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Automatic Target Recognition (ATR) Beyond the Year 2000

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Abstract

The goal of this paper is to project those video or picture based Automatic Target Recognition (ATR) systems likely to enter military inventories and alter mission planning in the year 2000 and beyond. Therefore, this paper avoids a discussion of specific technical approaches and their relative merits that often leads into proprietary or classified discussions. An emphasis is placed on the attributes of ATR as a military product and the factors that will determine the success or failure of efforts to move them in large quantities into military inventories. Some suggestions will be given on how the time to market can be shortened and where video ATR systems will first appear on the post cold war battlefield.

Introduction

ATR in some form has been part of military systems for many years and some of these systems operate total autonomously. It is in the area of Video ATR (VATR) systems where the human operator has played an unchallenged role because of the large quantities of data that must be processed rapidly. Surpassing the ability of the human mind to recognize military objects on the battlefield is a difficult challenge. With the advent of small, affordable video computers spawned by a growing commercial market, the potential exists to replace human operators in, at least, a portion of those functions requiring video data processing and target recognition.

The author believes that an objective look at the recent history of efforts to develop ATR as a product and sell that product to the guided missile user community has proven largely unsuccessful. Some people point to a need for even faster computers that will appear each year and the need to incorporate modern computer interfaces between the weapons and the platforms that launch them. New aircraft such as the F-22 and Joint Strike Fighter (JSF) will certainly contain modern computer interfaces. All of these shortfalls impact the size of the ATR market but do not necessarily account for the growing view that systems recently tested don't validate the claims of their developers when tested in settings representative of modern battlefields. The author believes that too much effort has been spent on new approaches to ATR and this means new algorithms, software, plus testing of these algorithms. Too little time has been spent on the system engineering that helps define a product and its relationship to other products in a context that potential customers can make an informed buy decision. This paper treats the ATR as a system or product and explores the functions they perform, the needs they fill, and the ways they are intended to be used by the military community.

ATR High Level Architecture

ATR can be thought of as a computer and software that tries to estimate what is the structure of the battlefield in front of the sensor base on three measurements; a.) knowledge of the transmitted or natural battlefield illumination, b.) observations of the reflected or emitted energy from the battlefield and c.) reconnaissance data about the battlefield. Figure 1 illustrates how the ATR uses all the data available to try and estimate the current state or makeup of the battlefield similar to the human observer. Because the ATR cannot process this information instantaneously, the data it provides the warfighter is late. This delay is more mission critical to a missile than an intelligence unit.

Levels of ATR

Figure 2 illustrates the various levels of ATR depending on the type of sensor and to what degree the target is resolved into more than a single point. If the target is a single point, the ATR designer must struggle to find a discriminator other than size or textual content. If the target is the brightest object on the battlefield, a simple threshold test suffices which is normally called detection. Beyond brightness, the design must look for motion with time, brightness fluctuations or patterns of points in military type formations such as a convoy on a road. Point target recognition is in many ways the most difficult ATR problem but these types of ATR systems have been used for years on such weapons as radar guided, antiship missiles.

If the target is bigger than a point but cannot be resolved into recognizable patterns, the designer can still exploit the spatial extent of the blob and blob detection algorithms have been used for many years. Features such as height to width ratio or area can be effective discriminants. Classifying the type of target is however not possible by these measurements alone.

Recently with the advent of high resolution snapshot sensors like Synthetic Aperture Radar (SAR) or Imaging Infrared systems using detector arrays of thousands of detectors, sensors produce target pictures which the human observer can exploit very efficiently for precision man-in-loop guidance. With the explosion of the information content has come the difficulty of processing all this information and matching the tremendous ability of the human mind. As computers progress from being efficient manipulators of textual data, speech data, and very soon, picture data, the dawn of video based ATR appears to be only a matter of time. Although, it might even appear first in a commercial form rather than a restricted military form once a profitable commercial market develops.

ATR As An Algorithm

ATR presentations are often centered around algorithm discussions. The algorithm is held to be highly proprietary and better than all other algorithms. The algorithm is the mathematics or recipe of the software design. As Figure 3 illustrates, there are a large and diverse number of algorithmic approaches to ATR. When mixes of these algorithms are considered, the number of choices becomes even larger. Each algorithm has its own group of advocates who may cluster around some academic discipline such as neural science, computer science, a branch of mathematics or some branch of engineering. Some even spawned new computer languages and processor designs. Prior to the dawn of algorithms as the core of ATR, high speed military processors were often found at the core but the decline in the market for military electronics compared to commercial electronics brought a rapid decline to the number of these processors. Often these special military processors were obsolete before they could find a home in a military product and corporations were unwilling to continuously invest in upgrades to both hardware and software tools with low expectation of achieving a significant return on investment.

Fixed Target ATR

Figure 4 illustrates perhaps one of the less stressful ATR problems associated with strike warfare. Even this problem of finding a large building or bridge has only recently been considered solved, at least, by a portion of the ATR community. A large building is made up of edges and a template made up of a sufficient number of these edges can be sufficient to find an aimpoint by matching the edge template to the incoming sensor edge detected image. The problem is complicated by lack of knowledge about the missile approach angles to the target but fortunately GPS fills this information gap for fixed targets. In this mission area, GPS has come to the aid of ATR by reducing the workload for man-in-the-loop systems. Once the attention of ATR moves from large fixed target to moving or relocatable target ATR, the challenge remains high.

Diversity of ATR

One of the aspects of ATR that complicates the transition from a technology to a product is the diversity of the ATR community as illustrated in Figure 5. Although, diversity is good in achieving technological breakthroughs, it is not necessarily good when it comes time to producing a marketable product that can be

sold for a profit. The algorithm designer always feels his algorithms need more tuning or new algorithms need to be added increasing the computational complexity. The target modeler can always build better models and the sensor designer can always improve the sensor performance. In this diverse community there is often a key person missing who is necessary to define a product and that is the ATR systems engineer. The ATR systems engineer understands requirements, specifications, acceptance testing, and “Cost as an Independent Variable.” The ATR technologist sees these concepts as separate from the ATR development and tasks that follow rather than lead the ATR design, which is not a product oriented view but technology oriented view. A need exists to grow ATR systems engineers to support the transition from technology to product. As Figure 6 illustrates, there has been growth in this area over the years as the need for increased funding levels and sustaining existing funding levels have altered the technologists view of ATR closer to a product.

Transition To A Product

This paper has suggested that ATR is a technology on the verge of becoming a product. There is a threshold, however, that still needs to be crossed and unfilled expectations by customers may delay the time when the military crosses this threshold. Figure 7 illustrates the main pillars of the bridge required for ATR to cross this threshold and they center around the concept of being in the right place at the right time. A major military program will surface which needs ATR but might move forward without ATR if it isn't production ready. This is similar to past missile programs needing adverse weather performance but being unable to find radar seeker products providing that capability at an affordable price which have moved forward accepting only day-night performance. Mature ATR designs must be available and this implies software running in real time on an affordable processor that fits into the allocated volume. The willingness of customers to proceed will depend a great deal on how mission critical the need is for ATR and the strength of the acceptance testing which supports a production go ahead decision.

Since ATR designs revolve around software and a computer, there is good reason to expect ATR to find its first markets in the civilian area. Once these commercial products receive public recognition and approval, the military may find itself in a follower position or developing militarized versions of commercial products. The author believe this scenario is the most likely one since the commercial uses of ATR seem limitless and video computers are already becoming an affordable commercial product as the movie industry has proven with ever increasing levels of animation.

The Military Development Cycle

What in the past has been the military ATR development cycle is illustrated in Figure 8. This cycle is not unlike other technologies waiting the time when they will transition into useful products. The cycle starts with a company hiring or promoting from within an algorithm expert who develops a non-real time simulation of his selection of an optimal approach to ATR. This software is often tested with synthetic imagery that allows tight control of the collection geometry and scenario. Once good performance has been achieved, a need develops to validate the software with imagery from a representative sensor for a particular mission area. A captive flight test of the sensor yields a test data set under somewhat controlled test conditions. If this step gives favorable results the software is moved into a real time processor but one that maybe larger than the application could accommodate. At this point, the government may test the ATR system and reach some conclusion as to its utility. The most likely outcome is a need to modify the algorithm and start the process over again. The number of cycles the process goes through depends on what new missile programs are on the horizon that might need this ATR product and the patience of funding sources.

