DRAFT

White Paper

Project STACI:
Systems Theoretical Approach to Counter IEDs

Tenet Lanes: Predict & Detect

Submitted To:
Joint IED Defeat Organization

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Executive Summary

Effective strategies to counter the IED problem require a systems theoretical approach. In short, systems theory aims to “contextualize” problems and steers clear of simple multi-disciplinary models. Our strategy, discussed in greater detail below, is derived from scrutinizing the IED threat objectively and comprehensively. Our approach is based on three of our team member’s long experience with systems theory and our grounded experience with the IED problem in Iraq. Our approach will utilize powerful visualization technologies (hyperspectral, LIDAR, etc.), GIS spatial analysis and modeling, and computational methods to treat the problem comprehensively. The theoretical approach follows the design of one of our team member’s 1500 hours training at IBM technology centers, an approach that has been applied in numerous complex governmental and private settings (Gharajedaghi, 2006). A few of these settings include ALCOA, Chrysler Corp., Ford Motor Company, and two internationally acclaimed projects: New Economic Order, a United Nations project and Goals for Mankind, a Club of Rome project.

Our systems approach will utilize the “Structure, Function and Process Iterative Model”. In general, scientific research tends to focus on independent multi-disciplinary pieces in which the whole is the sum of its associative parts. In our systems approach, we intend to reassemble the “puzzle,” and then study it as an interactive system—a synthesis of processes, data, and interpretation which is the key of our theoretical framework. The “system development process” has been used by the military since the second half of the twentieth century and a new version called DoD 5000 was just instated in 2000 (Kossiakoff and Sweet, 2003). Our proposed approach is also well grounded on direct our team’s experience with IEDs and the complex and chaotic combat environment of Iraq—a strength we intend to exploit as we study integrated systems to discover new methods for detection and prediction, and to develop effective counter measures.

Utilizing hyperspectral sensors, a technology familiar to and utilized by the Department of Defense (DOD), will provide a broad spectrum of digital intelligence which then can be combined with other data sets. Spatial analysis and computational modeling that is grounded in systems analysis then becomes the process by which we will sift through the “realities” of the IED challenge. The current use of narrowband remote sensing in UAVs and other platforms is well known to DOD scientists and field engineers as a test bed for solving complex problems facing U.S. troops in current and future combat scenarios. Publicized DOD hyperspectral remote sensing is being used to detect substances and devices (known or unknown) in a real-time “data fusion” environment. While these technology products are useful, we will use hyperspectral imaging (and other available data layers) to find the relevant materials, and bound the problem in several ways, ultimately going further back to identify possible sources (e.g. manufacturing, materials, etc.) or organizational infrastructure. .

The Techniques, Tactics and Procedures (TTP) employed in combat tactics has followed the action-reaction model first espoused by Boyd—one of observation, orientation, decision and action. Due the rapidly diminishing time cycle between introduction of new countermeasures and enemy response to overcome those countermeasures, we see the greatest opportunity for problem solving in two Tenet Lanes: Prediction and Detection. Subsequently, our model potentially introduces a major paradigm shift from traditional analytical scientific research models toward integrated and iterative systems modeling, and one we are certain will provide a new way of fighting insurgency and the IED threat. As stated by Mills, “Within this [intelligence] process, analysts must extract meaning from data and images. Specifically, theory enhances the ability to visualize a battle space. . .to contribute to analytical knowledge integration. . . theories work to bridge practical application gaps in the intelligence community—enhancing our ability to adapt and thwart failure” (Mills 2003). Thus application of systems theory to data collection and data fusion may lead to new ways to extract useful intelligence from geospatial data.

In terms of technology, we have three overall objectives. We intend to focus on the following areas of long-term research in advanced GIS spatial analysis with an emphasis on integrating hyperspectral remote sensing (and other imaging technologies) capability to enhance the mission objectives of JIEDDO:

- ***Classification and target identification using a combination of structure, function, and process methodologies in pattern and anomaly detection, as well as comparative GIS layer analysis using***

Hyperspectral data in combination with other data sets that help contextualize the problem (i.e. socio-economic, political, environmental). This approach will include a number of disciplinary models: Actor-Network Theory, Spatial Analysis, Adoption-Diffusion, and Structural Equation Modeling. We intend to present to DOD a short-term and long-term scientific-based training program for decision makers that will enhance their ability to predict those elements in a complex and chaotic environment that are likely to increase or reduce IED and other threats to U.S. troops.

