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14. ABSTRACT
Making the most of measurement and signatures intelligence (MASINT) requires a deeper, technical level of understanding and the creative insight to match MASINT applications to whole of government, mid to long-term problem sets that require the forensic-level data and rigorous analysis that MASINT is designed to provide. To explore these issues, a short background in the evolution of MASINT as a discipline will be presented. It will be followed by a description of each of the two problem areas mentioned above. In order to illustrate the issues, three examples of MASINT advanced geospatial intelligence (AGI) concepts will be discussed in terms of the basic phenomenology, requirements for processing, production of intelligence and recent success stories. The examples will be followed by a description of the efforts made to adapt MASINT technologies for faster response times. Finally, the conclusion will offer suggestions on reducing the knowledge gap and mitigating the time intensive nature of MASINT by encouraging greater creativity in applying MASINT principles to problem sets in all sectors of government.

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MASTER OF MILITARY STUDIES

MAKING THE MOST OF MASINT AND ADVANCED GEOSPATIAL INTELLIGENCE

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

MAJOR CONNIE LYNN, USAF

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Executive Summary

Title: Making the Most of MASINT and Advanced Geospatial Intelligence

Author: Major Connie Lynn, United States Air Force

Thesis: Making the most of measurement and signatures intelligence (MASINT) requires a deeper, technical level of understanding and the creative insight to match MASINT applications to whole of government, mid to long-term problem sets that require the forensic-level data and rigorous analysis that MASINT is designed to provide.

Discussion: As a result of the complex, diverse nature of MASINT, two fundamental problem areas emerge. The first problem is the relatively lengthy time required to produce relevant intelligence from MASINT. The second problem is that a knowledge gap still exists between the scientists who are well versed in the underlying principles of MASINT technologies and the operators and analysts who have intelligence questions that MASINT sources may be able to help answer. To explore these issues, a short background in the evolution of MASINT as a discipline will be presented. It will be followed by a description of each of the two problem areas mentioned above. In order to illustrate the issues, three examples of MASINT advanced geospatial intelligence (AGI) concepts will be discussed in terms of the basic phenomenology, requirements for processing, production of intelligence and recent success stories. The examples will be followed by a description of the efforts made to adapt MASINT technologies for faster response times. Finally, the conclusion will offer suggestions on reducing the knowledge gap and mitigating the time intensive nature of MASINT by encouraging greater creativity in applying MASINT principles to problem sets in all sectors of government.

Conclusion: In order to use MASINT to its fullest potential, the greater community of end users should be better informed on existing capabilities and the science behind them. Further, academia-based MASINT scientists should continue to be integrated into government intelligence programs in a way that minimizes loss of proficiency in their primary specialty. Finally, the MASINT community should continue to mitigate the lengthy timeline of MASINT processing without losing data integrity and value-added human analytical thought due to over-automation. When MASINT cannot be produced fast enough to be militarily relevant without losing critical analytical integrity, analysts should instead use these sources of MASINT in support of less time-sensitive intelligence problems. Through creative or unconventional approaches, MASINT data sets can be used to support foreign policy mission areas as diverse as economic development, humanitarian assistance, disease prevention, energy security, urban development and more.

DISCLAIMER

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Preface

This thesis is intended to challenge the current trend in intelligence toward faster processing, instantaneous sensor to shooter data, more automation and less human intervention. I specifically chose examples from the advanced geospatial intelligence segment of MASINT to illustrate to the reader that understanding the science behind MASINT isn't as daunting as it may appear. I hope the thoughts presented in the thesis will encourage the reader to explore more literature on the uses and applications of MASINT. There is much more information available on MASINT in classified sources, but I hope to reach a greater audience in keeping this document unclassified. This thesis isn't meant to teach the reader the technical aspects of AGI. It is simply to spark thought and interest in MASINT and to encourage creative, unconventional thought on applying MASINT in new ways .

I was fortunate enough to be able to accomplish a lot of my research on AGI through resources available at the National Geospatial-Intelligence Agency Library in Springfield, VA. I'd also like thank Dr. Pauletta Otis, my mentor, for her guidance and confidence in me as I progressed through the research and writing. And finally, I'd like to thank Dr. Adam Cobb, whose insights on intelligence process issues provided much of the inspiration for the framing of ideas in this thesis.

Introduction

Making the most of measurement and signatures intelligence (MASINT) requires a deeper, technical level of understanding and the creative insight to match MASINT applications to whole of government, mid to long-term problem sets that require the forensic-level data and rigorous analysis that MASINT is designed to provide. MASINT is a collective term that brings together disparate intelligence elements that do not fit neatly into the realm of signals (SIGINT), imagery (IMINT) or human intelligence (HUMINT).[1] Consequently, the MASINT discipline has traditionally been difficult to define, understand and apply, particularly in support of military operations.[2] The January 2012 release of Joint Publication 1-02 defines MASINT as follows:

> Intelligence obtained by quantitative and qualitative analysis of data (metric, angle, spatial, wavelength, time dependence, modulation, plasma, and hydromagnetic) derived from specific technical sensors for the purpose of identifying any distinctive features associated with the emitter or sender, and to facilitate subsequent identification and/or measurement of the same. The detected feature may be either reflected or emitted.[3]

A primer on MASINT written at the Air Force Institute of Technology describes MASINT as "a catchall for several 'boutique' intelligence disciplines."[4] It consists of very diverse elements such as acoustic intelligence, nuclear radiation, materials, effluent and debris sampling, spectroscopy, radar and radio frequency intelligence. Simply stated, MASINT attempts to derive intelligence value from almost any type of scientific measurement or signature.

