Smart Sensor Web: Web-Based Exploitation of Sensor Fusion for Visualization of the Tactical Battlefield

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Abstract - ***Smart Sensor Web (SSW)*** *is a recent DUSD(S&T) initiative inspired by extraordinary technological advances in sensors and microelectronics and by the emergence of the Internet as a real time communication tool. The overall vision for SSW is an intelligent, web-centric distribution and fusion of sensor information that provides greatly enhanced situational awareness, on demand, to Warfighters at lower echelons. Emphasis is on multi-sensor fusion of large arrays of local sensors, joined with other assets, to provide real-time imagery, weather, targeting information, mission planning, and simulations for military operations on land, sea, and air. This paper gives an overview of this new initiative, highlights some of the technology challenges in Sensor/Information Fusion, and presents a program approach for near-term demonstrations and long-term solutions, involving the DoD, National Labs, commercial industry, and academia.*

Keywords: Microsensors, thermal imagers, multisensor fusion, situational awareness, automatic target recognition, Image web, network architecture, microrobotics, the Internet.

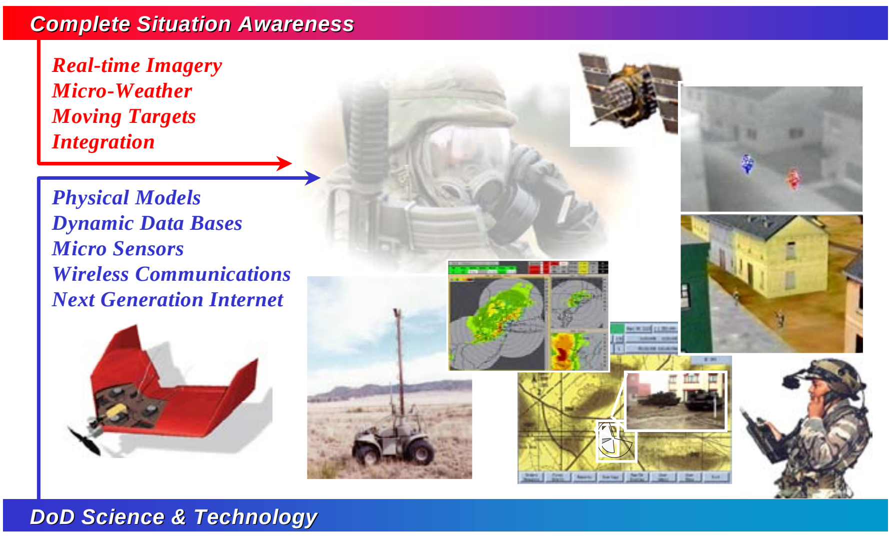

Figure 1: Smart Sensor Web - tactical information to the Warfigher, on demand

1 Smart Sensor Web : a new DoD Initiative for the Warfighter

Extraordinary advances have occurred over the last decade in sensors, microelectronics, and communications – in both the military and commercial sectors. In particular, the emergence of the Internet has inspired the overall vision for Smart Sensor Web (SSW) as a military tactical tool to provide battlefield commanders at lower echelons with access to dynamically-updated databases, collected from large arrays of local sensors. SSW will give the Warfighter *the right information at the right time…in real or near real time on the battlefield.* This includes the fusion of information from high resolution digital maps, 3-D terrain features, multi-spectral imagery from sensors deployed via manned and Unmanned Ground Vehicles (UGVs), Unmanned Aerial Vehicles (UAVs), air, sea, and national assets.

SSW will provide the Warfighter with critical and timely answers to the basic questions of Situational Awareness: Where am I? Where are my troops and other friendly forces and what is their status ? What is known about the enemy and what is his status ? What/when/where is my next action on the battlefield ? Smart Sensor Web will provide the necessary information to the Warfighter, on demand, tailored to his immediate battlefield needs and requirements.

1.1 It all starts with Sensors

Sensors will be everywhere. The last decade has seen an enormous proliferation of sensors, both militarily and commercially. Thermal imagers were used extensively on ground combat vehicles and aircraft during the Gulf War by the U.S. and Coalition Forces and allowed us to

"Own the Night." Second Generation, Thermal Imaging technology has now become the standard for most high-performance, Intelligence, Surveillance, and Reconnaissance (ISR) systems and Target Acquisition systems throughout the U.S., NATO, and Western World Allies.

advances in uncooled thermal sensor technology and unique microelectronics to provide a system weighing only 70 grams, with a volume of approximately 12 cubic inches, and requiring only 540 milliwatts of power.