- ***Utilization of hyperspectral imaging combined with atmospheric correctional modeling in both laboratory and in situ conditions utilizing current and new instrumentation.*** We believe this approach will enhance real-time data analysis.
- ***Material mapping and image analysis algorithm development, enhancement and improvement in processing.*** We believe this approach will allow us to develop new layers of data, internal and external correlations and anomalies, and a "wider" view of what the data represents.

Modeling and prediction capabilities are based on Texas A&M University's and this proposal's collaborative team, current operational hyperspectral equipment and research laboratory assets, and the Texaco Energy & Environmental Multispectral Spectrometer (TEEMS) which is currently operational in a laboratory. If necessary this device could be installed in an aircraft and deployed to capture data. However, we believe that current, relevant data may be available from existing government sensors such as COMPASS (Simi, 2001) and, ARCHER (Stevenson, 2005). These new devices can be installed on smaller aircraft than the TEEMS device, but more importantly current data should be accessible. Finally, we have assembled a team of scientists and technicians capable of meeting our stated objectives. Funding is requested to assist the DOD in examining these data, potentially adding new tools that can defeat IEDs and protect our troops through the development of solutions based on the TAMU systems approach.

Technical and Operational Approach

I. What scientific concept and/or associated technologies are being proposed? How will it contribute to one or more JIEDDO tenet lanes?

The complexity of the IED problem demands that a dynamic approach be used. Systems Theory (or thinking) provides a strong foundation for such an approach. Systems analysis does not simply entail a multi-disciplinary approach; rather, the real issues related to dynamic and changing problems like IED detection and prediction is to develop ways to synthesize separate findings into a coherent whole. This fact is far more critical than the ability to generate information from different perspectives. To illustrate our point, we use the elephant story found in Persian literature and narrated by Molana Jaladedin Molavi (Rumi). It presents the elephant story as a metaphor in which several men are attempting to identify the creature in the dark. The effort proves fruitless until another man shows up with a light. Gharajedaghi (2006) Page 108-109 presents this perspective in the following:

> "The light, which in this context is a metaphor for methodology, enables them all to see the whole at last.
>
> Rumi's version of the story means that the ability to see the whole somehow requires an enabling light in the form of an operational systems methodology." …. For our purpose here, … "one should be able to make one's underlying assumptions about the nature of the socio-cultural systems explicitly known and verifiable to oneself.
>
> Whatever the nature of the enabling light, my contention is that it must have two dimensions. The first dimension is a framework for reality, a system of systems concepts to help generate the initial set of working assumptions about the subject. The second dimension is an iterative search process to: 1) generate the initial working assumptions, 2) verify and/or modify initial assumptions, and 3) expand and evolve the emerging notions, until a satisfactory vision of the whole is produced. As Singer put it "Truth lies at the end, not at the beginning of the holistic inquiry" (Singer, 1959).

The problems presented by IED detection and prediction suggest that we consider "stepping-back" to gain new insights into the problem in order to develop more effective solutions. Based on one team member's direct and personal experiences with IEDs, intelligence analysis and application, and complex TTP cycles in Iraq, our approach is well grounded. The effective and efficient use of gathered information is a critical input for any model—analytical or systemic. Under our systems approach, grouping information sources such as HUMINT, SIGINT, and IMINT is not enough. It must be synthesized against a larger backdrop in order to produce a holistic model. According to Steels, "The traditional craft of intelligence has tended to fragment content from its context and be largely oblivious to timing. The new craft of intelligence recognizes that the value of any given information, apart from its relevance to the decision at hand, stems from a combination of the content in context and the content in time" (Steele 2002). Our hypothesis is that hyperspectral remote sensing applied across a wider spectrum may provide that larger correlation backdrop. New and novel approaches not constrained by preconceived ideas may provide significant advances for addressing the IED challenge.

