further enhancement by prescribing how we will fight in the early 21st century. This vision of future warfighting embodies the improved intelligence and command and control available in the information age and goes on to develop four operational concepts: dominant maneuver, precision engagement, full dimensional protection, and focused logistics." JV 2010 recognizes that "Technologically superior equipment has been critical to the success of our forces in combat." In the future "…multispectral sensing, *automated target recognition*, and other advances will enhance the detectability of targets across the battlespace, improving detection ranges, turning night into day for some classes of operations, reducing the risk of fratricide and further accelerating operational tempo." JV 2010 further states that "We must have information superiority: the capability to *collect, process*, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same." Joint Vision 2010 creates the template to guide the transformation of these concepts into joint operational capabilities.

The Advanced Battlespace Information System (ABIS) Task Force was formed to develop a focus for Research and Development to implement the concepts defined in Joint Vision 2010. "We chartered this Task Force on the Advanced Battlespace Information System (ABIS) to explore how emerging information technologies could be used to provide the warfighter with significant new capabilities as articulated by the Chairman, Joint Chiefs of Staff (CJCS) in his recently

published Joint Vision 2010." – Arthur Cebrowski, Vice Admiral, USN, Director for Command, Control, Communications and Computer Systems.

The operational capabilities defined by the ABIS study fall into three areas: The Information Grid, Battlespace Awareness and Effective Force Employment, as shown in Figure 1. In each of these areas, technology base areas and new demonstration opportunities were identified. These are shown in Tables 1 and 2. In the Battlespace Awareness area demonstration areas included *Information Monitoring* and Management, *Real-time Cognition Aiding Displays*, and Distributed Situation Assessment. Technology base areas included *Improved Human Computer Interface* and Computer Support. In the Effective Force Employment area demonstration opportunities included *Automated Target Recognition*.

Effective Force Employment
- Rehearse, Evaluate and Adapt Plans Rapidly
- Synchronize Distributed Force Operations
- Acquire Targets and Execute Timely Response

Battlespace Awareness
- Collaborative Situation Assessment
- Consistency of View Across All Forces
- Tailored Information Distribution

The Information Grid
- Single Federation of Heterogeneous Information Systems
- Infrastructure Support of Distributed Processes, Information Search, and Collaborative Work
- Seamless Responsive Communications
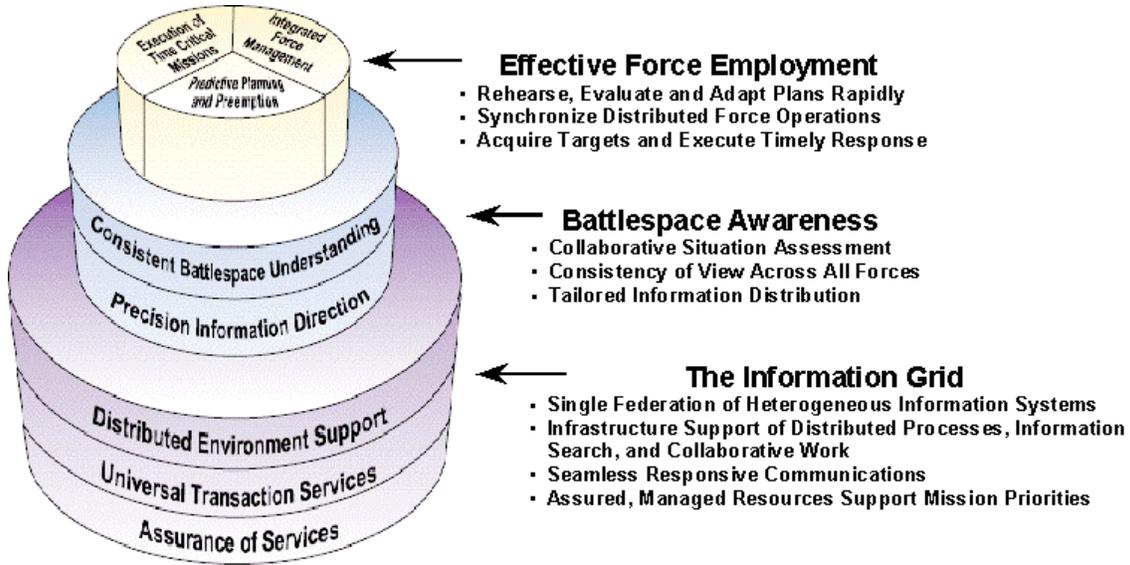- Assured, Managed Resources Support Mission Priorities

Figure 1. Operational capability areas of the ABIS study.

The need for a reassessment is driven by the drawdown in military strength, which is naturally resulting in a smaller number of personnel in every job specialty. This is particularly acute in the intelligence, surveillance and reconnaissance areas. As the nature of the threat changes from the Cold War paradigm to one of smaller but more numerous threats, intelligence activities require that more sensors be employed to monitor vast areas of the earth's surface. Additionally, more sensors that collect higher resolution data for long periods of time, e.g., the Darkstar and Global Hawk UAV's, are being developed for wide scale deployment in the near future. These will collect vast amounts of imagery and other intelligence data, which needs to be exploited. Simultaneously with this increase in imagery data the number of image analysts (IA's) has decreased dramatically in the last few years.

One of the technologies that DOD is pursuing to deal with this problem is Automatic Target Recognition (ATR), the capability to identify enemy targets via computer algorithms. ATR progress has been slow but steady. However, ATR performance has not yet reached the point where ATR algorithms can reliably identify large numbers of target types in all actual imaging conditions. Targets with similar signatures can still be confused; target articulation and aspect angle differences also cause signature variation. Finally target obscuration, i.e. the blocking of part of the target by revetments or other targets, and targets in tree lines are difficult to deal with since only a partial signature is obtained.

Due to these current difficulties the only viable approach to fielding an ATR capability in the near term is to provide an interactive ATR capability that keeps the man in the loop. At the same time the lack of IA's makes it desirable for IA's at remote locations to be able to collaborate with each other. This is an effective force multiplier since any exploitation site in the world can consult an IA expert in a particular area. The overall Battlefield Awareness goal is to have as much intelligence data available to the decision-maker as possible. This implies that all intelligence data be assembled in one location at some point of the overall intelligence process, and that a user interface exists that gives the IA intuitive and efficient access to the entire assemblage of data.

Table 1. ABIS technology base areas.

• Grid Services
  – Intelligent Agent and Tool Support for
    Operational Functions
  – Support to Seamless Networking
  – Tools for Management and Defense of Grid
  – Improved System Capability, Architecture, and
    Integration
  – Robust, Secure, Real-Time Geolocation and
    Timing

• Battlespace Awareness
  – Improved Intelligence Processing and Fusion
  – *Improved Human Computer Interface and*
    Cognitive Support
  – *Information Warfare Event Detection,*
    Classification, and Tracking

▪ Effective Force Employment
  – *Automated Planning and Reasoning Tools*
  – Fast Running Modeling and Simulation

Table 2. Near term ABIS demonstration opportunities.