The greatest strength of MASINT is that the sensors have the potential to isolate very precise signatures and characteristics of objects or activities that can't be seen or detected by human senses. In this way, MASINT enables analysts to see and evaluate the intangible characteristics of an object or scene. In addition, MASINT data sets are highly versatile and can be used to support a wide variety of problems. For example, a digital elevation model is a MASINT derived data set that can be used to assist military maneuver elements in identifying obstacles and routes of travel for an operation. The same data set can also aid partner nation disaster preparedness planners in identifying areas at risk of flooding during rainy season.

Like any of the intelligence disciplines however, MASINT has limitations. As a result of the complex, diverse nature of MASINT, two fundamental problem areas emerge. The first problem is the relatively lengthy time required to produce relevant intelligence from MASINT. The highly technical nature of this collection of boutique intelligence disciplines usually requires complex software and extensive data processing algorithms in order to transform raw measurements into analytical intelligence products. As such, an analyst may need several hours to process the data and build an intelligence product derived from MASINT. In a warfighting era of data automation and fleeting targets, even two-hour old MASINT data may likely become irrelevant before its intelligence value can be realized.

The second problem is that a knowledge gap still exists between the scientists who are well versed in the underlying principles of MASINT technologies and the operators and analysts who have intelligence questions that MASINT sources may be able to help answer. The nature of this knowledge gap can be explained in two ways. In one way, there is a significant lack of knowledge of MASINT capabilities among intelligence customers. In another way, and partially as a result of the technical nature of the discipline, intelligence customers have difficulty verbalizing, in the form of a collection requirement, exactly what data or measurements they need in order to answer the core intelligence problems.

To explore these issues, a short background in the evolution of MASINT as a discipline will be presented. It will be followed by a description of each of the two problem areas mentioned above. In order to illustrate the issues, three examples of MASINT sciences will be discussed in terms of the basic phenomenology, requirements for processing, production of intelligence and recent success stories. The examples will be followed by a description of the efforts made to adapt MASINT technologies for faster response times. Finally, the conclusion will offer suggestions on reducing the knowledge gap and mitigating the time intensive nature of MASINT by encouraging greater creativity in applying MASINT principles to problem sets in all sectors of government.

Background

MASINT is a relatively new intelligence discipline although many of the applications have been in existence for years. Seismic, acoustic, water and air sampling devices, for example, were being used for decades before the official designation of a MASINT discipline in 1986.[5] It was within the past forty to fifty years that these types of scientific measurement and mapping techniques started to gain explicit recognition for their ability to produce information of military significance. Since then, the collection of MASINT sciences has gone through a number of transformations in an attempt to categorize, centralize and streamline the definition and management of the discipline throughout the national intelligence community and the Department of Defense.

According to the Air Force Institute of Technology, MASINT is categorized by its six subdisciplines; electro-optical, radar, geo-physical, nuclear, radio frequency and materials.[6] Each subdiscipline includes an assortment sensors that take on a wide range of shapes, sizes and types that often overlap with SIGINT and IMINT platforms. Sensors can be active, passive, ground-based, underwater, airborne or space borne. In order to organize all of these capabilities and their respective prioritization and tasking mechanisms, the Department of Defense issued DoD Instruction 5105.58 in 1993. The instruction assigned central management of MASINT to the Defense Intelligence Agency's (DIA) National MASINT Management Office (NMMO).[7]

Although central management resides with DIA, the practice of individual MASINT subdisciplines still remains widely dispersed among a variety of agencies and organizations that specialize in their own particular segment of MASINT. The highly disperse nature of the discipline and its capabilities has been challenging for government and military operators to learn and integrate into their efforts.

Also challenging is the fact that the underlying concepts and technologies of MASINT are highly scientific and often difficult to understand for those who do not have a specialized scientific background.[8] Scientists that study these specialties understand the technical intricacies of the sensors and processing techniques, but they are often less knowledgeable of intelligence requirements and how the sensor data needs to be presented for decision makers and operators. Likewise, military operators or decision makers without a scientific background sometimes shy away from the MASINT sciences if they have difficulty understanding a direct relevance of the science to the intelligence problem. Bridging the knowledge gap between the science and the intelligence value is generally not directly intuitive and requires individuals who have a deep understanding of both the science and the intelligence problem. A staff study released in 1996 by the House of Representatives Permanent Select Committee on Intelligence found that scientists well versed in MASINT type capabilities cannot generally be professionally developed within the intelligence community; they must come from academia.[9] The study claimed that when these scientists are pulled into a career in the government, they lose their proficiency in their scientific expertise. This knowledge gap makes it difficult to use MASINT to its fullest potential in support of government and military intelligence problems.

In addition, MASINT is one of the most difficult intelligence disciplines to derive actionable intelligence from quickly. Most warfighters understand that there is great intelligence potential for MASINT when it is produced within an operationally relevant timeline. Unfortunately, the complex nature of MASINT derived information usually requires extensive processing, analyzing and producing. Most of the time, it does not meet the timely requirement that most warfighters have come to expect.

The emphasis on recent counterinsurgency and counterterrorism campaigns has created an operational intelligence environment characterized by an insatiable demand for actionable information delivered in near real time, or "fast intel." Typical counterinsurgency and counterterrorist targets are often evasive, fleeting and increasingly unpredictable. As such, operators and decision makers require fast intel in order to action those targets before the window of opportunity closes, the target vanishes, and target development has to start from scratch. To meet this demand, intelligence producers had to deconstruct the intelligence process and find a way to push intelligence through the steps much faster. The intelligence process as described in Joint Publication 2-01, Joint and National Intelligence Support to Military Operations, is shown in figure 1.[10] In deconstructing the process, the goal was to analyze each phase and eliminate or minimize unnecessary steps. The result was faster end-to-end delivery of actionable data from the sensor to the decision makers and operators. An unfortunate consequence of this evolution is that time-saving occurs in the processing, exploitation, analysis and production phases at the expense of context rich depth of analysis. Fast intel is undoubtedly necessary when supporting action against fleeting targets. But

Figure 1: Intelligence Process
Source: Joint Pub 2-01, 2011

minimization of processing and analysis writ large by increasing automation has the potential to wrongly exclude more complex and time-intense methods of extracting intelligence information.