Effective use of GIS spatial analysis that integrates all of the available intelligence (primarily HUMINT) will help us determine *where* we look for materials of interest. Our approach will target the capture of GIS data layers and intelligence and to coordinate that with hyperspectral imaging. Our approach to counter the IED problem is sensible and efficient, because 1) the pressure to decide on things in real-time is significantly reduced because, practically speaking, it takes considerably more time and equipment to move a significant explosives making effort, and 2) we are aiming at the "source" of the problem rather than just treating a "symptom". Timeliness is still critical, but chances are that what we find will still be there tomorrow because it is just too difficult to move explosive making operations quickly.

Critical to addressing the issue of a timely solution we are proposing a dual-cycle synthesis and analysis for rapid data fusion, analysis, modeling and decision support. A priority of our proposed approach is a speedy deployment solution to get soldiers in the field better intelligence for improved decision-making. To meet this aim we will perform a short-cycle and long-cycle data processing. In other words, our team of experts will develop a "mini" systems approach (see diagram 2) to create a robust but short-term solution to get this novel technique on the ground in the shortest possible timeframe. The long-cycle will be performed ongoing, constantly upgrading the approach that is developed from the previous cycle. It's focus will be more towards strategies to counter the IED problem, likely using hyperspectral imaging to find and identify various materials which are being used to construct IEDs, and then to use that information to find the persons responsible.

Perhaps tagging, tracking, and locating of these persons or materials will lead to preventative strategies rather than "after-the-fact" reactive strategies. The power of our systems approach is that each time a cycle is run, a new product for "in-theatre" application will be available. We will utilize appropriate mathematical techniques such as principal component analysis to "sift through the haystack" in an expedient fashion.

With systems thinking as a foundation, we propose the following three Focal Areas as strategies for dealing with IED prediction and detection. The first focal area provides an overarching umbrella while the other foci address more specific issues. Not only does our proposed approach have a strong theoretical grounding through the use of "enabling tools" (hyperspectral sensors, LIDAR, GIS analysis, Intelligent Transportation Systems, etc.) but also it has the experience of "in-the-field" operations. We are proposing a novel and reality checked approach for systematically studying and analyzing the IED problem. The ultimate aim will be to generate effective, timely solutions. Diagram 1 depicts the structure of the Systems Approach that is outlined in more detail in Focal Area 1 below.