• Grid Services
  – Robust Tactical/Mobile Networking
  – C4I for the Grid
  – Information Security

• Battlespace Awareness
  – Integrated Sensor Tasking
  – *Real-Time Cognition Aiding Displays*
  – Distributed Situation Assessment

• Effective Force Employment
  – Integrated Fusion and Target Tracking
  – Automated Weapon-to-Target Pairing
  – *Automated Target Recognition*
  – Joint, Early Entry C4I for Rapid Force
    Projection
  – IW Battle Management

Various types of intelligence may be required to be exploited and made available to the decision-maker. This paper primarily addresses Image Intelligence (IMINT) applications, which is broken down into Electro-optical (EO), Infrared (IR) and Synthetic Aperture Radar (SAR) imaging sensors. The primary focus of the INIMEX program is SAR imagery and SAR ATR. A certain amount of EO imagery is included to demonstrate certain concepts.

In addition to data from real time intelligence sources certain other data is required to support the exploitation process. This information includes, Digital Terrain Elevation Data (DTED), Digital Features Analysis Data (DFAD) vector data, terrain type data, hydrologic, bathymetric and military unit symbology to provide and high view of the battle space. Not all applications will need all of these data types. Also, in some applications such as site monitoring, site models are useful to help determine changes which may have occurred in the scene over time.

2. INTRODUCTION TO INIMEX

INIMEX is a DARPA program that was conceived to provide an exploitation environment for the MSTAR ATR algorithms. The primary goals of INIMEX are:
- Give the IA ready access to georegistered context information: maps, current and historical imagery, reports, and collateral data such as signals intelligence, etc.
- Give the IA an intuitive and efficient user interface so the analyst can incorporate large amounts of information into an analysis task.
- Give the IA intuitive methods for navigating within a 2D world space, and for navigating through a spatio-temporal world space. The IA must maintain a good sense of spatial context.
- Give the IA intuitive methods for selectively viewing and navigating through this information. The IA must maintain a good sense of task-specific information context.
- Give the IA insight into and control over interactive or semi-automated analysis aids. This project focuses on (a) interactive aids for cueing and identification of vehicles utilizing model-based vision, and (b) semi-automated aids for wide area search and facility monitoring utilizing image understanding technology.
  - Provide the user context which is not currently available for ATR algorithms.
  - Provide IA insight and control over MSTAR algorithms.
  - Share this context and MSTAR algorithm results with a distributed user base.

The INIMEX program is using the results of several DARPA programs to achieve these goals. These include: MSTAR [4,5], Image Understanding (IU) [3], MOSTAR, SAIP, Human Computer Interaction [2,6], and Collaborative Exploitation.

As a result of a DARPA study panel on Interactive Exploitation the concept of an electronic sand box was developed as a method of organizing and displaying imagery and the support data required for effective image exploitation. The concept essentially provides for data to be organized in layers which are georeferenced. Subsets of the data from any of the relevant layers can be visualized. The sandbox also has the advantage of being compatible with any of the intelligence sources and support data that rely on geolocation. The sandbox concept is illustrated in Figure 2. INIMEX is exploiting the sandbox concept through the use of the Pad++ Zoomable User Interface.

Pad++ is an approach to graphical user interfaces that relies on zooming as its primary mechanism for navigating through a conceptually infinite 3-dimensional space. Data of essentially any type (e.g., imagery, maps, text) can be stored and manipulated using the Pad++ paradigm. The Pad++ space is illustrated in Figure 3. Conceptually Pad++ is infinite in 3 dimensional space with a specific type of data stored on each layer in the z direction. As can be seen from comparing figures 2 & 3 the Pad++ design offers an ideal mechanism for implementing the electronic sandbox concept.

Zooming can be of two basic types. In the case of imagery, for example, an operator can zoom to increase the resolution of a small area that he wishes to examine in more detail. Zooming out allows the operator to traverse large areas of image coverage more efficiently, as opposed to trying to traverse the image at high resolution. Since the lower resolution imagery has fewer pixels, the traverse can be done more quickly. Then, at the desired location the operator can zoom back in to get the detail desired. The second type of zooming, semantic zooming, allows the user to zoom through layers of data to access different levels of detail. For example, consider text data. The highest level might be a technical manual title. Lower levels might be chapter, section headers, and the text itself. The user would begin with a screen of manual titles, place his cursor on the title desired, and then zoom to get progressively the desired chapter, section and text.

Pad++ enables a new paradigm for IA's, one which allows the analyst to greatly increase the amount of data available through the use of the 3-dimensional organization of data as opposed to the 2-dimensional space available in traditional Electronic Light Table approaches. Pad++ also has the advantage that virtually any software function can be bound to a Pad++ lens allowing functionality such as the MSTAR ATR algorithms to be easily incorporated into an IA workstation.

It is important that basic ELT tools be incorporated into INIMEX. This is true for two reasons. First these functions are required to do the IA job and secondly this provides a familiar frame of reference to ease the transition for IA's from the ELT paradigm to the INIMEX paradigm. In a study done by the Air Force[1], various IA tools were evaluated for utility. These tools are listed in Table 3 ranked by utility for wide area search and detailed analysis scenarios. Air Force and Army IA's were asked to rank the utility of these tools from 0 to 4. It is interesting to note that the ability to zoom on imagery was ranked first for both scenarios. INIMEX is incorporating most of these tools prioritized by their utility. INIMEX is also incorporating tools that are new to most AI's, such as ATR and interactive online target folders.
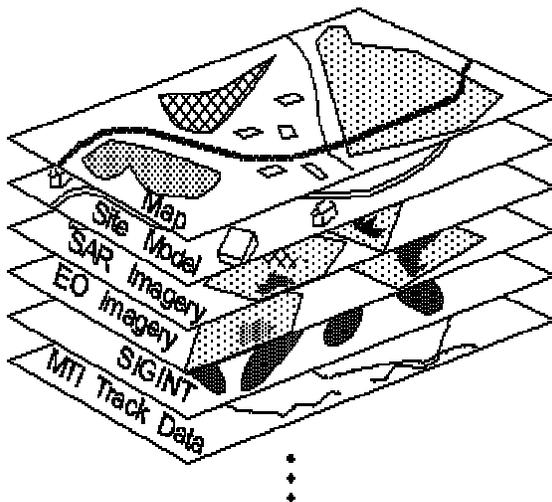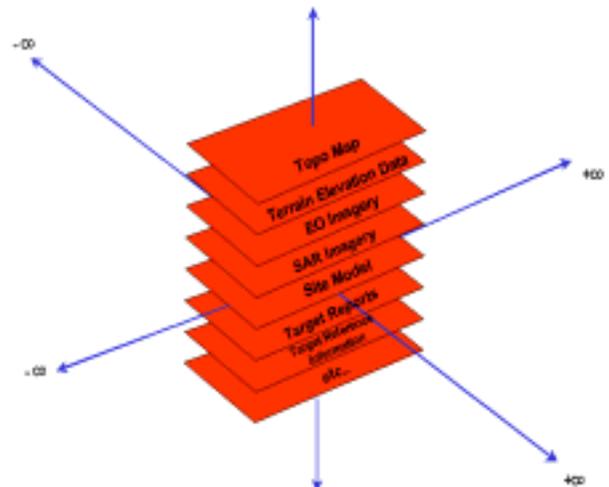

Figure 2. Electronic sandbox.