On one hand, rapid transmission of sensor data to the operator represents a great leap forward in adapting technology and the intelligence process to warfighter needs. On the other hand, increasing the amount of data automation can set a dangerous precedent through the assumption that sensor data should be disseminated straight to the warfighter for determination of its ultimate intelligence value rather than to the intelligence professional for evaluation and analysis in a broader context. Essentially, emphasis on automation can end up creating an environment that stresses the tangible aspect of intelligence at the expense of the intangible.[11]

Reduction or elimination of the processing and analysis steps of the intelligence process may be suitable for intelligence problems that are very literal and tangible, such that any professional operator or decision maker can resolve. However, there are a number of intelligence problems and greater national security issues that cannot be solved simply by transmitting sensor data as quickly as possible from the sensor to decision maker. Likewise, there are sources of data, such as those contained in the MASINT discipline, that can provide exceptional value to such intelligence problems, but they require iterations of processing and analysis in order extract the hidden or intangible information. Valuable intelligence can indeed be derived and used effectively from these MASINT sources that are necessarily time-intensive in processing and analysis. MASINT applications simply need to be matched smartly and creatively to problem sets that are conducive, or may even benefit from, a more deliberate, analytical approach.

Tackling intelligence problems involves deriving information from multiple sources that can be fused and analyzed as a whole in order to build a complete intelligence product. Sources of intelligence are categorized into disciplines including imagery intelligence (IMINT), signals intelligence (SIGINT), human intelligence (HUMINT), open source intelligence, (OSINT), and measurement and signatures intelligence (MASINT). All sources progress through the intelligence process in their own unique respects. Each discipline has its own collection requirements management system, sensor collection parameters, processing methodologies and interpretation techniques. Intelligence derived from the more tangible disciplines such as IMINT and SIGINT has greater potential to be transmitted directly from the sensor to the decision makers in minutes while intelligence from other disciplines such as MASINT must take a more complicated path. The extensive processing and contextual analysis required by most MASINT applications makes it difficult to adjust to meet demanding timelines. This limitation should not detract from the usefulness of MASINT in solving intelligence problems and supporting matters of national security. Instead, analysts should look for creative ways to use MASINT to support the myriad of other intelligence problems that are not as time-sensitive.

Remotely Sensed Advanced Geospatial Intelligence Concepts

Discussion of all known MASINT phenomenology, sensors and techniques would require several volumes of written literature. Rather, this thesis will explore examples from the segment of MASINT that works with data collected by remote sensing electro optical and radar imaging platforms. This collection of technologies is also referred to as advanced geospatial intelligence or AGI. Joint Publication 2-03, Geospatial Intelligence Support to Joint Operations, defines AGI as an important subset of geospatial intelligence (GEOINT):

> AGI employs advanced processing techniques to extract technical, geospatial and intelligence information from imagery or imagery related collection systems. AGI was previously referred to as imagery derived measurement and signature intelligence (MASINT) and often employs nonliteral analysis.[12]

Advanced geospatial intelligence concepts include the use of multi and hyperspectral imaging, infrared imaging, light detection and ranging (LIDAR) and synthetic aperture radar (SAR) in order to derive intelligence information. These are all imagery based MASINT technologies with sensors designed to measure a spectral, optical, infrared or microwave signature emitted or reflected by an object or scene. The data will then undergo several iterations of processing that will transform it into some type of visual representation, usually an image of some kind, that an analyst can interpret. The processing and analysis-intense nature of AGI makes it difficult to adapt to fast intel problems. The following paragraphs will describe three different categories of AGI source technologies with the intent to demonstrate the scientific, technical nature of the concept, the systemic difficulties in achieving fast intel and the importance of depth of analysis when working with these technologies. Furthermore, while AGI may indeed be difficult to apply to fast intel problems, each of the technologies described below has enjoyed recent successes in other matters of national security that should encourage intelligence community professionals, warfighters and national policy makers to consider additional creative ways in which AGI and other MASINT applications can support a wide range of national security interests.

Hyperspectral Imaging

Hyperspectral imaging or imaging spectroscopy, is a process to measure, interpret and analyze the reflected, emitted or backscattered electromagnetic energy of a specific object or scene in hundreds of bands across the electromagnetic spectrum.[13] Traditional optical imaging sensors measure and interpret the visible portion of the spectrum (wavelengths ranging from approximately 390 - 750 nanometers) in order to create a literal representation of the earth's surface. This type of imagery enables analysts to describe objects by traditional imagery interpretation features including shape, size, pattern, texture and color. Hyperspectral imaging can measure reflected energy across a much larger wavelength range. NASA's Airborne Visible Infrared Imaging Spectrometer (AVIRUS) hyperspectral sensor, for example, measures reflected energy in 224 bands of wavelengths ranging from 400 - 2500 nanometers.[14] Hyperspectral imaging sensors are capable of measuring emitted or reflected energy in bands well outside that which is visible to the human eye and provides an opportunity for more detailed image analysis. Using hyperspectral data, analysts can distinguish spectrally similar materials, and extract sub-pixel scale information.[15] This enables analysts to more precisely characterize the composition of objects, not just the outward appearance as seen by the naked eye.