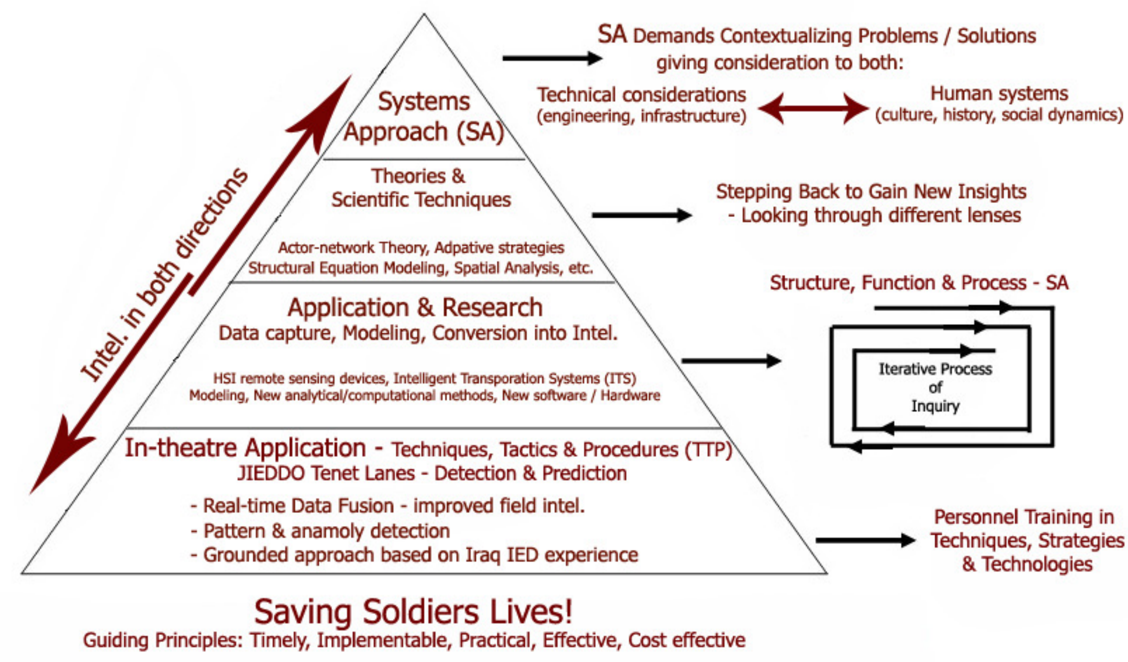

Diagram 1: Structure and details of TAMU Systems Approach to defeat IEDs

Prediction - Focal Area 1: Classification and target identification using a combination of structure, function, and process methodologies in pattern and anomaly detection, as well as comparative GIS layer analysis using Hyperspectral data in combination with other data sets that help contextualize the problem (i.e. socio-economic, political, environmental).

Derived from existing and captured data and intelligence (Focal Area 2 and 3), we will synthesize these data to research pattern and anomaly detection, interpretation, and target identification methodologies. Rather than utilizing a traditional multi-disciplinary focus that creates independent representative models based on discreet data sets, we will process this information via systems analysis, iteratively moving through “function”, “structure and “process” within a “context”, which was the process that Wolfram (2002) suggests is at the core of all complex natural phenomena that develop effortlessly (Gharajedaghi, 2006). We propose that this same perspective—a new conceptual framework in which we focus on the “multi-dimensional topography” (including socio-economic and geo-political)—can provide insights into the dynamic and accelerating nature of the IED threat.

The value of this iterative process allows for constant evaluation and modification, establishing “validity of assumptions, then compatibilities and/or conflicts are identified and dissolved” (Gharajedaghi, 2006). Re-conceptualization of variables is necessary when conflicts are dissolved. This iterative process results ultimately in an integrated design and process that can also evolve as the IED threat changes. Under the umbrella of Systems Theory, the following theories and analytical techniques may provide useful for improving our model. Specifically the aim for this process is to create new models for predicting threat accumulation and subsequent action-reaction cycles leading to IED employment:

1. Actor-Network Theory, Adaptive Strategies, and Structural Equation Modeling can provide holistic systems in which to infuse hyperspectral and other GIS data sets to find iterative patterns and variables. These theories and statistical approaches can provide novel perspectives by which hyperspectral and other data might reveal significant interdependencies. Ultimately these views will be used to identify potential new systems, functions and processes.
2. Historical military patterns of TTP development based on what we see, what hyperspectral remote sensing can show us, and how political, sociological, psychological, economic and other inter-related disciplines can be extracted and represented through hyperspectral remote sensing. Whatever patterns emerge, identify and bring in experts and develop patterns and new data analysis methods.

3. Solution development – application of data analysis to provide paradigm shifts or new paradigms that can disrupt enemy TTPs or create new action-reaction cycles that enemy forces cannot interpret and interdict.
4. Training and implementation for our intended discoveries may lead to immersive visualization for end-users (training element included), as well as policy and procedure development for decision makers in IED threat environments.