ATR As A System

The systems approach taken in the past to defining ATR as a system is centered on the “black box approach.” ATR was sold as a stand alone system only loosely tied to the sensor whose imagery it uses as an input to make a recognition decision. The impact of this black box approach and the arbitrary separation of the ATR function from the sensor function limits ATR system engineering to a computer and software trades space. When it becomes clear at a higher system level that trades need to be made between the complexity of the

ATR and the complexity of the sensor, it becomes a very painful process and often leads to an expensive sensor design. There are many reasons why a black box approach to designing an ATR product should be looked at with great skepticism. Almost always, the requirements, flowdown process results in sensor image quality requirements that insist on perfection in all circumstances.

When an ATR product advertises its value to a potential buyer, it normally concentrates on probability of acquisition and false alarm rate or false alarm density. An ATR system is a user of information so its probability of acquisition is only meaningful if the sensor can provide a good image and that condition doesn't occur with probability one. At times, the scenes or viewing conditions are such that no sensor will provide a good image.

Probability of acquisition is a function of several equally important factors and the equality claimed in Equation (1) is not at all obvious or has it been proven to be true.

$Prob_{acq}[\text{Target in ATR Design Space, Sensor Image Quality at ATR Levels, Mission Planning Data Still Current, User Operates ATR Correctly}] =$

$$\begin{aligned} & Prob[\text{Target in ATR Design Space}] * \\ & Prob[\text{Sensor Image Quality at ATR Levels}] * \\ & Prob[\text{Mission Planning Data Still Current}] * \\ & Prob[\text{User Operates ATR Correctly}] \end{aligned}$$

All the factors that the final probability of acquisition depends on are very interrelated. The mission planner needs to know how the sensor and the ATR function. The problem does not nicely partition itself into four, five or more totally separate design problems and all of these factors must be included in the ATR design space.

ATR Requirements

A complete set of ATR requirements must address more than probability of acquisition and false alarm rate. It must address system interfaces and input-output data including such factors as:

1. Inputs into the ATR system
2. Reconnaissance data required to plan a mission
3. Number and types of targets that must be recognized
4. Quality of data products needed
5. Sensor Performance
6. Output to the missile guidance computer
7. Maximum number targets in scene that can be processed
8. Estimate of target types - tank, truck, jeep, etc. that are in the design space
9. Accuracy of target measurements - length, width, area, angle
10. Computer required to host software – throughput and memory
11. Programming language
12. Type of acceptance testing to sell off a product

A complete set of ATR requirements must be addressed by the design similar to a hardware specification for a sensor system.

Number of Pixels on the Target

One basic requirement for an ATR system is number of pixels on the target for the ATR system to achieve a specified level of performance. This number has been hard to extract from the ATR community. However, it is possible to perform a requirements level of analysis that indicates what is needed. Consider Figure 9 which shows one simple approach to answering this question. If the target of interest is a simple square which is N by N pixels of value 1 and it is embedded in a noisy image where the noise has value 0 or 1. This could correspond to an infrared sensor with signal to noise ratio of 1 or an image after edge detection. What is

important is the number of times the noise looks like a square, target. The plot on the right of Figure 9 was computed by passing a $N \times N$ template over the 256×256 image then computing the correlation. The plot shows the ratio between the target correlation and the largest noise correlation (false target). A ratio of 1 means you cannot tell the difference between a target and a false target. The plot shows that the target must be 6×6 before there is any separation between target and false targets and even at 8×8 the separation between targets and false targets is low. The 8×8 number has been used at times as the capability of a human observer so this simple analysis correlates with this traditional threshold. More analysis such as this can add further insight into where to reasonably set the bar for ATR performance. In the past this has been a problem for users not knowing what is a reasonable design specification.

Complexity of Template

Another important area where requirements need to be developed is in the area of template complexity. How much detail should be put into a target template. Consider Figure 10 that shows the edge detected image of the same building used previously. Underneath the edge detected image is a simple template created by extracting lines from the buildings in the image. One question that might be asked is the number of lines that should be used in the template. What the plot on the right illustrates is that the building only has a few line types (distribution of line angles relative to image horizontal) but the clutter has a continuous distribution of line types. The template match score goes up rapidly as you pick the first couple of line types, but after that, there is little increase in match score and adding more lines increases false target recognition more than true target recognition. This example problem illustrates why it is unlikely that any system can achieve zero false alarm rate since every target has something in common with the background and the military tries to increase this similarity using camouflage. The target in Figure 10 is so large, it is not easily missed but ATR must work at longer ranges and distinguish one building from another.

Sensor and ATR Separability

A basic question that needs to be addressed is whether the ATR system and the sensor can be developed separately. As Figure 11 illustrates, this question revolves around whether the key performance parameters can be separated between sensor and ATR and whether the associated requirements can also be separated. It is the authors opinion that they cannot be separated in a real system or product and the two must be developed as an integrated seeker system. The interconnection between the two is too interdependent and design trades cannot be made for one without impacting the other design.

ATR Detection Requirement

Many missile designers have become used to seeing a requirement for target detection. But ATR designers don't generally think in terms of detection as illustrated in Figure 12.

Recognition for an ATR designer is what detection is for a radar moving target indication designer. In a way detection is embedded in recognition and does not separate out into detection followed by recognition. The ATR designer starts his process by finding all those things in an image that could potentially be a target and these are points of interest rather than detections. Points of interest are sorted into valid targets, false alarms or are discarded as non-targets. The ATR system engineer views recognition as a higher level of detection bringing with it more information than target location.

Variability in Mission Planning

Mission planning is a very important aspect of ATR and an area the ATR designer has very little control over how it is conducted. One past approach has been to try and design for the minimum requirements in the area of mission planning such as one picture of the target. As Figure 13 illustrates there is a great difference between stationary targets and moving targets. Stationary targets can be mapped, surveyed and characterized a long time advance of an actual mission. In this case the designer can perform a high degree of mission planning. Moving targets such as ships at sea are difficult to mission plan and the ATR system must be more robust. Moving targets are also more likely to be targets of opportunity where the warfighter encounters them

in the course of a mission not originally directed at them. It should be no surprise that ATR systems will enter the inventory first for stationary target before moving targets. Even with this being the case, mission planning will continue to be an area of constant trades between ATR needs and reconnaissance capabilities even for stationary targets.

In addition to finding ships at sea, armor targets represent a difficult target to mission plan as illustrated in Figure 14. There is a greater likelihood of a mix of friendly, civilian and enemy forces. Armor can be masked or hidden by trees, hills or buildings.

Although ships are normally always moving, armor can often be moving or stationary and rapidly change from one state to another. The functionality required for armor targets has more dimensions associated with it such as picking a lethal aimpoint or rejecting civilian or friendly vehicles.

One difficulty associated with recognizing armor targets that has increased with the end of the cold war is the numbers and types of armor. As figure 15 illustrates, they all have all have similar attributes (ie. treads, wheels, hatches, barrels, etc.) and it makes designing a target template difficult. If the distinguishing part of a target is masked and the common part is visible it can easily be assigned the wrong target type. A higher fidelity in processing is required for armor or the performance goals must be set lower than for large stationary targets.

Defining A Reasonable Set of ATR Requirements

Before a company can pursue building, marketing and selling an ATR product with or without a warranty, a reasonable set of ATR requirements must be selected as illustrated in Figure 16. Considering the ATR design space or mission space, the product must be designed not for every mission or application but for a reasonable subset that a designer can satisfy and a systems engineer can define requirements that can be converted to acceptance tests. This requires the ATR developers to become focused on a narrow market and remain focused long enough to create a true product.

Not every mission area is ready for this product focus as illustrated in Table 1. Some mission areas such as finding camouflaged targets requires technological breakthroughs or near instantaneous reconnaissance data.