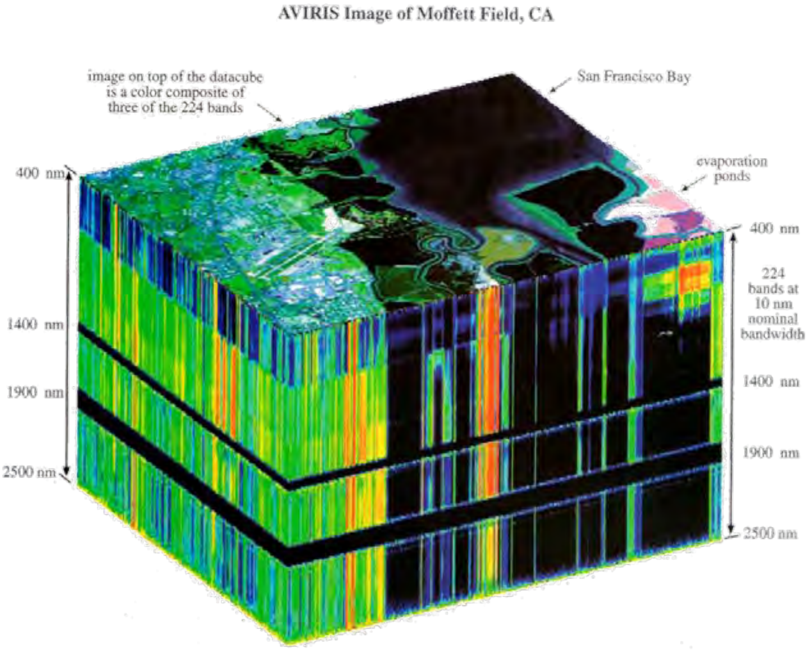

Figure 2: AVIRUS Hyperspectral Data Cube
Source: NASA Jet Propulsion Laboratory, 1992

All bands of hyperspectral data are collected simultaneously by the sensor and can be visualized as a cube of raw data as shown in figure 2. The top layer in this example from AVIRUS is a color composite image using three of the 224 bands. Stacked below the top layer are each of the 224 bands in its own individual layer. Each individual layer contains hundreds of pixels that indicate the strength of spectral reflectance of the scene for that particular band.

The enormous amount of data collected in one hyperspectral data cube must undergo several processing steps before it can be analyzed for intelligence value. As with all digital imaging systems, the data must be corrected for radiometric and geometric errors encountered during collection.[16] Generally, this is accomplished through sophisticated image processing software and processing algorithms. Following the initial processing, the data can be imported into a geographic information system (GIS), where the data will be further manipulated for visual analysis, extraction of the intelligence information and preparation of the final intelligence product. This stage involves any number of image data transformations including display enhancements, spectral processing, georectification, filtering, classification or algebraic operations.[17] The number of additional transformations and the specific parameters of each transformation depends on the type of intelligence information that the analyst is attempting to extract. The analyst will then use both literal and non-literal image interpretation techniques to analyze the data. Standard literal interpretation techniques include size, shape, height, shadow, tone, texture, pattern, association, site and time.[18] Non literal analysis involves analyzing the spectral reflectance of a scene across several bands in order to further identify, classify or discriminate objects, elements or activity. For example, green camouflage covered equipment has a significantly different spectral signature in the infrared bands than does the surrounding vegetation. Also, mineral elements such as hematite, calcite, gypsum and many others have distinct spectral signatures in the long wave infrared bands.[19]

The extensive amount of processing and data manipulation requires highly trained analysts with a deep understanding of digital imaging phenomenology in order to produce reliable information. Data automation can save the analyst a lot of time and uncover details in a scene that could not otherwise be extracted. However, automation must be used with great care so that the data does not become so manipulated that it ceases to be a true representation of the original scene. Also, understandably, the more transformations that are required, the longer it may take the analyst to build the final product. Some projects may take several hours to process and analyze once the raw hyperspectral data is imported into imagery processing systems.

Depending on the size of the area imaged, one hyperspectral data cube can contain well over 20 gigabits of information. These large file sizes require huge amounts of bandwidth if an image is to be transmitted directly from the sensor to a ground station for immediate use. In a military operation, competition for bandwidth in the communication architecture is a growing challenge. Resource constraints will almost always restrict the amount of available bandwidth. New techniques in data compression are being developed in order to minimize transmission times,[20] but the necessity to electronically transmit large quantities of data will continue to hinder the ability of AGI to adapt to fast intel problems.

Another limitation of hyperspectral imagery is that it cannot image through clouds or foliage. The impact has not been as severe in areas of operation such as Iraq or Afghanistan where the weather and terrain is relatively conducive. However, as the United States increases its involvement with partner nations in areas such as central and southeast Asia, the Caribbean, and Central and South America, cloud cover, poor weather and dense jungle foliage become a greater limiting factor.

In spite of its limitations, hyperspectral imaging is slowly gaining momentum in its use across a wide range of intelligence problems. There are a number of recent cases of successful application of hyperspectral technologies that speak volumes to its future potential. One such case occurred in Iraq where hyperspectral imagery was used to assist in identifying mass graves. The analyst started by imaging a known mass grave site in order to identify any unique spectral signatures that might help identify other gravesites.[21] That spectral data was then compared with about 240 other possible grave sites. In at least one case, a mass grave site was identified with hyperspectral imagery based on the presence of gypsum, which is normally a sub-soil in that region. However, when there is digging, such as that associated with mass graves, the gypsum is turned up to the surface. The signature of gypsum was identified with hyperspectral imagery and the site was then further investigated for confirmation as a mass grave site.