Figure 3. Pad++ space.

Table 3. Utility of image analyst tools and capabilities

Wide Area Search Tool or Capability	Utility	Detailed Analysis Tool or Capability	Utility
Magnification/Zoom	4.0	Magnification/Zoom	4.0
Mensuration	4.0	Mensuration	4.0
Lat./Long.	3.9	Lat./Long.	4.0
Coordinate Determination	3.8	Contrast	4.0
Imagery Header	3.8	Image Chipping Tool	4.0
Dynamic tasking	3.6	UTM	4.0
Change Detection	3.5	Rotation	3.9
Contrast	3.5	Dynamic tasking	3.8
Brightness	3.5	Brightness	3.8
Annotation	3.5	Annotation	3.62
Image Chipping Tool	3.5	Edge Sharpening	3.6
Edge Sharpening	3.5	WGS	3.6
Gray Scale	3.4	Edge Detection	3.6
Pixel Sharpening	3.3	Coordinate Determination	3.5
Rotation	3.3	Imagery Header	3.5
UTM	3.2	Gray Scale	3.5
WGS	3.1	Scene Comparisons	3.5
Imagery Key Tools Online	3.1	Change Detection	3.4
Automatic Target Cueing	3.0	Imagery Key Tools Online	3.25
Edge Detection	3.0	Pixel Sharpening	3.0
Waterfall Image Display	2.9	System Coordinate Accuracy Data	3.0
Scene Comparisons	2.9	Automatic Target Cueing	2.85
System Coordinate Accuracy Data	2.9	Automatic Target Recognition	2.85
Automatic Target Recognition	2.8	Declutter	2.85
SIGINT/Imagery Correlation	2.8	Range and Bearing Tool	2.8
Lines Of Communication Overlays	2.7	Lines Of Communication Overlays	2.7
Range and Bearing Tool	2.7	SIGINT/Imagery Correlation	2.57
Target Nomination	1.9	Waterfall Image Display	2.4
Declutter	1.4	Target Nomination	2.0

3. IA CAPABILITIES WITHIN INIMEX

This section discusses how the top-ranked capabilities in Table 3 are instantiated within the INIMEX zoomable user interface.

Magnification/Zoom (Utilities of 4.0 and 4.0)

The smooth pan/zoom capability of the INIMEX system and the overall ease-of-use for spatial browsing are simple, basic strengths. The ability to perform smooth zooming, smooth panning, and combined smooth pan/zoom movements is of fundamental importance in an image analysis workstation. Current systems provide smooth panning (or an approximation), and most provide jump zooming by factors of two of isolated image displays or of relatively plain map displays. INIMEX provides smooth continuous zooming of a single unified sandbox surface. The standard mouse bindings currently used for INIMEX allow the user to pan using the left mouse button and to smoothly zoom in and out with the middle and right mouse buttons. Dragging during a zoom results in a smooth simultaneous pan and zoom motion.

The IA utilizes zooming for basic navigation through a georeferenced space -- for example to move from analyzing something at one side of a large industrial facility to something at the other side, perhaps one kilometer away. The continuity provided by an intuitive ability to smoothly pan and zoom greatly enhances an analyst's ability to maintain spatial context during analysis tasks.

An animated two-step pan/zoom capability, presently unique to Pad++ and INIMEX, is a powerful technique that further helps the IA maintain spatial context during analysis tasks. This animated move transforms the display from one position/scale to another by first zooming the display out so that both the start and end positions are visible, then panning over toward the end position, and finally zooming in to the final zoom. During this process the user gets a clear idea of the relative positions of the starting and ending locations.

Scale adds a third dimension to the space in which user interfaces can be designed. Every piece of text, graphical object, or widget in a zoomable graphics display system generally has a minimum and maximum screen size at which it is visible. A widget remains active no matter what zoom the widget is viewed at, as long as the widget is visible. Figure 4(a)-(d) show a simple example of how objects can be organized in scale space and made selectively visible. Here one object, a slide, is organized "behind" another slide (specifically in-between two letters on the first slide).