Trends in ATR Technology

As shown in Figure 17 there are many technology trends in the ATR area but probably the one with the greatest attention is multisensor ATR that requires fusing data from multiple sensor systems that potentially operate at very different wavelengths. The impact of GPS has already been felt in the ATR community but even tighter coupling between ATR and GPS can be expected in the future. Treating ATR as a systems problems is a new trend and the author hopes one that will gain even greater interest because it is this trend that will lead to more of a product focus. Trends in the area of artificial intelligence and other new processing approaches have decreased some and now fall more in the category of another tool available to the ATR designer.

Future Weapons Employing ATR

In the next millenium, ATR will reach the product phase and enter the military inventory. The most likely first significant introduction will be in the area of Strike Warfare for large fixed targets. This well especially become important in the long range destruction of an enemies air defense systems during the first few days of a military conflict. Although Synthetic Aperture Radar seekers are growing in maturity, ATR will be used first with the new generation of infrared seekers using high resolution, focal plane arrays. When cloud cover obscures the target, these weapons will rely on GPS to get to the target area and then acquire the target just beneath the cloud cover. Missiles such as these will have a minimum useable cloud cover since the missile has a limited maneuverability. This may even create a need for airframes with higher maneuverability in the end game. Ballistic missile defense is another area where ATR will have some early success since targets are

easier to find above the clouds and against a clear sky background. These systems will use infrared and millimeter wave seekers. The emphasis in these applications will be on recognizing a lethal aimpoint.

Deployment of anti-armor seekers using ATR will be restricted to targets in the open and this means dual mode seekers using laser acquisition for more stressful target scenarios. Because anti-armor missiles traditionally have small warheads, aimpoint determination will continue to be a key figure of merit for these systems. ATR guided weapons for use against relocatable missile launchers will be slower coming because of the greater difficulty of the problem and the need for synthetic aperture radar seekers and new types of missiles which fly at hypersonic speeds to reduce time-to-target.

Summary and Conclusions

It can be expected that the next millenium will be an exciting time for ATR systems as high speed video processors reach the commercial marketplace and video software development tools rapidly become common place. ATR technology can be expected to transition from technology to product. The first applications will be in the area of strike warfare against large fixed targets and air defense installations but anti-armor systems will follow shortly after. These first systems will encounter difficulties caused by the complexity of the ATR problem, lack of adequate user training and the growing unpredictability of the post cold war battlefield. The author believes that this process can be accelerated by more of an integrated seeker approach and the training of ATR seeker systems engineers who can define product requirements and key system design trades. ATR must move from a "Algorithm Centered World" to a "Product Centered World."