More recently, NASA's WB-57 aircraft, carrying its hyperspectral sensor, has been used successfully in Afghanistan to assess its natural resources, accelerate infrastructure development and ultimately lead to job creation for Afghan nationals.[22] This program, called HALO Falcon, is an excellent example of the use of AGI intelligence sensors to support engagement, security cooperation and economic development efforts in Afghanistan. In this case, the relatively lengthy processing and analysis of hyperspectral data was less mission-critical, making the overall value of the finished product much more relevant for the Afghan government supportive of United States foreign policy goals in the region.

Recognizing the unlimited potential of hyperspectral imagery following NASA's lead, the United States Air Force has initiated an upgrade program to modify 18 U-2 high-altitude ISR aircraft to carry hyperspectral sensors called SPIRITT (Spectral Infrared Remote Imaging Transition Test-bed).[23] The SPIRITT equipped U-2s are initially indented to collect hyperspectral data over Afghanistan, but as more airframes are equipped and operations in Afghanistan wind down, the aircraft will potentially become available for use in other partner nations in support of security cooperation, engagement, disaster planning, urban planning, and more.

Synthetic Aperture Radar (SAR) Imaging

Synthetic aperture radar is also used to create advanced geospatial intelligence products. Similar to hyperspectral imaging, advanced SAR applications require non literal interpretation and multiple iterations of processing and analysis in order to generate an intelligence product. Unlike hyperspectral sensors though, radar is an active technology. SAR AGI sensors can be placed on airborne and spaceborne platforms. The sensor sends out a pulse of microwave energy and the returned energy is recorded for subsequent processing and analysis. Imaging radars generally operate in the wavelength range of 1mm – 1 meter.[24] Also, unlike hyperspectral sensors that have the capability to collect several wavelengths simultaneously, radar imaging generally operates in only one specified wavelength (L band, C band or X band, for example). However, more technically advanced radar imaging systems are being developed that allow greater frequency and polarization flexibility.

There are essentially four parameters that radar imaging sensors capture: position, reflectivity, polarization and phase.[25] Several stages of processing transforms the data into an image of some sort. Prior to the digital age, radar data was recorded as an analog hologram.[26] Therefore, additional image transformations and processing were minimal. Radar image collection has since transitioned to digital formats that can undergo intense processing in order to extract greater detail. Exploitation of a radar image involves the same techniques as discussed for hyperspectral imagery. The key difference is that the radar image shows backscattered microwave energy rather than reflected sunlight.[27] Correct interpretation of the radar image requires the analyst to have a solid understanding of how microwave energy reacts to surfaces, as it is significantly different than the way visible light reacts to surfaces.

Radar AGI has been in use for several years in South America as a foliage penetration (FOPEN) capability to detect activity and structures underneath the thick vegetation canopy. U.S. Southern Command (SOUTHCOM) recently began to employ the Tactical Reconnaissance and Counter-Concealment-Enabled Radar (TRACER) to support its missions in counterterrorism, humanitarian assistance, and disaster relief operations.[28] TRACER is a light weight, low-frequency synthetic-aperture radar that can be placed on an airborne platform where it can peer through foliage, rain, darkness, dust storms, or atmospheric haze to provide real-time, high-quality tactical ground imagery.[29] SOUTHCOM's foliage penetration predecessor to TRACER is still in use and produces images similar to those shown in figures 3 and 4. The white spot in the upper third of figure 3 represents a structure under the surrounding forest canopy that appears in shades of red in the image. Figure 4 shows two buildings as large white spots. The thick triple-layer canopy of countries in South America provides excellent concealment of activity occurring below the tree lines. Foliage penetrating radars have been instrumental in assisting partner nation law enforcement and military efforts with identification of activity below the canopy.

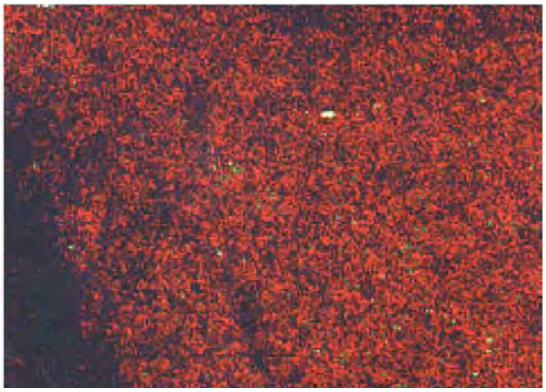

Figure 3: Foliage Penetrating Radar
Source: International Radar Consultants
http://int-radar.com/sar.htm

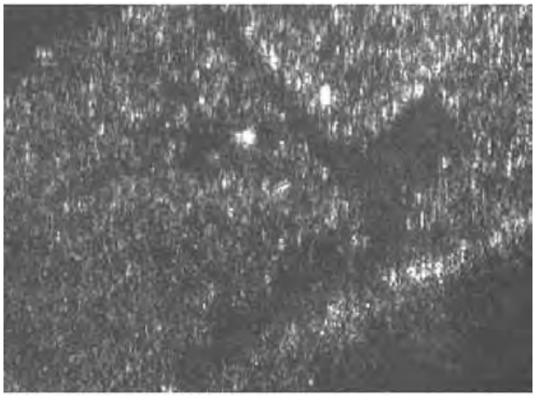

Figure 4: Foliage Penetrating Radar
Source: International Radar Consultants
http://int-radar.com/sar.htm

SAR interferometry is also used to generate digital terrain models (DTM) and monitor changes in surface terrain. Figure 5 is one example of a radar terrain model of the Washington DC area. The image was collected in June 1993 using the Joint Propulsion Laboratory (JPL) AIRSAR sensor on a NASA Ames DC-8 aircraft.[30] SAR interferometry works by collecting two images of the same scene from two spatially separated antennas or from the same antenna at two different times.[31] Combining the two images with automated processing algorithms produces accurate elevation measurements. In the example image, taller features are color coded in red, fuchsia and dark blue while the low lying areas are yellow and green. An alternative application of the same principles can be used to detect terrain changes in the scene. If two images of the same scene are collected from the same antenna position at separate times, the resulting combination of the two images will show where terrain has been disturbed. In this application, analysts can detect terrain deformations caused by earthquakes, volcanoes, and glaciers.[32] In military applications, this technique can be used to detect disturbed terrain caused by vehicle movement or digging and placement of improvised explosive devices.