In semantic zooming, an object's visual representation and the information it conveys changes in a coordinated fashion along with the amount of spatial zooming of the object. Typically the amount of detail conveyed will increase as the view of an object is zoomed in more. A simple example of semantic zooming, illustrated in Figure 4(e)-(l), causes different resolution raster maps to automatically fade in and out as the analyst smoothly zooms in from an overview of a large area to a close-up of a small area. Of course any one map being displayed will smoothly zoom over its visible range. The effect is that the analyst always sees the best map for the immediate zoom level. Existing analyst workstations typically require the user to select a specific map for display from a tabular list.
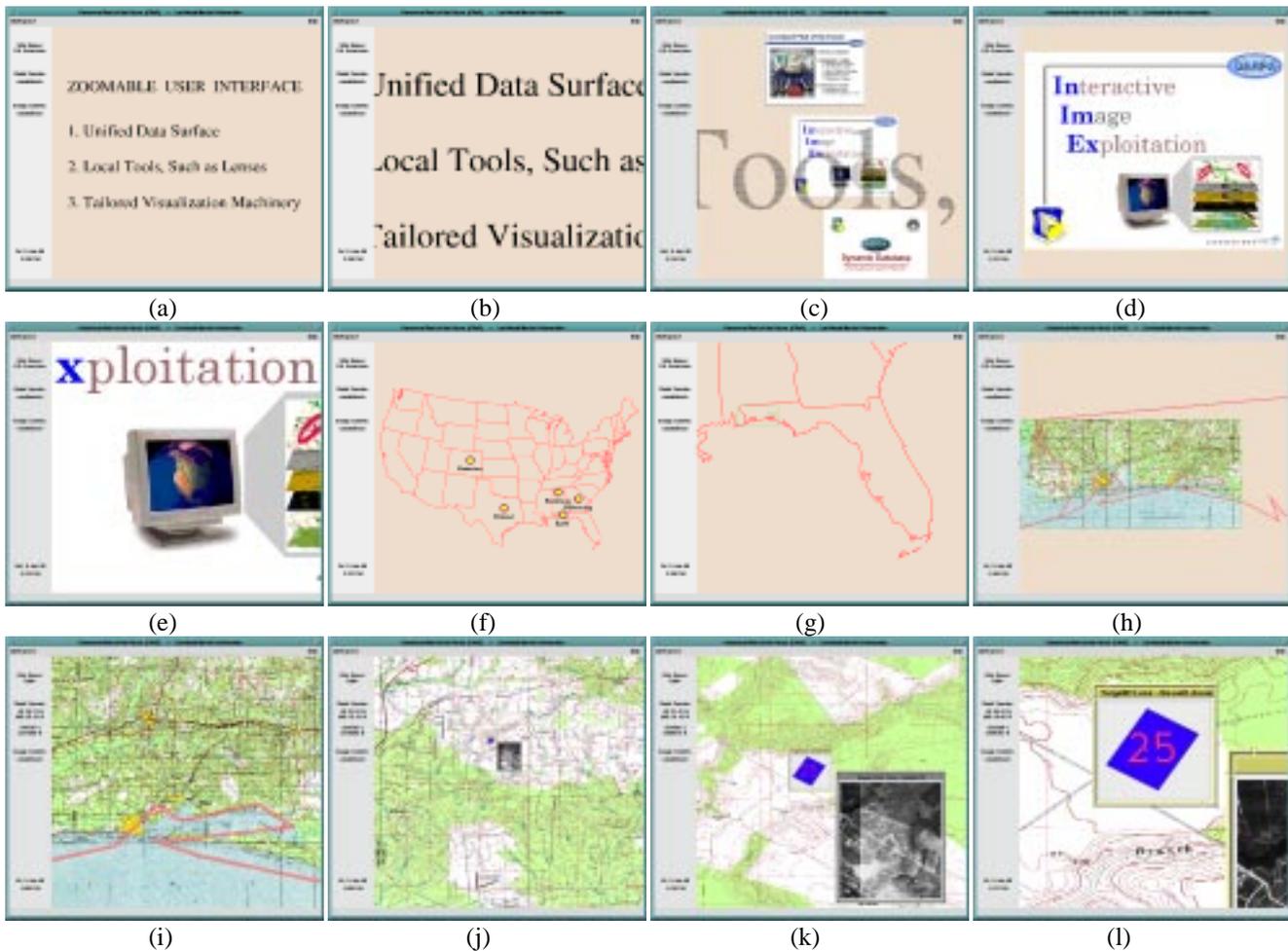

Figure 4. This sequence of screens shows how one slide can be hidden behind another using the scale dimension, and then it shows a form of semantic zooming of multi-scale maps.

Semantic zooming can be extremely useful for pigeon-holing military deployment information into INIMEX's georeferenced world. For example, in Figure 5, as the user zooms in on a specific target vehicle in a synthetic aperture radar (SAR) image, increasing amounts of vehicle information are displayed. The information displayed here reflects automated analysis performed by the MSTAR target identification system. Initially a number of target identification objects are visible, displayed as boxes, which indicate only that vehicles have been detected there. Further zooming shows: the highest scoring target identification hypothesis, the ranked list of identification hypotheses, the addition of a bar graph depicting the matching scores for each hypothesis, and finally numerical labels for the bar graph. Note that as an alternative to semantic zooming, each one of the visual representations for a single target identification object could alternatively be provided by a separate lens (see Figure 14).

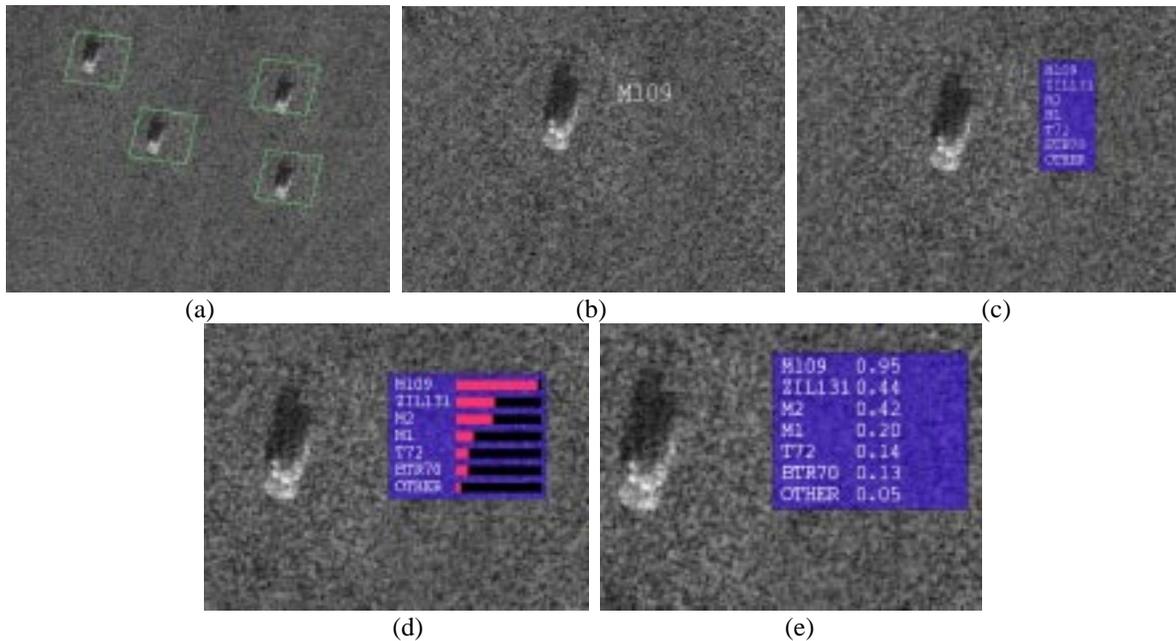(a)　　　　　　　　　　　　(b)　　　　　　　　　　　　(c)

(d)　　　　　　　　　　　　(e)

Figure 5. This sequence of display fragments shows a form of semantic zooming of the results from a automated target identification system that analyzed the SAR image shown in the background. These display fragments are from inside the view of a lens that is too large to be visible here.

Mensuration (Utilities of 4.0 and 4.0)

Lenses are user interface tools that provide a window with different views of the INIMEX data surface. Lenses reside on the INIMEX surface. A lens shows a particular visual representation of a particular subset of objects that overlap the lens, and the user interacts with objects through a lens, or in some cases interacts with the lens through various kinds of controls embedded in the lens itself. What a lens displays is called a view, since it is a view onto the INIMEX surface.

Mensuration, the ability to measure real-world distances (meters typically), is a basic requirement for the IA. Types of distances can range from the dimensions of a vehicle, building, or facility to the movement of a force element on the battlefield. Since everything in INIMEX is georeferenced (as in the sandbox), distances on the screen are always proportional to distances in the real world.