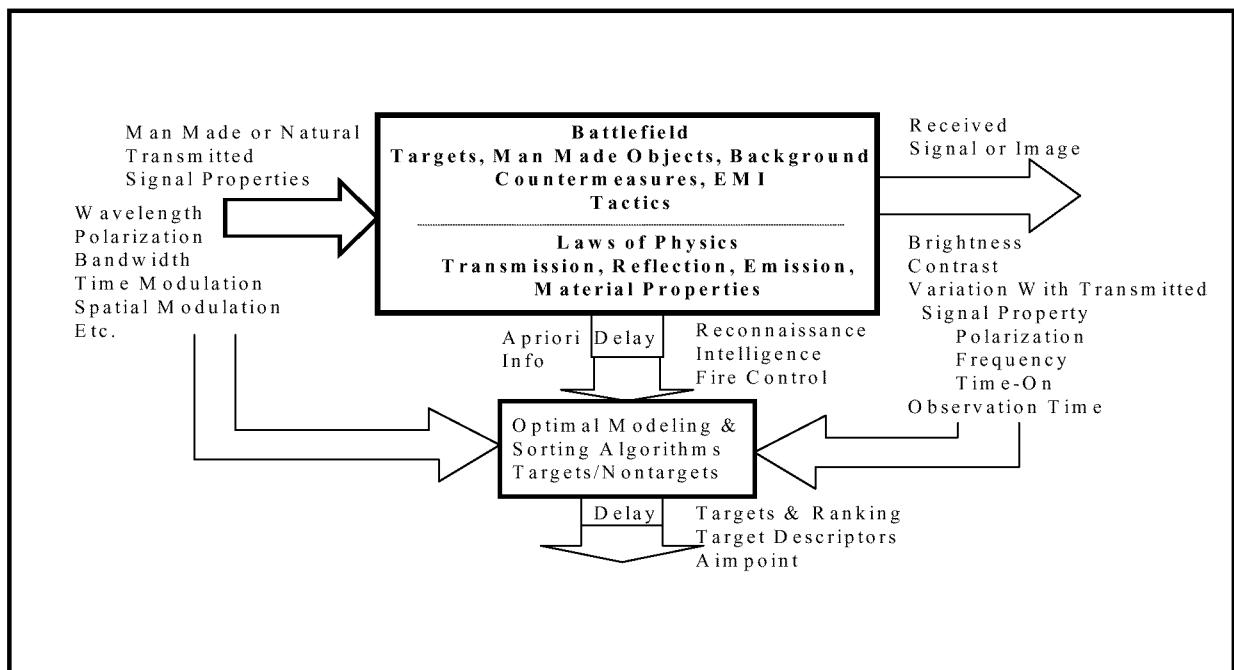


Figure 1. ATR High Level Architecture

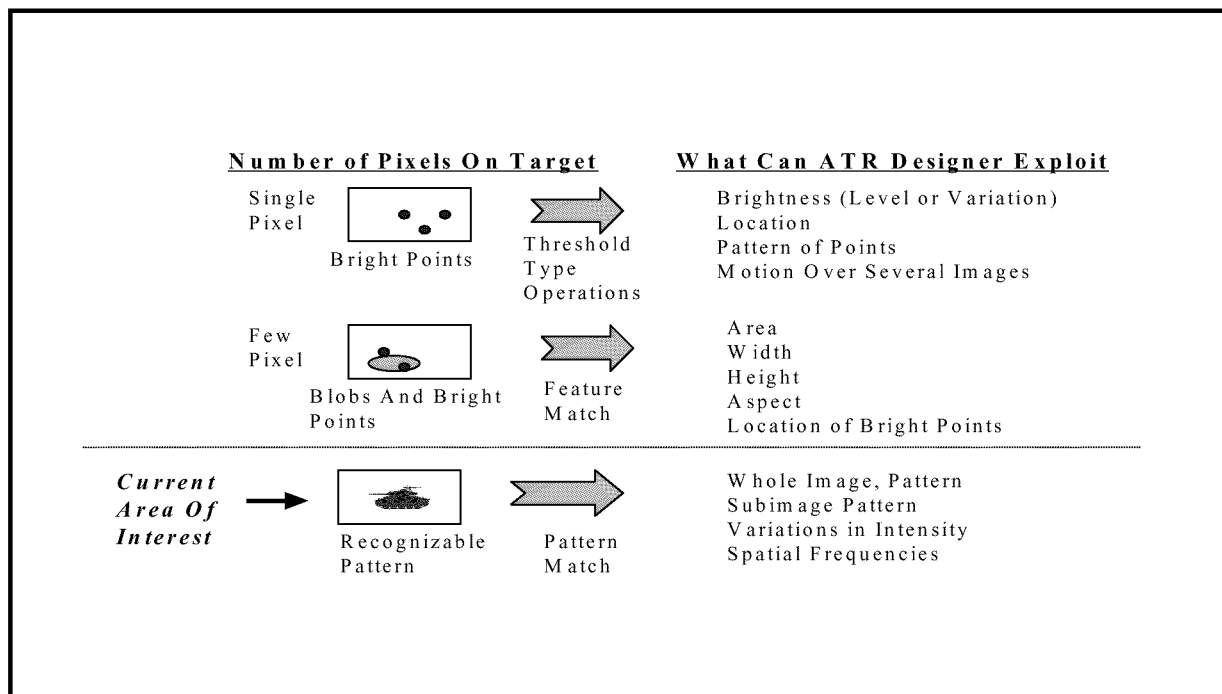


Figure 2. Levels of ATR

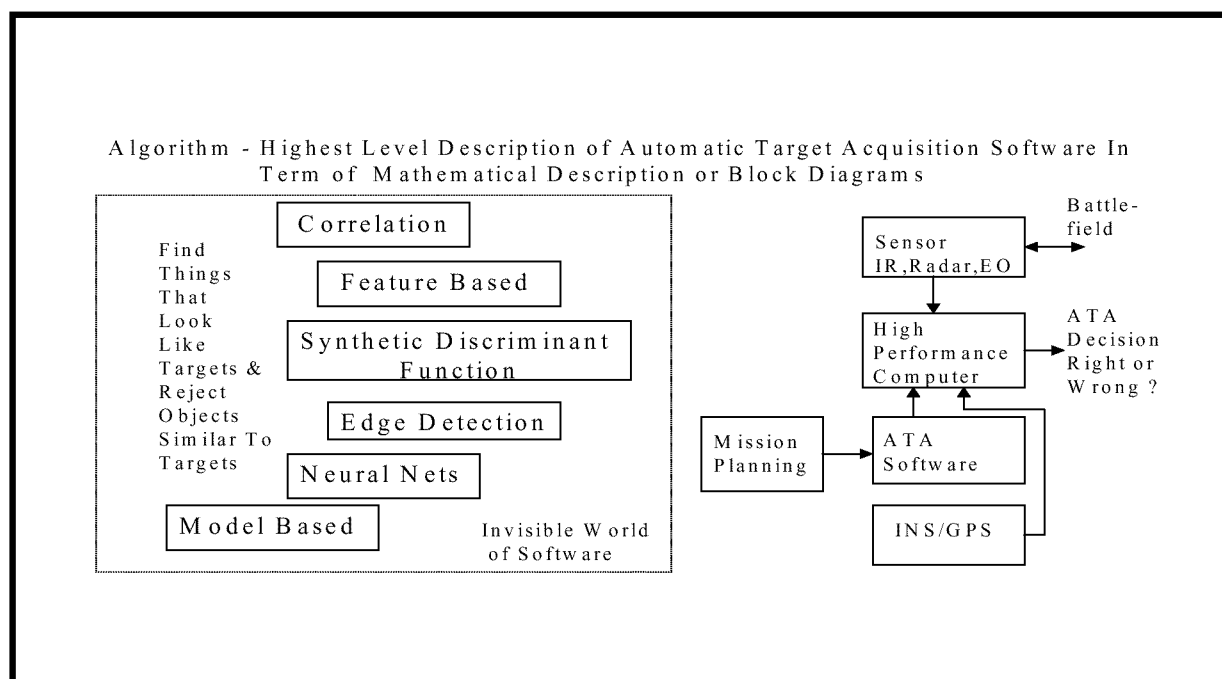


Figure 3. ATR Algorithms

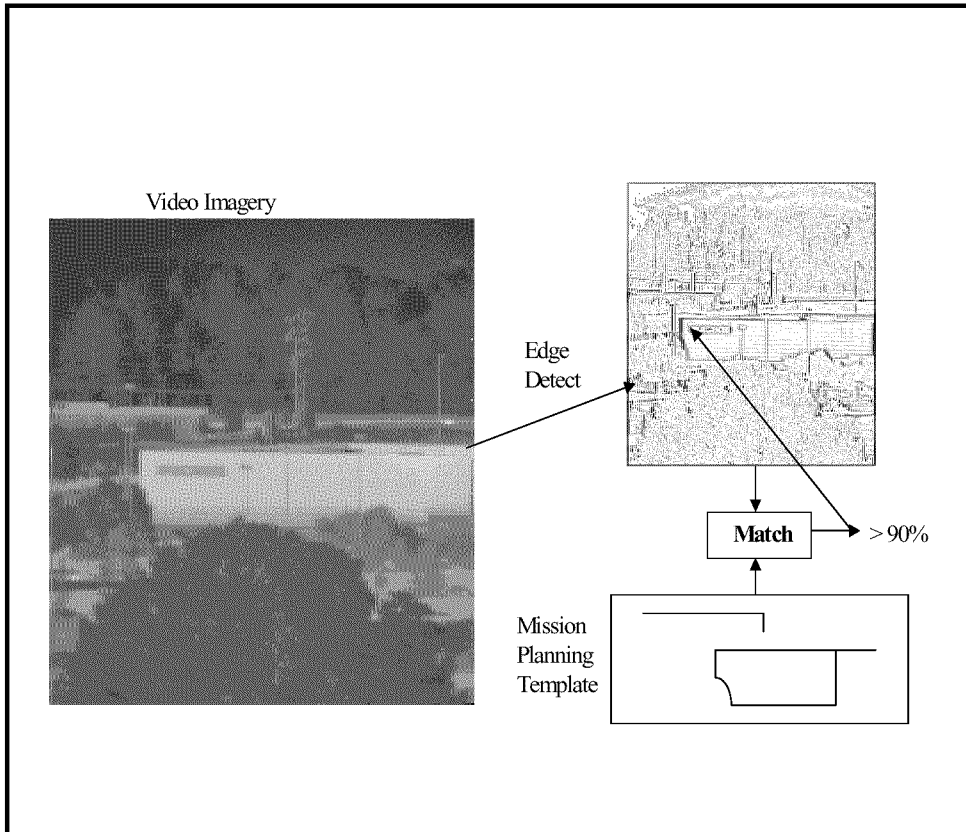


Figure 4. Standoff Weapon ATR

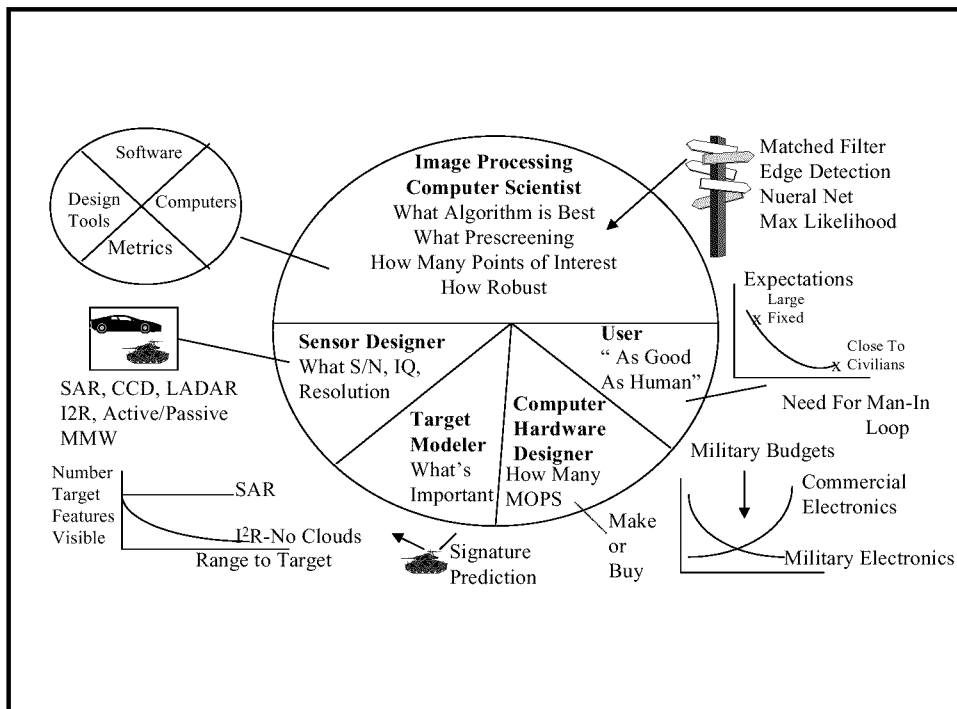


Figure 5. Diversity In ATR Community

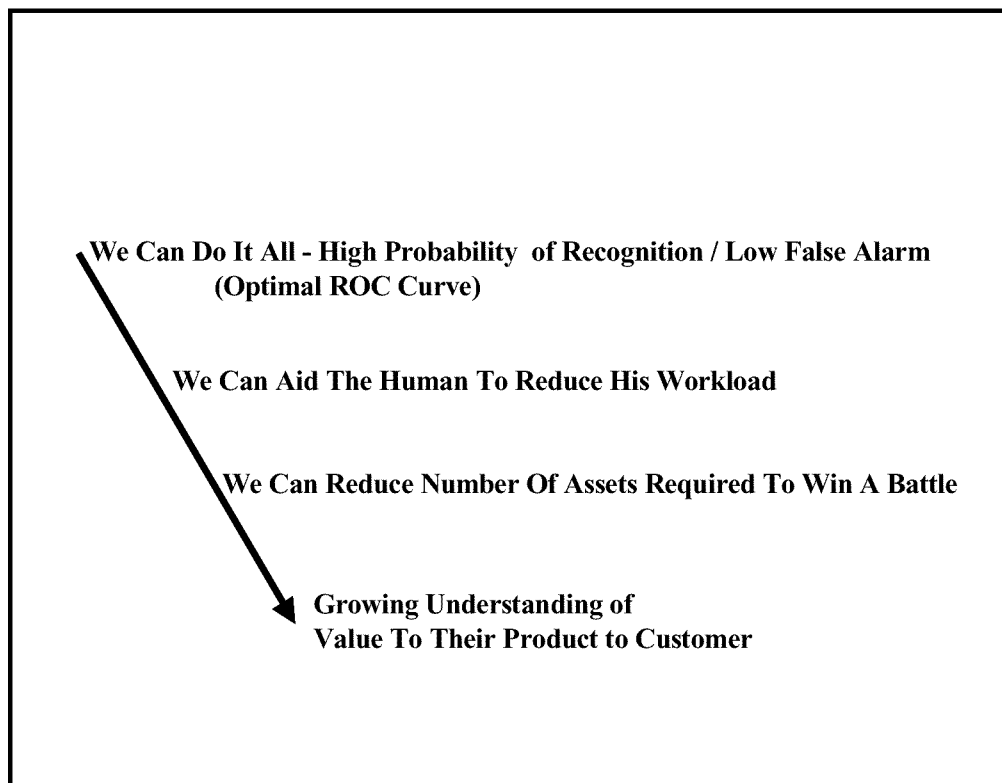


Figure 6. ATR Changing Vision of Benefits