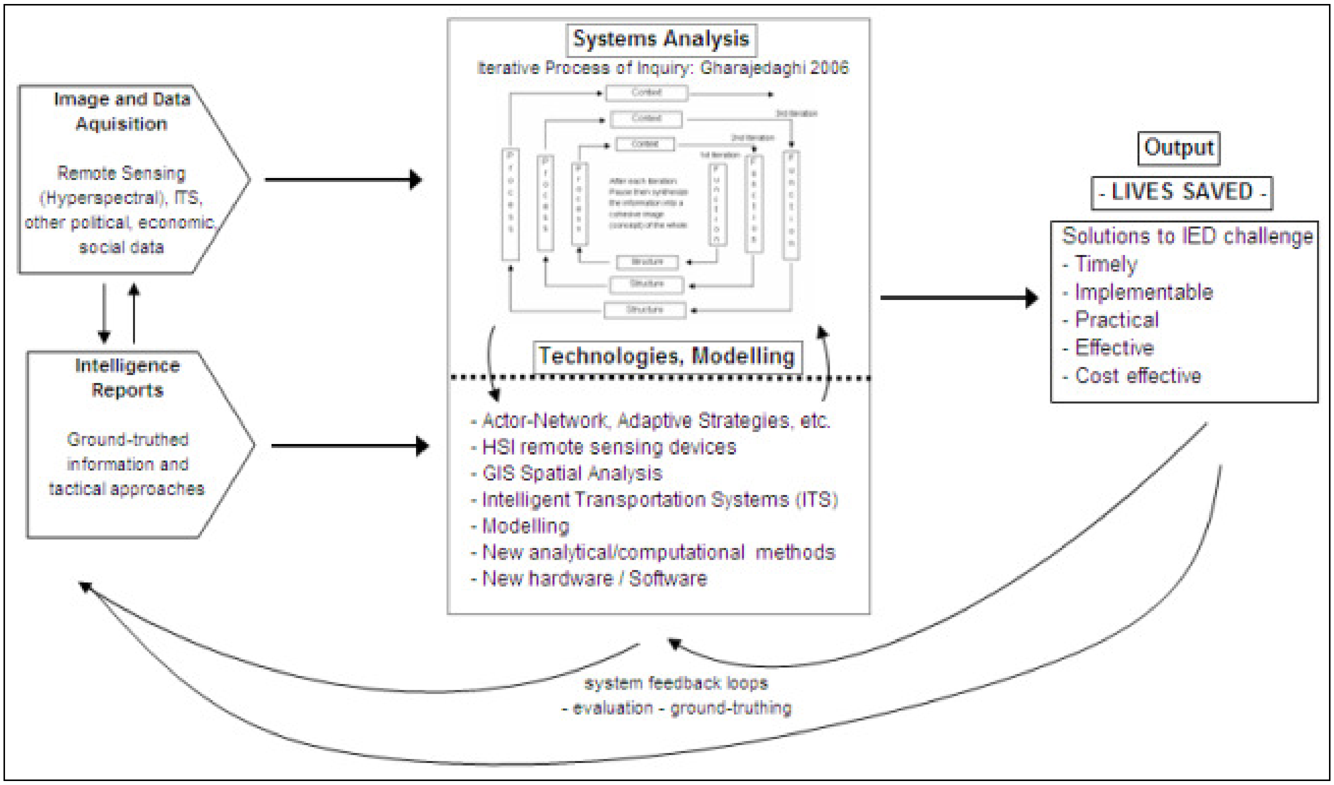

Diagram 2: Input and output flow model driven by a Systems Theory process utilizing a variety of technologies and modeling approaches.

Detection – Focal Area 2: Utilization of hyperspectral imaging combined with atmospheric correctional modeling in both laboratory and in situ conditions utilizing current and new instrumentation.

As described above, hyperspectral sensors provide a new array of geospatial data that can create significant new knowledge. Combining this digital imaging with other data sets and processed using spatial analysis and computational modeling will allow us to "reconstruct" the IED problem with new perspectives. An important result of our approach is to examine the problem "end-to-end" and in context, with an emphasis on identifying the problem earlier in the production cycle (e.g. manufacturing, coordination or distribution of materials, etc.) or to determine organizational infrastructure. .

It appears that an area to improve hyperspectral science is in the area of atmospheric interpretation and correctional modeling. We intend to address this oversight in both laboratory and *in situ* conditions utilizing current and new instrumentation in live interpretation. There are a number of new hyperspectral remote sensors that are currently in production and/or recently delivered to DOD which can be employed for detection of IED devices. These devices, due to the nature of deployment, primarily use mathematical modeling to correct for atmospheric conditions rather than on-board real-time sensors or instruments that can interpret and input accurate conditional data for validation of collected data. While current atmospheric collection devices may not lend themselves well to employment on UAVs, we believe that such devices can be built and integrated to current deployment platforms.