INIMEX provides a simple mensuration lens, as shown in Figure 6. The user drags the endpoints of a line segment -- through the lens -- and the lens always shows the length of the line segment. Other mensuration lenses could present shapes (e.g., polygon) and display relevant measurements.
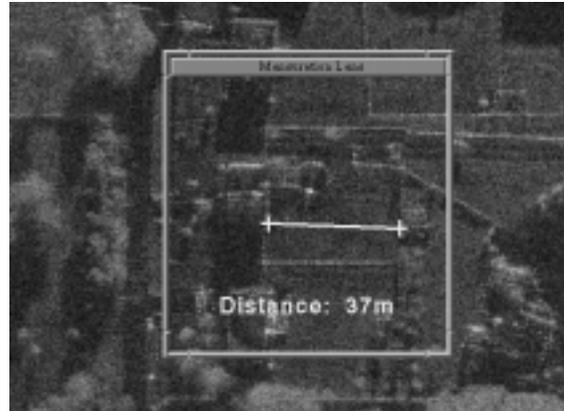
Figure 6. This mensuration lens shows the length of a line segment manipulated by dragging the segment's endpoints through the lens.

Lat./Long. (Utilities of 3.9 and 4.0)
Coordinate Determination (Utilities of 3.8 and 3.5)
UTM (Utilities of 3.2 and 4.0)
WGS (Utilities of 3.1 and 3.6)

It is crucial for an IA to maintain a feeling for the spatial context in which he is working. Since INIMEX fully implements the sandbox concept, coordinates and distances on the INIMEX surface correspond directly with world coordinates and distances, specifically the internal coordinate system is latitude/longitude in WGS-84. The world coordinates of the mouse are always displayed, in multiple forms, on the far left side of the screen.

Analysts often prefer to see a reference map or overview image in the background of the screen in order to help maintain an idea of where they are located in the world. Unfortunately there can only be one background at a time, and such a background can confuse the appearance of the primary data the analyst is studying. Two lenses, a rastermap viewing lens and an image viewing lens, provide simultaneous display of both types of data, as illustrated in Figure 7. An important aspect of this example is that the user can scan one of the lenses around on the screen, for example by following a road with the rastermap lens, and thus simultaneously combine a (registered) view of the overview image and the rastermap.

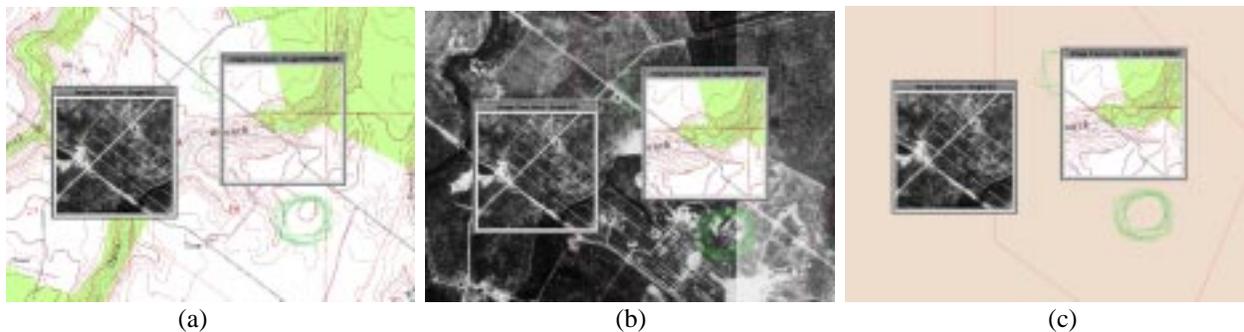(a)   (b)   (c)

Figure 7. (a) A rastermap is displayed globally (by clicking through the rastermap viewing lens) while an image view lens lets the user see specific details in an EO image. (b) The EO image is displayed globally while a rastermap lens provides a selective view of the map. (c) The user utilizes both lenses, freeing up screen space for other more important data or tools.

Image Chipping Tool (Utilities of 3.5 and 4.0)

A surface portal is a generalization of a lens that provides an independent view of any area of the Pad++ surface at any zoom. The view may show any set of the display layers on which all Pad++ objects reside. Figure 8 shows an example of a surface portal used within INIMEX, a kind of spatial bookmark called a teleportal. The teleportal shows a view of the bookmarked area, and clicking through the teleportal causes the main display (itself a view) to be transformed via an animated pan/zoom to

the bookmarked area. Once there, the teleportal view is reset to the position and zoom before the teleport motion was initiated. Normally, all lens and surface portal tools in INIMEX reside on the georeferenced surface. The teleportal has a different property enabled, called stickiness, that effectively causes the tool to be glued to the glass of the display screen as the main display's view changes. If the teleportal was not sticky it would remain at the previous geolocation, an option available to the user through the popup property menu shared by all lenses.

Other than teleporting to a bookmarked location, a surface portal can simply serve as a convenient visual reference. For example, one can provide a thumbnail overview of the current site under analysis, or one can provide a close-up of specific vehicles located in some imagery from a week ago and suspected of being the same vehicles found today at a different location on the battlefield. The collection of world views provided by a set of surface portals that an analyst has created during a session can readily be inserted as image chips into a report creation tool. Alternatively, a *cut/paste portal* would paste an image chip of its own current view into a report creation buffer whenever a button built into the cut/paste portal is pressed.
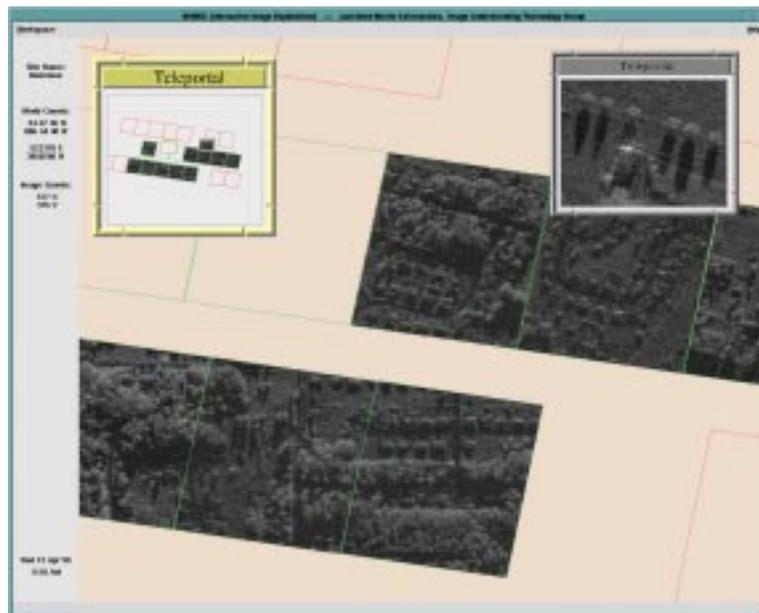

Figure 8. The teleportal tool is essentially a Pad++ portal widget with window dressing and one mouse binding. The portal displays a view of a bookmarked area, and clicking the mouse through the portal causes the main display to be transformed to view the bookmarked area.