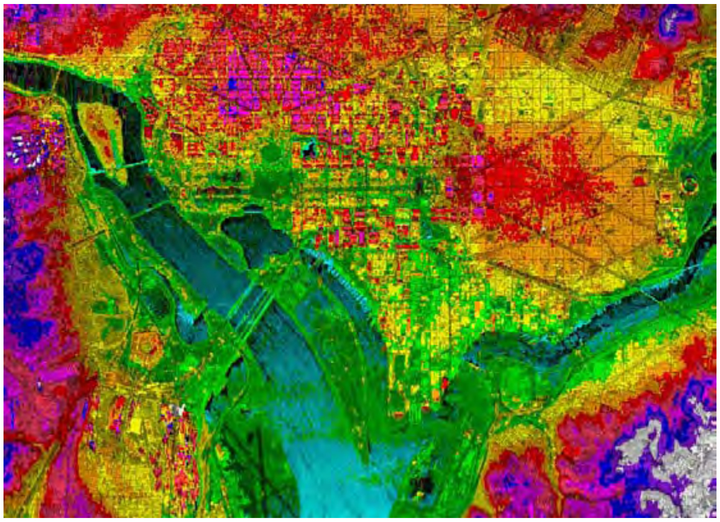

Figure 5: AIRSAR Radar Image

Source: FAS Intelligence Resource Program, Jan 1997
http://www.fas.org/irp/imint/isfar.htm

As demonstrated, one of the greatest advantages of using radar in AGI is that it has the capability to penetrate foliage, clouds, soil and water. Radar energy in the microwave range and has a longer wavelength than visible light. The longer wavelength enables it to penetrate layers of vegetative coverage or even into the top layers of soil. This enables the analysis of objects and activities that are otherwise camouflaged, covered by foliage or partially ground covered. Its ability to penetrate cloud cover makes radar a great alternative in poor weather conditions. Also, as an active sensor, it can be used day or night.

There are a few disadvantages as well. Radar AGI, especially when combining images, is subject to several processing errors such as signal-to-noise ratio, navigation and motion compensation errors.[33] Automated processing can reduce, but not completely eliminate these errors. Another disadvantage of radar AGI is that it requires highly skilled analysts to correctly interpret radar returns. Again, automation saves a lot of time in the processing and analysis phase, but the more an image is processed, the farther away it is from its raw form, and the more the analyst must correctly understand each transformation that data has experienced in order to extract data with integrity from the image.[34]

Light Detection and Ranging (LIDAR) Imagery

Lidar is not a new technology. The term itself was coined shortly after WWII, following the widespread use of radar.[35] The technology is also similar to radar in that it is an active system. Essentially, an electromagnetic pulse is transmitted from the sensor and interacts with the surface where it is scattered, absorbed or reflected before returning to the sensor for detection and analysis. The key difference between radar and lidar is the wavelength of the energy emitted from the sensor. Lidar operates in the optical range (ultraviolet, visible light, infrared), while radar operates in the microwave range of frequencies. This distinction is important because energy in different frequency ranges interacts with objects in distinct ways that can reveal different characteristics of the land surface, water or target object. Ground-based lidar sensors have been widely used for atmospheric and oceanographic studies over the past few decades. More recently, with the advancements in precision global positioning systems, lidar sensors are being used on airborne platforms to conduct three dimensional surface mapping, including urban terrain and vegetation canopy mapping. The ability to place lidar sensors on air and space platforms created a surge of new innovation and development in lidar applications. Air and spaceborne lidar can cover wider geographic areas and have the ability to reach areas that were previously inaccessible to ground sensors.[36] As such, lidar is already being used in support of a number of national security and defense intelligence issues.

The most common application is the use of high resolution lidar data to create digital terrain models. DTMs from both radar and lidar sources are used for orthorectification of electro optical imagery.[37] This allows greater precision in extracting coordinates of discreet objects or terrain features that appear on an image. Lidar DTMs can also be used to conduct line-of-sight analysis or change detection.[38] Lidar DTMs are extremely useful in mapping flood hazard areas and severely sloped areas that are prone to landslides or mudslides.

Another common application of lidar is conducting bathymetric surveys of coastal areas. In bathymetric surveying, lidar pulses are used to map the contours of the littoral surface. While lidar bathymetry has been most effective in surveying clear waters, its effectiveness is also being explored further in very shallow riverine areas where sediment content is higher and surface-based acoustic bathymetric survey equipment is either ineffective or unable to access targeted areas of interest.