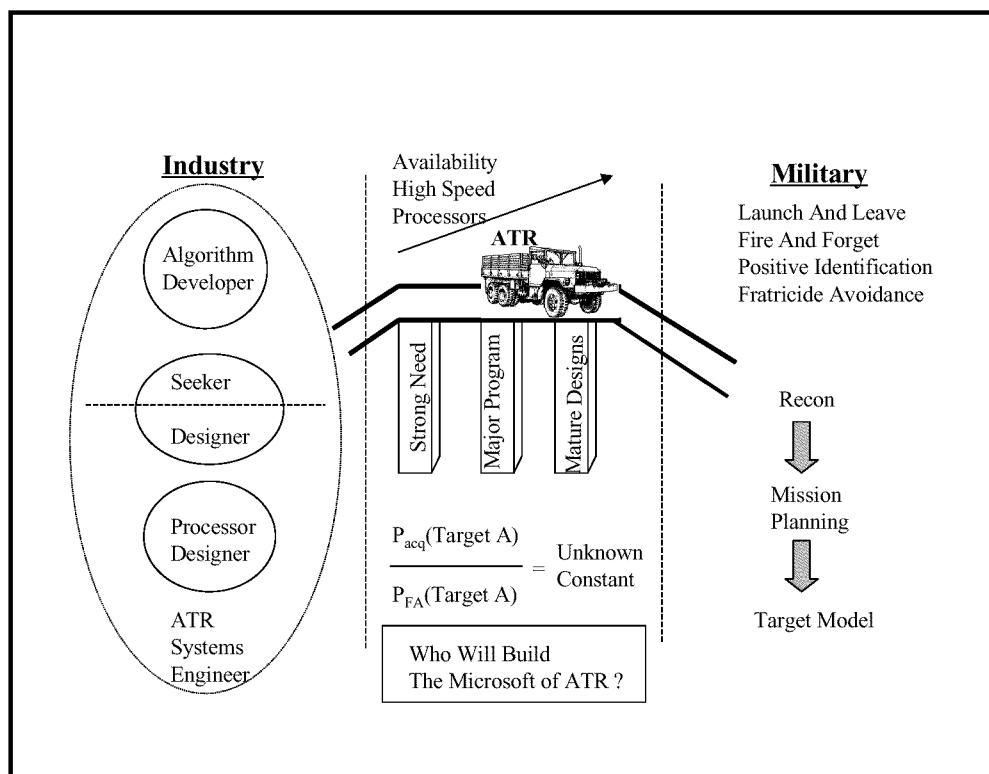


Figure 7. Transitioning To a Product

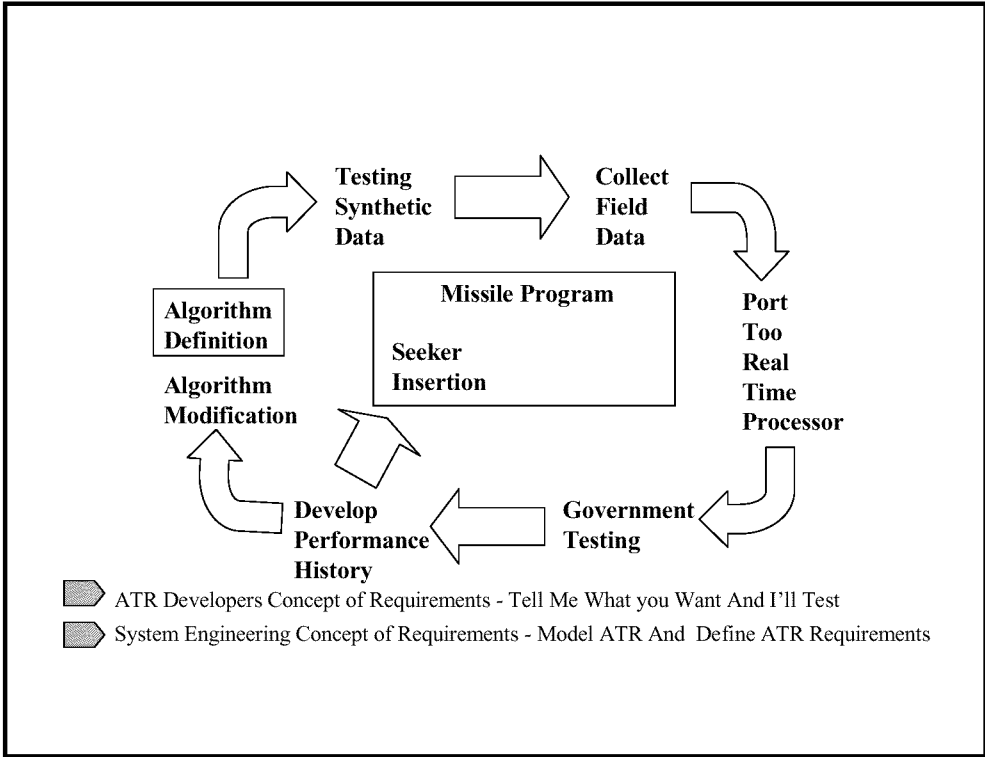


Figure 8. ATR Development Cycle

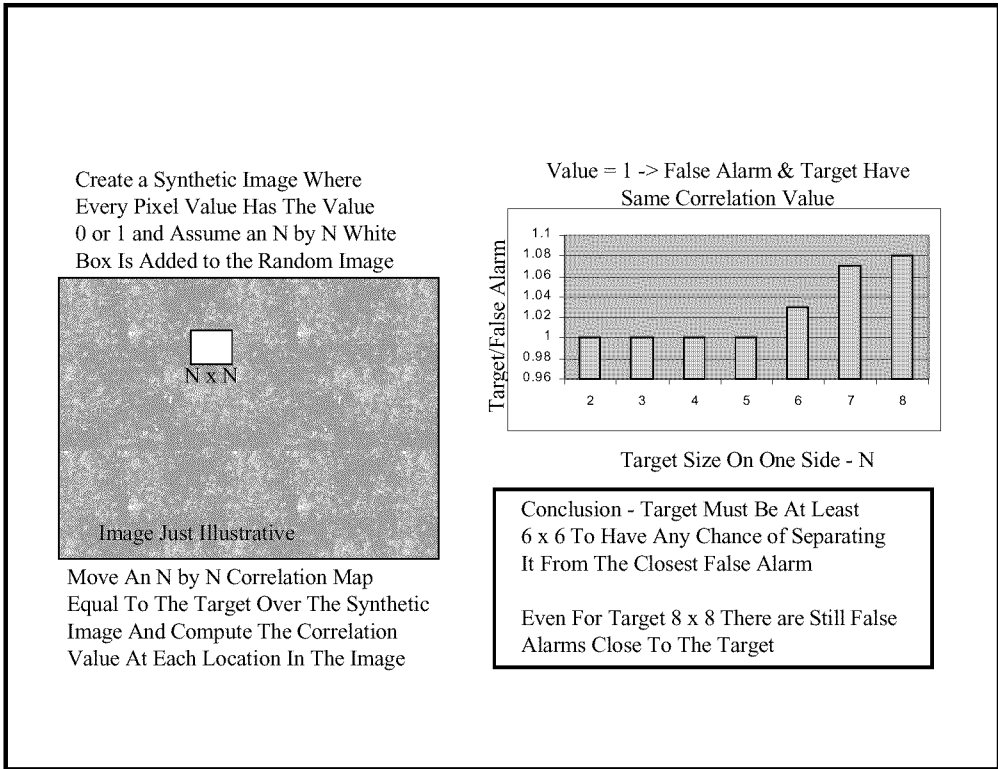


Figure 9. Number of Pixels on Target

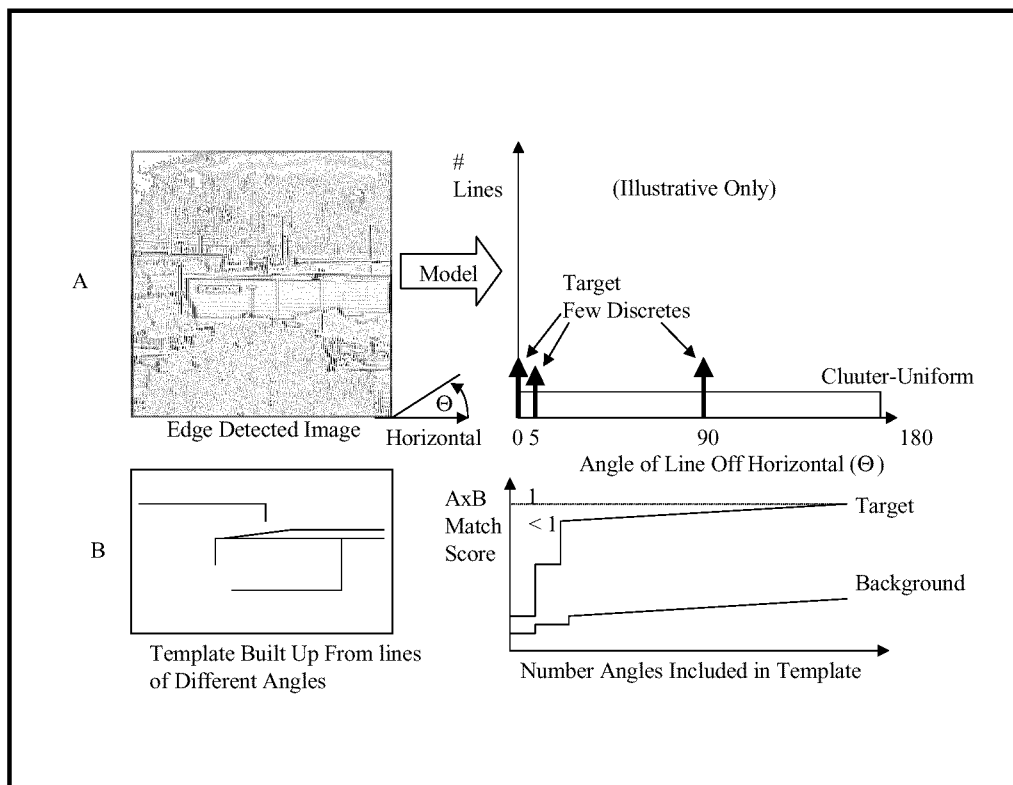


Figure 10. Template Complexity

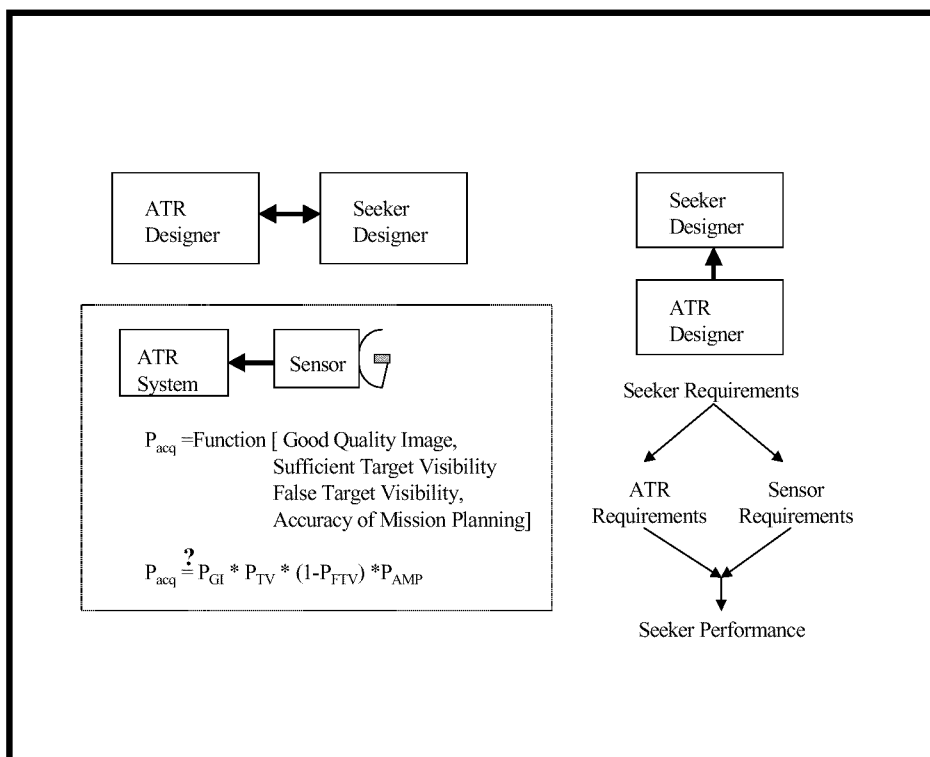


Figure 11. Sensor and ATR Separability

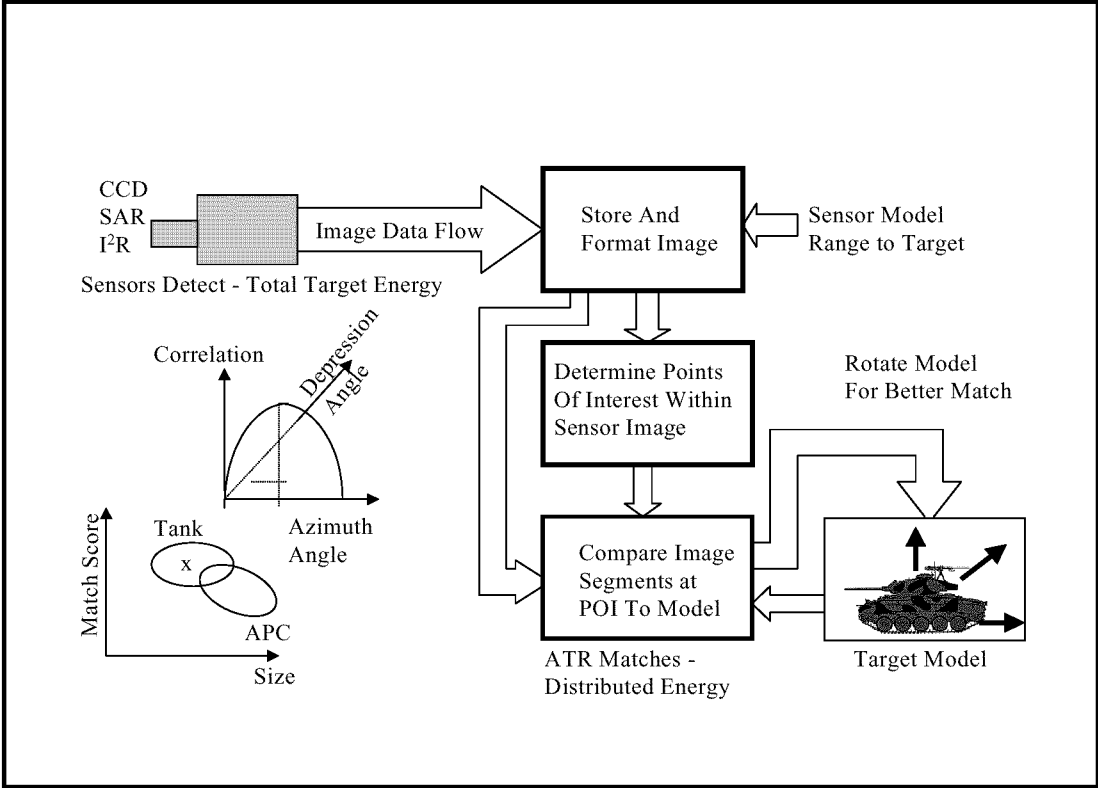