Contrast (Utilities of 3.5 and 4.0)
Brightness (Utilities of 3.5 and 3.8)
Edge Sharpening (Utilities of 3.5 and 3.6)
Pixel Sharpening (Utilities of 3.3 and 3.0)
Gray Scale (Utilities of 3.4 and 3.5)
Edge Detection (Utilities of 3.0 and 3.6)

The user's conceptual model for a lens, as described so far, is that the lens provides a view of (or operates on) only the data directly underneath the lens. Most image processing operations require intense numerical computations that seldom can be accomplished in anything close to real time, especially when images have as many as ten thousand rows and columns. Lenses enable an analyst to view image processing results in real time, such as an image enhancement. This is possible because the lens actually only performs the operation on the portion of the image visible underneath it. In practice, an analyst is usually zoomed in on a small portion of an image, so any image processing lens will cover only a very small portion of the entire image. By scanning a small-sized lens over areas of interest the analyst can perform analysis operations over a large area in real time. Thus, operations such as contrast and brightness (Figure 9), edge sharpening, pixel sharpening, edge detection, etc., are all done via lenses within INIMEX.

Figure 9. The image controls lens gives the user a fast preview of the brightness and contrast settings for an image. The preview is only for the image area inside the lens, rather than for the entire image.

Rotation (Utilities of 3.3 and 3.9)

Image rotation is another image processing operation, as above, and thus rotated images will be viewed inside lenses.

Dynamic tasking (Utilities of 3.6 and 3.8)

INIMEX includes more complex lenses that could be used to review new imagery as it arrives in near real time. The footprints (i.e., outlines) of incoming imagery would immediately be inserted into INIMEX's database system and would be seen on the INIMEX surface, if that area is currently visible. The analyst can query when the footprints in an area were collected by using a *timeline image selection* lens, as shown in Figure 10. This lens associates image footprints displayed in the upper panel of the lens and collection times as depicted by icons on a timeline in the lower panel. The timeline panel is a view of a separately zoomable timeline surface, which supports semantic zooming over different timeline scales (i.e., hour, day, week, month, year).

The georeferenced INIMEX surface is an ideal medium for entering dynamic tasking requests. The user would click on the desired collection areas through a *dynamic tasking* lens.
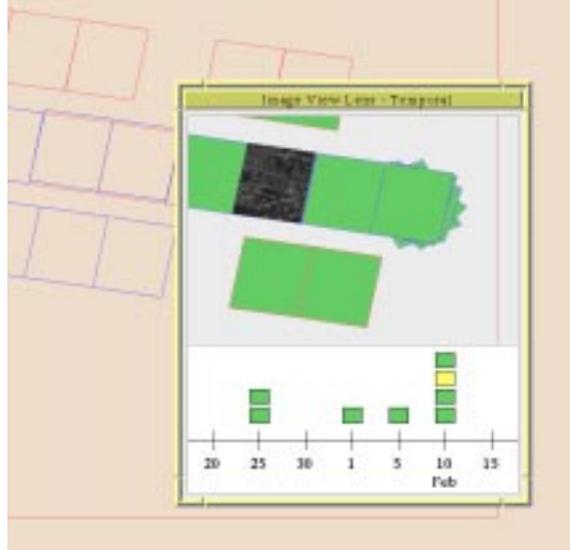
Figure 10. The timeline image selection lens shows image footprints and corresponding icons on a timeline that show when the images were collected.

Imagery Header (Utilities of 3.8 and 3.5)

The set of lenses available to the user must provide a huge variety of functions. How to provide this variety of functionality in the user's mind and hands is a fundamental design question. At one end of the spectrum, the user could be provided with a set of complex, monolithic lenses. Each lens would provide a number of related functions, selectable through various kinds of option selections built into the lens. At the other end of the spectrum, the user could be provided with a set of primitive lenses, several of which must be stacked to compose a complex function. The monolithic approach to lenses is straightforward, but the stacked primitive approach to lenses is more natural for certain functions. Conceptually, a stack of lenses implements a sequence of operations on a set of input objects: The bottom-most lens selects a set of input objects (overlapping the lens' view), applies an operation to the set, and outputs a set of objects. The objects output from a lens are rendered and may be passed as input to a lens stacked above. One example is a stack of image processing lenses, where each lens operation is essentially specified by a parameterized operator.

Collection date and time information stored in an image header can be visualized by a temporal range selection lens, which can also be utilized to select a collection of images based on a time range. This kind of lens could be stacked under an image exploitation lens under a plotting lens. More generally, multiple database query/visualization lenses can be stacked to compose a complex database query on other data fields in the image headers for all the image objects underneath the lens. Pre-defined or user-customized lenses provide displays of the most commonly desired image header information (date, time, depression, squint, etc.).

Annotation (Utilities of 3.5 and 3.62)

User created annotations are simply another type of data object embedded inside the INIMEX geosurface, as illustrated in Figure 11. Simple hand-drawn annotations are supported, as is standard military symbology. More sophisticated embedded annotations are possible, such as a folder containing more detailed analyst notes. Annotations are usually organized into layers, and like other data layers such as vector maps, are best viewed using lenses.
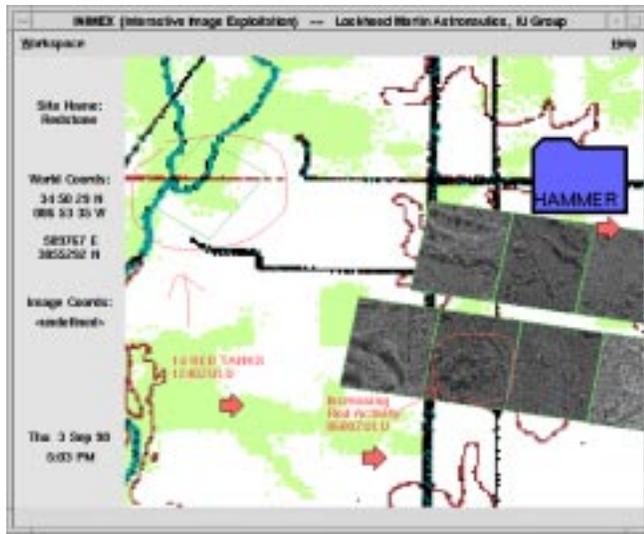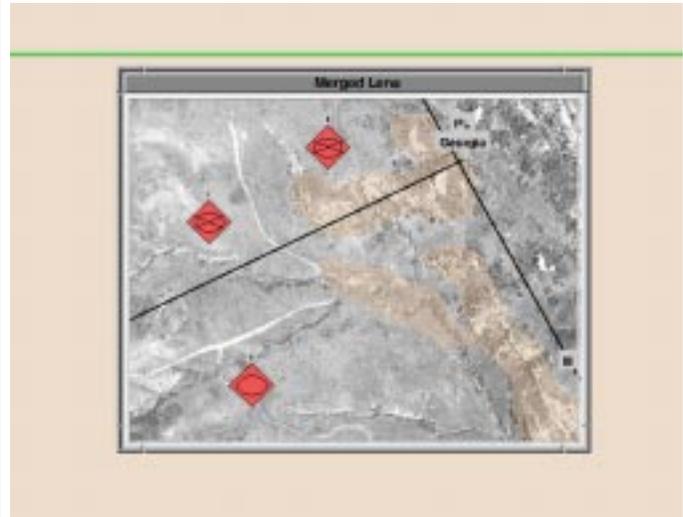
<div align="center">(a)   (b)</div>