Furthermore, The Naval Research Laboratory, Coastal and Ocean Sensing Branch (7320), has several initiatives underway to study atmospheric correction which have led to the development of the hyperspectral atmospheric correction algorithm called Tafkaa. Tafkaa is a heavily modified version of ATREM (Gao & Davis 1997). Such algorithms, while very adept at rendering data via algorithm application, may not present the level of accuracy needed to ensure proper detection of patterns and anomalies in hyperspectral data collection.

In terms of current and new instrumentation, there will be two areas of focus. The first is on-board sensing devices similar to those in modern aircraft that detect current atmospheric conditions and correct for those conditions in *real-time*. Many sensors already exist in the aviation and meteorology community that collect, interpret and display instantaneous data to pilots and on-board scientists, but there does not appear to be any research that is currently underway to build *in situ* atmospheric correction sensor systems other than mathematical algorithmic modeling or scene based modeling. New instrumentation should be developed that will collect, interpret and then feed data into an algorithm that corrects data as it is captured by the hyperspectral imaging sensors. It will also lead to real-time data analysis technique improvement that we expect will greatly enhance real-time data fusion, which is critical to operator detection of IED devices, and subsequently may lead to better detection of devices on the ground.

It is our contention that through the utilization of atmospheric sensing devices and interpretive algorithms in a systems approach, we will be able to propose iterative solutions. As the iterative process is utilized, solutions will be discovered in our analysis and modeling initiative. Novel approaches can be extracted from the process and tested for viability for IED detection and prediction. These analytical approaches are described in the following section.

Prediction - Focal Area 3: Material mapping and image analysis algorithm development, enhancement and improvement in processing

Integration with other captured sensor data and using other visualization and data manipulation techniques and technologies (GIS Spatial Analysis, Pictometry, Strip Mapping, LIDAR, RADAR, and Immersive Visualization) is an effective way to increase the total volume of data available for data analysis and pattern detection. The use of these independent yet inter-related collection devices will assist us in addressing other areas of intense focus – geo-location and rectification of data sets. Using data from only one source cannot provide adequate information that is required for use in a comprehensive, or systems modeling approach, nor does it validate its own accuracy. The ability to see multiple data sets from single sources while seeing single data sets from multiple sources provides parallel tracks for pattern detection.

There are two areas in which we believe overlaying multiple sensor data sets may present new perspectives: First, most researchers are aware that swath width and pixilation of data sets are specific to particular environments. Our innovative approach will seek to produce new patterns of data representation by introducing variation of pixilation within each bandwidth as well as across all the bandwidths simultaneously. This will provide internal compare/contrast data sets in addition to external data sets, in addition to the development of new data sets from old data.

By comparing and contrasting collected data from various instruments, we will continue to refine the process of geo-rectification. Additionally three-dimensional modeling, not yet introduced to hyperspectral imaging, can expand visualization capabilities that will significantly improve anomaly detection. By combining Pictometry, Strip Mapping, and GIS Spatial Analysis tools, we will render multi-layer data sets into three-dimensional interactive models that can provide unique and novel—previously undiscovered—methods of immersive visualization. The Immersive Visualization Center provides the latest in advanced visualization capabilities to researchers at Texas A&M University. Based on a semi-rigid, rear projected, curved screen, the IVC facilitates the imaging of very large datasets from a diverse set of disciplines. Currently these technologies have been used for energy exploration, geophysics, life and physical sciences, engineering, and architecture. Researchers use the “larger-than-life” format to gain a better understanding of their research by taming the complexity of their data through visualization—we believe hyperspectral imaging and interpretation will benefit similarly.