Figure 12. Detection in an ATR System

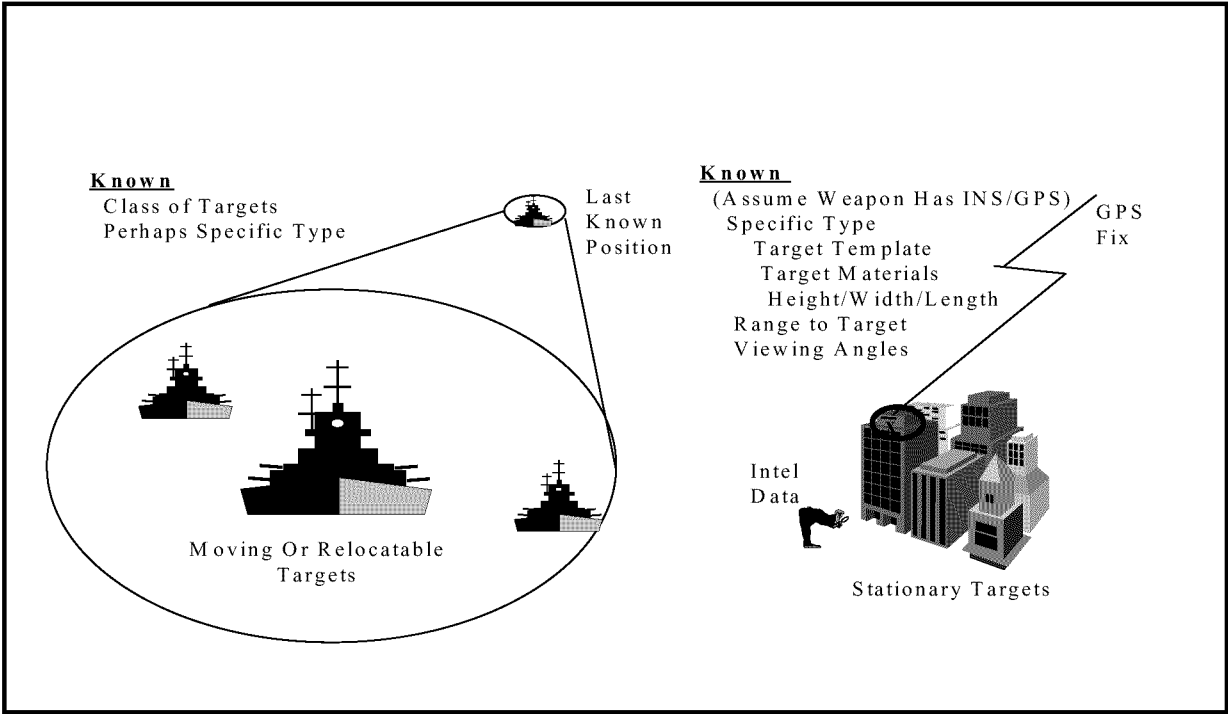


Figure 13. Mission Planning Variability

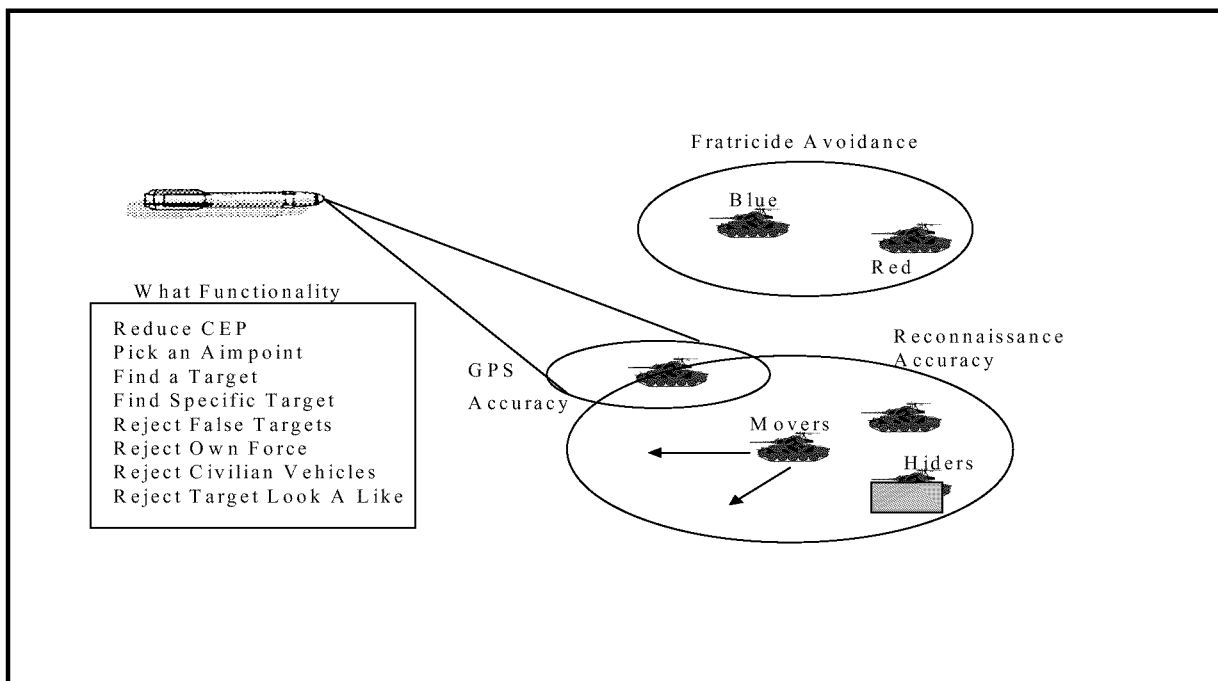


Figure 14. Armor Target

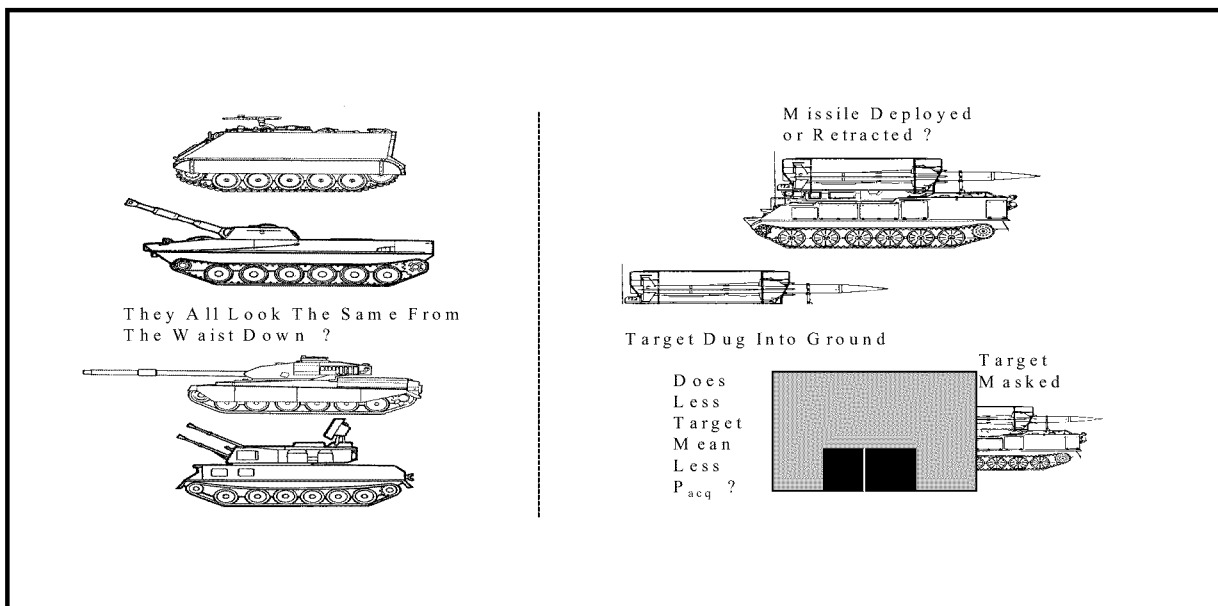


Figure 15. Variability in Armor Targets

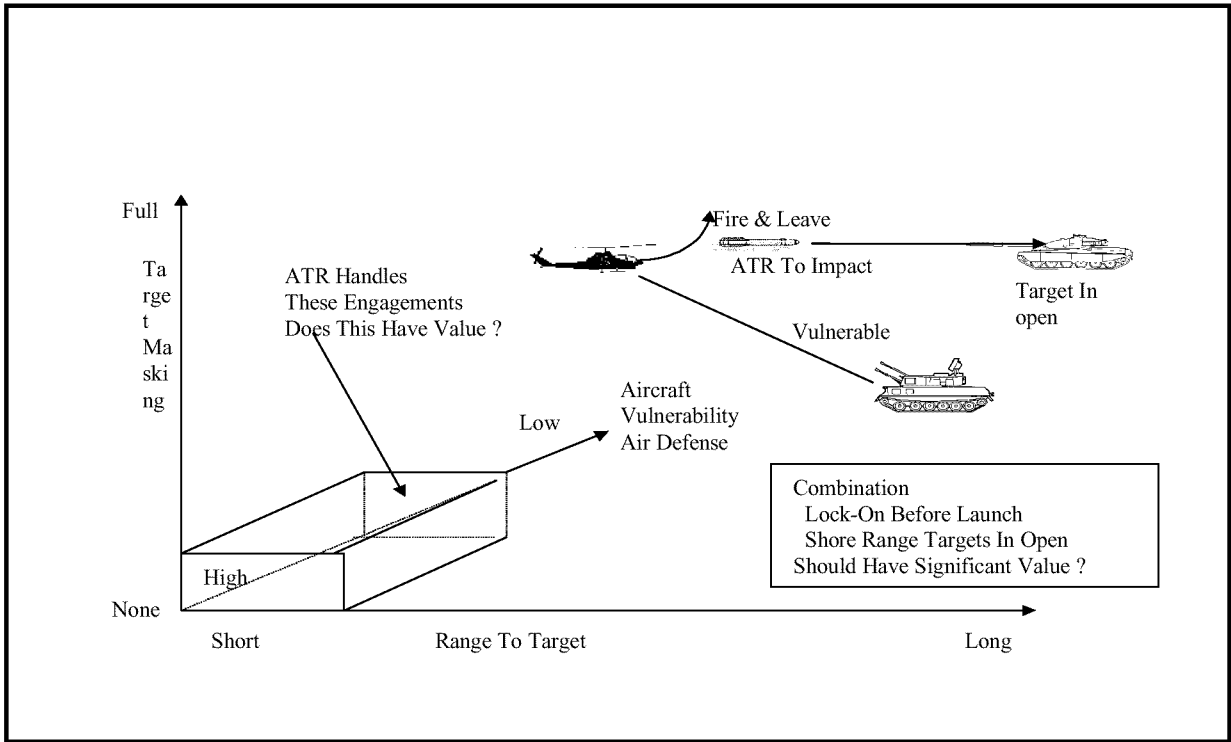


Figure 16. Bounding The ATR Requirements

Table 1. Mission Area Maturity

Requirements & Targets		Fixed Target		Moving Or Relocatable	