More recently, lidar has been explored for its ability to detect objects under foliage canopies as the demand for foliage penetration capabilities sharply increases. In March 2011, the US military ordered two King Air 350ER (MC-12) aircraft to be integrated with the Tactical Operations Light Detection and Ranging (TACOP LIDAR) sensor.[39] Initially lidar was developed in a single wavelength that had little capability to penetrate foliage due to its short wavelength. However, more recent lidar apparatus is made with multiwave polarimetric lidar.[40] This enhances its ability to identify objects under canopy in a couple of ways. In a single wavelength of visible light, for example two similarly colored objects may have a very similar reflected signature, making them difficult to distinguish on an image. However, when multiple wavelengths and polarimetric signatures are introduced, it becomes easier to distinguish between a green tree canopy and a green camouflage covered object because the spectral and polarimetric reflectance in multiple bands versus one is different due to different textures and surfaces.[41]

While lidar wavelengths are generally too short to reliably penetrate through canopy, it still has the ability to pass through openings in the canopy to the surface and return to the sensor. The technique is based on time-distance calculations in order to characterize the three dimensional space below a canopy of vegetation. When a radar or laser pulse is emitted, the time it takes to return to the sensor gives us information on the structure of the surface. Theoretically, a pulse of radar can penetrate the vegetation, be reflected underneath the canopy several times and then return to the sensor. The later the pulse returns to the sensor, the more it may describe the structure under the canopy.

As demonstrated, lidar has many applications, but the data must undergo extensive processing in order to be transformed into concise products that support decision making. When the sensor collects the information, the data is stored in a raw data file, usually in a simple text or binary format, that can contain well over 10,000 three dimensional point locations. Each single point has at least four basic components that describe the intensity of the return and the x, y and z position relative to the sensor when it was collected.[42] The raw data file must be interpreted with imagery processing and/or geographic information system software in order to produce a visual representation of the data, or point cloud, such as the image of New York's ground zero shown in figure 6. In order to produce a viewable representation like this, each point in the cloud is

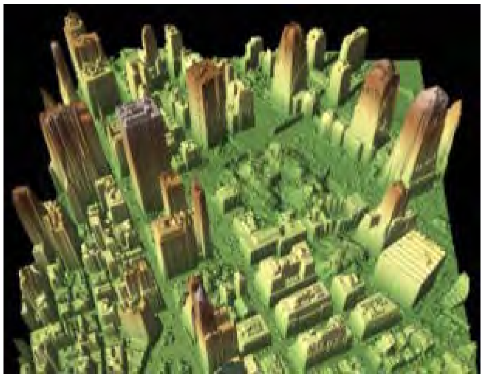

Figure 6: New York Ground Zero Lidar Point Cloud
Source: TGMG, Inc., 2009
http://www.govmap.com/LIDAR.htm

analyzed by the software and assigned a color. In this case, the points with the lowest elevations were colored green and the highest elevations were colored brown. The process of receiving data, applying any necessary geometric corrections or calibration algorithms, importing it into a GIS and manipulating it for display can take hours depending on the file size of the raw data. Once the data is transformed into a format that can be evaluated, the analyst can draw out the intelligence information and prepare a final product for distribution to the requestor.

There are many advantages in using lidar. It provides greater resolution in digital elevation mapping than radar. The shorter wavelength of lidar energy provides better range resolution and spectral purity than radar.[43] For example where radar terrain mapping does not have the resolution to detect smaller towers or power lines, lidar can detect those smaller features. Also, like radar, lidar is an active sensing technique and can be used during the day or at night and in highly shadowed areas where passive sensors have difficulty collecting emitted energy. Finally, it can map bare earth elevations where vegetation covers the ground. As long as one or more lidar pulses reaches through to the ground and returns to the sensor, the elevation of the bare earth surface will be detectable.[44] Finally, like the other AGI techniques, there are limitations to lidar imaging. Lidar is less effective in hazy or lightly clouded conditions, and ineffective in rain or mist. Similarly, it produces unreliable returns from water.[45] Highly trained analysts are required to interpret this type of data.

Adapting AGI

All of the AGI capabilities described in the preceding paragraphs are limited by the time it takes to process and analyze the data. However, advancing technology has enabled many data automation techniques that, when prudently applied, have greatly improved the intelligence community's ability to push timely, relevant advanced geospatial intelligence to warfighters.

Analysts have the capability to build scripts in image processing software that automatically apply a series of image processing steps to an image. The burden remains with the analyst however, to understand how the transformations affect the data in the image and where the ultimate intelligence value lies within the context of multiple complementary sources of intelligence.

Automation has also enabled faster identification of known signatures. Over decades of research and experimentation with MASINT sensors, extensive databases of spectral, acoustic, nuclear and radar signatures have been built. The appropriate signature library can be pre-loaded into a sensor so that if the sensor detects a match, it can alert the user immediately.[46] This technique works exceptionally well when the intended target signature is already known. However, the technique becomes ineffective when there is no existing signature for the target of interest. For example, if an adversary builds a new type of target acquisition radar, the signature of that particular radar will not be available in a radar signature database until it can be collected and studied. Spectral signature libraries are also far from exhaustive, especially for urban-related spectral signatures.[47] Continued research and development of a comprehensive signature database is necessary in order to make the most timely, relevant use of AGI and other MASINT technologies. Again, the burden will be with the analyst to ultimately determine the intelligence value of a signature as it relates to the intelligence problem.

Recommendations and Conclusion

In order to use MASINT to its fullest potential, the greater community of end users should be better informed on existing capabilities and the science behind them. Further, academia-based MASINT scientists should continue to be integrated into government intelligence programs in a way that minimizes loss of proficiency in their primary specialty.

Finally, the MASINT community should continue to mitigate the lengthy timeline of MASINT processing without losing data integrity and value-added human analytical thought due to over-automation.