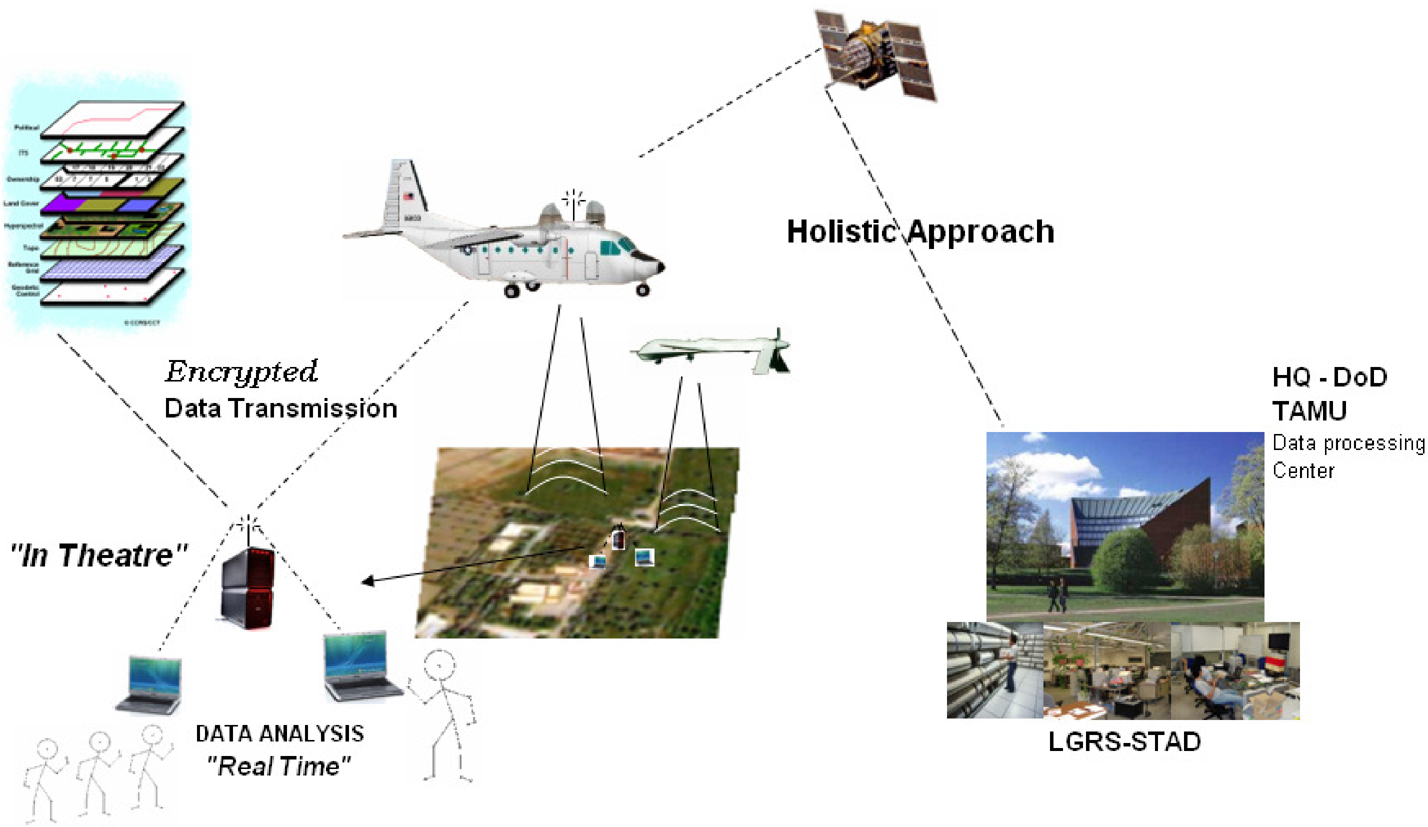

Diagram 3: Conceptual view of employment of TAMU Systems Approach defeat IEDs

II. How will this technology be used in the field, i.e., what is the concept of employment?
We intend to fly our device and future devices in an aircraft in order to pursue our research objectives for Focal Point 1 and in the lab for Focal Points 2 and 3. Our procedural method will include gathering data sets to be used as layers for spatial and systems analysis, testing new instruments and algorithms, and then focusing heavily on developing pattern and anomaly detection and image interpretation using hyperspectral data in the lab.