		Large	Small	Not Obscured	Obscured
Good Weather	No Countermeasures	INS/GPS Has Made This Practical	Stress Weapon Maneuverability	Faster Processors & Timely Cueing	Fine Resolution Sensors
	Countermeasures GPS Jammig Sensor Jamming Deception High Probability Obscuration	Multisensor Fusion Systems	Requires Sensor Development And Higher Weapon Maneuverability	Requires Development Of Multisensor Fusion Systems	Multisensor Fusion Systems And Fine Resolution
Adverse Weather	Cloud Cover	Faster Processors	Faster Processors & Higher Resolution	Rapid ATR & Sensor Search	Rapid ATR & Sensor Search Plus Fine Resolution
	Worst Day Of The Battle	Sensors That Are Not Weather Limited	High Resolution Sensors Not Weather Limited	Sensors That Are Not Weather Limited	Fine Resolution Sensors That Are Not Weather Limited

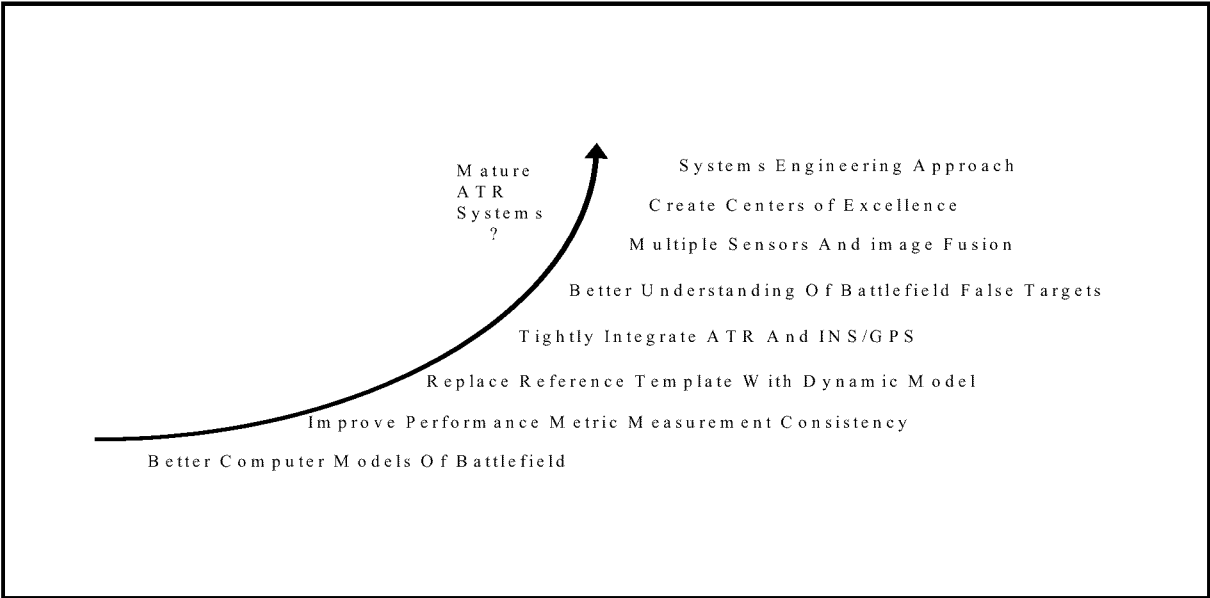


Figure 17. ATR Technology Trend