The MASINT community has made great progress in adapting MASINT technologies to deliver intelligence to the customer faster. However it is important to keep in mind the potential dangers associated with more automation and less human analysis. It is counterproductive to automate data processing to the point that the intangible, fine details are no longer perceivable. Additionally, and especially in light of a resource constrained environment, there is a danger that too much time, effort and money may be spent trying to make MASINT faster when it may be more prudent to devote critical resources to improving the quality or resolution of current sensors or in wider training and education of MASINT analysts, collection managers and end users.

When MASINT cannot be produced fast enough to be militarily relevant without losing critical analytical integrity, analysts should instead use these sources of MASINT in support of less time-sensitive intelligence problems. Through creative or unconventional approaches, a solution may be discovered that links seemingly unrelated ideas in order to support issues of national interest. NASA's WB-57 aircraft with its hyperspectral sensor is a good example of this. The two seemingly unrelated ideas in this example are hyperspectral technology and economic development in Afghanistan. The challenge is to find the link or links between these concepts that moves the US closer to its economic development goals in Afghanistan. In this case, one of the links is mineable minerals such as copper or magnesium. Indicators of these elements can be detected with hyperspectral imagery. Discovery of these elements might subsequently lead to mining contracts and new job creation that ultimately supports economic development. This type of forensic level analysis can make MASINT an extremely potent instrument of foreign policy.

In order to promote more effective use of MASINT, the community should continue to provide education and awareness of the technologies that works to minimize the aforementioned knowledge gaps. When ordinary end users are better educated in the sciences underlying MASINT, they will be better able to articulate the right questions to ask about what MASINT can do for them. Equally, the scientists will benefit from developing a greater understanding of how commanders use intelligence information to support decision making. Since 1993, when DoD Instruction 5105.8 was first issued, The MASINT community has made a great effort to promote awareness and continue to refine central management so that the community can take full advantage of MASINT capabilities. This effort to promote awareness must continue, especially as new technologies are developed.

In addition, greater emphasis must be placed on training analysts to be able to identify the individual data points that will aid their overall analysis. In other words, the analysts should be trained on techniques to help them identify the "links" between seemingly unrelated concepts as described above. Analysts need to be able to deconstruct an intelligence problem and identify the discreet, unique elements or components that have distinct signatures that our sensors can detect. Identifying those key elements will help the analyst articulate that need in the form of a collection requirement that can be tasked to a specific collection platform. Instead of submitting a broad, nonspecific collection request to the collection manager, the analyst can learn to ask for a specific element of data that supports the core intelligence problem.

MASINT data is exceptionally well suited to support not only military applications, but a variety of whole of government intelligence issues. Data sets can readily be adapted to suit a number of different purposes. Through the course of foreign policy action in other countries, each agency or department of government may often have slightly divergent goals, yet all can make use of the same baseline hyperspectral data, radar, or lidar data collected in that country. It is simply tailored in its analysis and final appearance to meet the needs of that particular department and its host nation representatives. In this way, the same MASINT data sets can be used to support foreign policy mission areas as diverse as economic development, humanitarian assistance, disease prevention, energy security, urban development and more. By using commercial imagery, "these unclassified products can be distributed to local, federal and non-governmental emergency management agencies to assess and mitigate danger in situations where geospatial intelligence (GEOINT) adds an incredible amount of value."[48] Solutions like this enhance engagement, security cooperation and partnership efforts with other nations while promoting cooperation among US military and interagency partners.

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Glossary

advanced geospatial intelligence — Refers to the technical, geospatial, and intelligence information derived through interpretation or analysis using advanced processing of all data collected by imagery or imagery-related collection systems. Also known as imagery-derived measurement and signature intelligence. Also called AGI. (JP 2-03)

change detection — An image enhancement technique that compares two images of the same area from different time periods. Identical picture elements are eliminated, leaving signatures that have undergone change. (JP 2-03)

geographic information system (GIS) — A computer-based system designed to input, store, manipulate, and output geographically referenced data.*

hyperspectral imagery — Term used to describe the imagery derived from subdividing the electromagnetic spectrum into very narrow bandwidths. These narrow bandwidths may be combined with or subtracted from each other in various ways to form images useful in precise terrain or target analysis. Also called HSI. (JP 1-02)

intelligence process — The process by which information is converted into intelligence and made available to users, consisting of the six interrelated intelligence operations: planning and direction, collection, processing and exploitation, analysis and production, dissemination and integration, and evaluation and feedback. (JP 2-01)

interferometry — The combination of two radar measurements of the same point on the ground, taken at the same time, but from slightly different angles, to produce stereo images.*

light detection and ranging — LIDAR is an active remote sensing system that uses a LASER light beam (instead of a microwave radar beam as used in RADAR) to measure vertical distance.*

measurement and signature intelligence — Intelligence obtained by quantitative and qualitative analysis of data (metric, angle, spatial, wavelength, time dependence, modulation, plasma, and hydromagnetic) derived from specific technical sensors for the purpose of identifying any distinctive features associated with the emitter or sender, and to facilitate subsequent identification and/or measurement of the same. The detected feature may be either reflected or emitted. Also called MASINT. (JP 1-02)

multispectral imagery — The image of an object obtained simultaneously in a number of discrete spectral bands. Also called MSI. (JP 3-14)

remote sensing — The science, technology and art of obtaining information about objects or phenomena from a distance (i.e., without being in physical contact with them).*

spectral signature — The frequency distribution patterns of radiation reflected and/or emitted by an object.*

synthetic aperture radar — A synthetic aperture radar, or SAR, is a coherent radar system that generates high resolution remote sensing imagery. Signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture to create an image.*

** Source: Natural Resources Canada, Glossary of Remote Sensing Terms, http://www.nrcan.gc.ca/earth-sciences/glossary/index_e.php*

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