III. What is novel or innovative about this technology?
Our approach is novel in that we are using a holistic systems approach to rethink live interpretation, predictive modeling, and sensor/data integration with an emphasis on hyperspectral remote sensing. While we realize that hyperspectral remote sensing is only one tool in the toolbox, it is incredibly powerful for redefining the focal point of current approaches to defeating IEDs. In addition the introduction of 3D visualization methods into the toolset available to hyperspectral researchers (in particular) and counter IED researchers (in general) will be a significant step forward.

How does it differ from existing technologies?
Using a systems approach will address the counter IED problem by fusing multiple signatures and other forms of intelligence into a new paradigm for detection and elimination of IEDs and the persons responsible for creating them.

Are you proposing to?
(a) Use an existing product or platform in a new way?

Our systems analysis approach will use multiple existing technologies in a new way in the sense that the data will be analyzed with a different mindset. In addition, the detection of specific material signatures using hyperspectral technology will benefit from new, real time measurements of atmospheric effects.

(b) Add new features or capabilities to an existing product or platform?
Yes. A portion of our team intends to research new atmospheric sensors, instruments, and algorithms capable of real-time atmospheric correction of hyperspectral data. improving. We predict that the employment of these devices will be in a UAV, and potentially on a satellite platform.

(c) Develop an entirely new product or platform? Yes. See (b).

IV. What are the major issues to be resolved, and the approaches to resolve them?

1. Atmospheric conditions hamper spectral collection, so immediate detection and resolution as well as prediction of atmospheric effects will be a focal point of part of this study.

2. What patterns and anomalies between various data layers that previously were not interpretable or identifiable that could assist in predicting IED deployment or distribution

A. Data analysis using multiple sensor data sets and material mapping.
B. Predictive modeling via iterative systems analysis.
C. Solution prediction and development utilizing layering, spatial analysis, and holistic systems analysis (sociology, geopolitical, historical patterns, etc.).

3. How do we manage this process?
Collaborative approach centralized with accountability by staff (chain of command and chain of custody), and strict timeline on process, collection, results.

4. Employment: Integrate with real military and training as well as decision-making.
5. Future: Modeling versatility and power, for long-term DOD relationships.

V. Have any preliminary tests or demonstrations been conducted?
The TEEMS device, donated by Texaco in 2006, was inventoried, reassembled, and laboratory tested at Texas A&M University on April 28th and 29th, 2007. The device worked properly and is ready for calibration and further testing. If necessary the device is available for deployment, but this would be a secondary strategy as per discussions above.

VI. What issues should be considered relative to maintenance and logistics?
See attached timeline, Appendix __

VII. Images and data plots: attached as Appendix __.

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Cost and Schedule Summary

Work to develop, ruggedize, and/or deploy the technology:
Our preferred approach will to utilized existing data available through the DoD or to gain access to sensors that have been built for the Night Vision and Electronic Sensors Directorate. The Texas A&M TEEMS device is most cost effectively utilized in a laboratory environment. In this case the device requires very little work to make operational. The device was flown for eight years, so it could be deployed relatively easily for use. Due to the size of the device however, the most cost effective approach would be to use at a site nearby Texas A&M University in College Station, Texas (e.g. Fort Hood).

Who will perform work? And where?
If hyperspectral and other data sets and intelligence are available from the DoD, work could be performed at any location. However, computational demands may require significant computing power. Texas A&M has considerable computing capabilities on campus.

Schedule to demonstrate significant aspects of the technology:
See Appendix __ for timeline.

Funding estimate for the proposed work:
See Appendix __.

Government Agency Contacts

Summary of past government funding received by Vice President for Research at Texas A&M University – attached as Appendix __.

This technology has not previously been submitted to JIEDDO for funding considerations.

Qualifications and Expertise

Team members, experts, and business partnerships listed in Appendix __.

Where does this go?

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