Figure 11. User-created annotations are another type of data object embedded on the INIMEX surface. Annotations can be made (a) globally visible, or (b) they can be viewed more selectively through lenses. Clicking the mouse through a lens displaying an annotation layer toggles the global display of that annotation layer.

Change Detection (Utilities of 3.5 and 3.4)
Automatic Target Cueing (Utilities of 3.0 and 2.85)

INIMEX uses an approach similar to *profiles* developed in the RADIUS project [3], but also extended to a wide area search problem domain. The IA will associate a region in the world and an algorithm (MSTAR or an IU module) to be run on images covering that region. The IA could also specify conditions detected by the algorithm for which the analyst is to be notified. Notifications will appear as iconic alert symbols embedded in the INIMEX surface. The analyst could also peruse these alerts via lenses, or ask that the system automatically sequence (using animated pan/zoom moves) through a set of alert locations.

Scene Comparisons (Utilities of 2.9 and 3.5)

Various lens tools can be used to compare two scenes or two images. For example, lens A can display image A, and lens B can display image B, and reference image X may be displayed globally in the background. Comparisons are made by scanning the lenses over specific areas of interest. Figure 7 showed a similar arrangement used to compare one EO image with one rastermap. A single lens with a built-in "wipe bar" could also be used to display two images side by side or blended together inside a single lens. These same lens tools can be used to compare entire scenes of objects, instead of just two image objects.

Automatic Target Recognition (Utilities of 2.8 and 2.85)
Imagery Key Tools Online (Utilities of 3.1 and 3.25)

The first interactive-ATR tools for SAR imagery were designed within the classic windows, icons, menus, pointers (WIMP) user interface design paradigm. One such I-ATR tool is shown in Figure 12. A top-level window contains all elements of the interface, including several panels where distinct types of data are displayed, an extensively populated menu bar with submenus, and a scattering of other commands and options embedded within the panels. This I-ATR tool was also designed primarily for developers of ATR technology, rather than for an image analyst.

INIMEX is developing I-ATR tools for the image analyst, based on the Zoomable User Interface (ZUI) design paradigm and the electronic sandbox concept. While the target user and the interface are very different, the core functionality is similar to earlier SAR I-ATR tools. Typically, the analyst is looking at a single target vehicle in a recently collected SAR image. The I-ATR tool lets the analyst select a specific vehicle type, manipulate the state of that vehicle's model (orientation, turret angle, presence of external fuel tanks, etc.), and the analyst then sees a predicted SAR image based on the specified model state. The analyst can interactively change the model state and compare predicted SAR images with the observed SAR image until the analyst is confident about his identification of that vehicle.
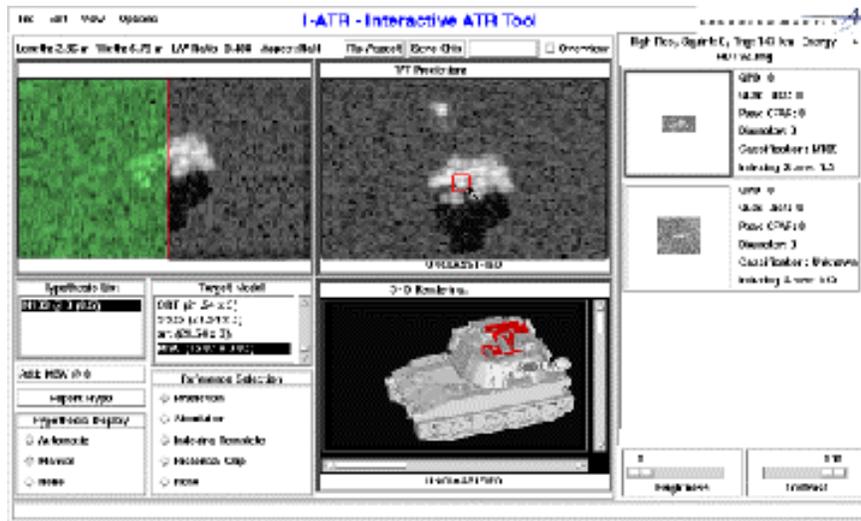
Figure 12. Example of a developer-oriented window-based interactive-ATR user interface that is neither zoomable nor designed for an electronic sandbox.

Exploitation problem domains that INIMEX is addressing are installation and force monitoring (IFM) and wide area search for time critical targets (WAS/TCT). At various points during a particular exploitation effort, the IA will need to focus inward on specific vehicles and identify them. This is the point where the IA may chose to utilize an I-ATR tool to aid and speed up his work. I-ATR tools used at this point are just another part of the unified analyst workstation, so they are readily called up and provide familiar user interfaces consistent with the rest of the unified analyst workstation. All images within INIMEX are warped so they are properly georegistered.

An I-ATR tool's functionality must match the needs of analysts with varying levels of experience in identifying vehicles. Any SAR IA will have an initial idea of the category of a vehicle, if not an initial guess at the identification of the vehicle. For example, a modern Soviet-design main battle tank has a signature that can often be readily recognized. However, much more detailed analysis is required to determine the exact type of tank (e.g., T-72 vs. T-62). I-ATR tools can be invaluable to help the IA make this final decision. As another example, when a long gun barrel is visible, the vehicle category is narrowed down (e.g., tank or artillery), and then the analyst might use an I-ATR tool as an on-line recognition key to quickly narrow the category down further. In practice, the MSTAR system will have processed and identified every vehicle in every image, so the analyst may generate his own initial identification (without the I-ATR aids) and then call up the MSTAR-generated identification, with explanatory displays such as an annotated display of MSTAR's guess at the vehicle state, and this display may provide sufficient to help boost the IA's level of confidence in his identification. If not, the I-ATR tools can be used to explore different vehicle configurations until the IA is satisfied with his reasoning

The I-ATR tools being developed within INIMEX will be hosted inside a set of lenses. One lens will display a view of the 3D model, and will allow the model state to be changed by directly manipulating the model. Other associated lenses will show the predicted SAR image and extracted features. Selecting a feature will highlight the model facets that account for that feature, and selecting a model facet will highlight any associated features in the predicted SAR image. From any given model state, the IA can ask the MSTAR system to search for a better model state, and can watch the automatic search process via the lens displays. The IA can interrupt at any time, modify the model state, and have MSTAR resume the search process. In addition, the IA can take over control of some model state parameters, while letting the MSTAR system try to optimize the remaining parameters.

Figure 13 shows an initial lens that permits manipulation of the vehicle model state. Several I-ATR lenses (model state, predicted SAR image, extracted features, etc.) can be associated in different ways. All use techniques, still under development, for constructing *composite lenses*. A set of lenses can be associated by stacking them so they overlap. All the stacked lenses operate on one vehicle detection and one model state. A set of lenses can be associated by logical connections, called a locked set of lenses. For example, all lenses with a green marker placed on the lens header are associated. Finally, a set of lenses can be docked, in which case they are physically abutting one another.
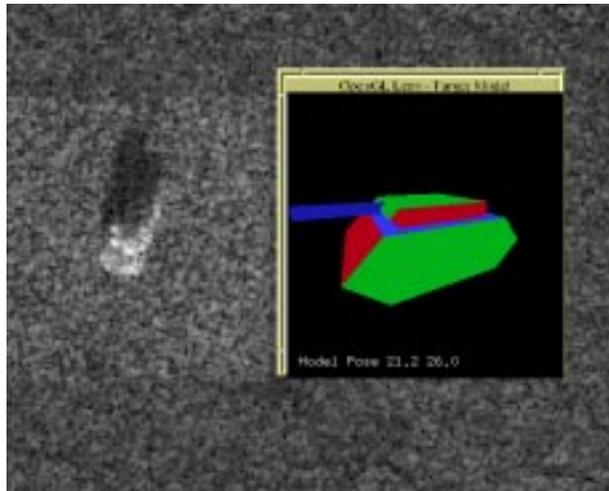
Figure 13. Lens that displays an OpenGL rendered view of a vehicle model associated with a specific target identification. The user will be able to manipulate the hypothesized target model state and generate new predicted SAR images and MSTAR results for the modified model state.

The target identification hypotheses generated by the MSTAR system are currently created off-line before the time that imagery is first ingested into the INIMEX system. Depending on the specific system configuration and desired output, the MSTAR target identification system can require many minutes to process a single SAR image chip of a detected target. Some MSTAR functions run at speeds close to those needed for interactive uses and we are working to speed up some functions.

One of the more striking and useful aspects of a lens is that different lenses can show different graphical representations of an object. The INIMEX application domain contains many types of objects for which the user may want to see different visual representations at different times. For example, a set of lenses can provide different visual representations of a vehicle identification hypothesis, as shown in Figure 14.
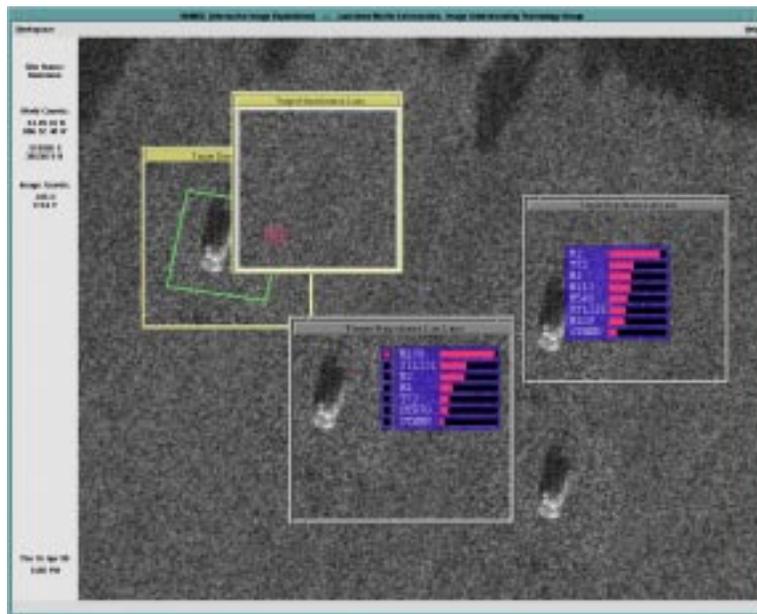

Figure 14. This set of lenses provides different visual representations of the vehicle identification hypothesis data for vehicles.

4. SUMMARY

INIMEX is introducing a new paradigm for image exploitation that incorporates existing IA tools along with new tools such as automated target recognition. INIMEX addresses ABIS documented requirements in the areas of automated target recognition, real time cognition aided displays and improved human computer interface and cognitive support.

INIMEX has demonstrated the following novel claims:
- First image exploitation application using a zoomable user interface.
- First illustration of sophisticated lenses for image exploitation.
- First coherent set of lens tools for the image analyst.
- New types of stacked lenses whose operations combine.
- First zoomable tool palette and task-step tool organizer.

The INIMEX program includes human factors evaluations. This will be accomplished in two ways. Firstly, structured human factors will be conducted. Secondly interim versions of the INIMEX software will be provided to users to evaluate and provide feedback for subsequent software versions.

5. ACKNOWLEDGEMENTS

6. REFERENCES

1. Adroit Systems Incorporated, Technical Staff, "An Evaluation Of Required Tools For The Image Analyst," Report to Crew Systems Directorate, Human Engineering Division, Armstrong Laboratory, Wright-Patterson Air Force Base, October 1997.
2. B. Bederson, et al., "Pad++: A Zoomable Graphical Sketchpad for Exploring Alternate Interface Physics," Journal of Visual Languages and Computing, 1996, Volume 7, pages 3-31.
3. O. Firschein, T. M. Strat, eds., *RADIUS: Image Understanding for Imagery Intelligence*, Morgan Kaufman, 1997.
4. E.R. Keydel, S.W. Lee, J.T. Moore, "MSTAR Extended Operating Conditions: A Tutorial," Proceedings of SPIE, Vol. 2757, SPIE'97 Algorithms for SAR Imagery IV, April, 1997, pages 228-242.
5. J.C. Mossing, T.D. Ross, "An Evaluation of SAR ATR Algorithm Performance Sensitivity to MSTAR Extended Operating Conditions," Proceedings of SPIE, Vol. 3370, SPIE'98 Algorithms for SAR Imagery V, April, 1998.
6. K. Perlin, D. Fox, "Pad: An Alternative Approach to the Computer Interface," Proceedings of SIGGRAPH'93, pages 57-64.
7. V. Velton, T. Ross, J. Mossing, S. Worrell, M. Bryany, "Standard SAR ATR Evaluation Experiments Using the MSTAR Public Release Data Set," Proceedings of SPIE, Vol. 3370, SPIE'98 Algorithms for SAR Imagery V, April, 1998.