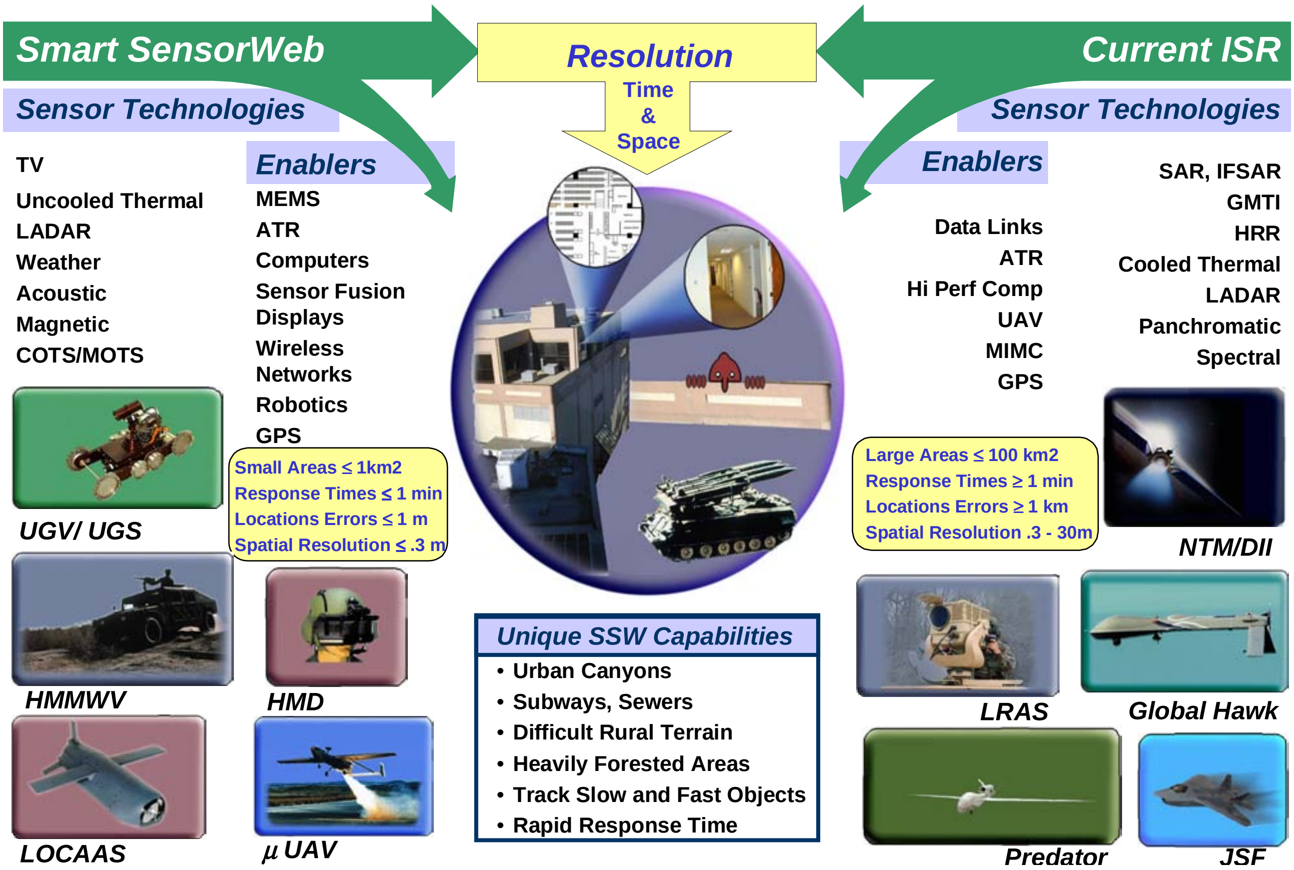

Figure 2: The numerous elements of SSW create a challenge for Sensor/Information Fusion

We *should* "own the night ;" we certainly *paid enough for it*. The development and fielding of sensor systems represents a massive investment in R&D and procurement dollars over the last 30 years. But with declining defense budgets over the last several years, the requirement for more affordable military products has become a higher priority. As a result, technology advancements were intensified to achieve improvements in manufacturing processes, low-cost materials and low-cost, integrated assemblies. Dual-use technologies and commercial off-the-shelf (COTS) products are being exploited for military use. National and international sales of these products for civilian use has also increased … all adding up to dramatic reductions in the cost of military sensors.

Reduction in the size of the U.S military has provided a strong incentive for more effective, rapid deployment forces, with greater mobility and military effectiveness. Hence, the DoD continues to invest in microelectronics, again with dramatic results in smaller, cheaper, lighter sensors. A notable example is the development of the "MicroFLIR," sponsored by the US Army Night Vision and Electronics Directorate (NVESD), Ft. Belvoir, Virginia. This device utilizes

With the ever-increasing proliferation of low-cost thermal sensors and related technologies, we can no longer expect to be the only military forces to own the night.

Tomorrow's battlefield will be proliferated with sensors of all types that could contribute to *local* situational awareness. SSW will exploit the information from commercial products distributed throughout an area (local TV cameras and other commercial devices already transmitting over commercial airwaves and the Internet), or ***seed the battlefield*** by rapidly deploying military sensors via air drops, robotic vehicles, pre-positioned assets, soldier platforms, UAVs, or overhead surveillance. Imaging

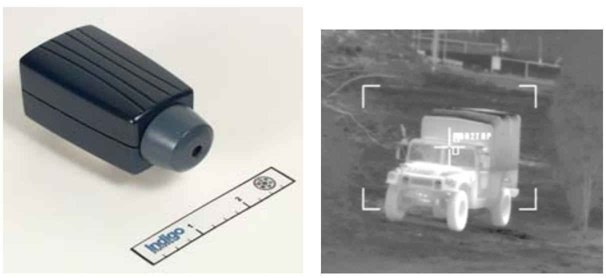

Figure 3 : Micro FLIR - to *seed* the battlefield

sensors include : TV cameras, low light level CCDs, cooled and uncooled thermal cameras, laser radar, multi-spectral imagers, and imaging radar. Non-imaging sensors include : laser rangefinders, designators, weather sensors, chemical and biological agent sensors, physiological status sensors, seismic, acoustic and magnetic sensors.

1.2 Creating the Web

Having sensors everywhere on the battlefield is of very limited value unless the information gained from them can be accessed and shared in a timely manner by the appropriate level of military commanders. Currently, this sensor information is largely "stove-piped" to specific users operating a specific sensor, for a specific military mission. Digitization of this sensor information and the capability to transmit it over wireless links now make it possible to share this information among several users by creating larger, more complex sensor networks and an architecture to facilitate the linkage of numerous local networks of sensors on the battlefield.

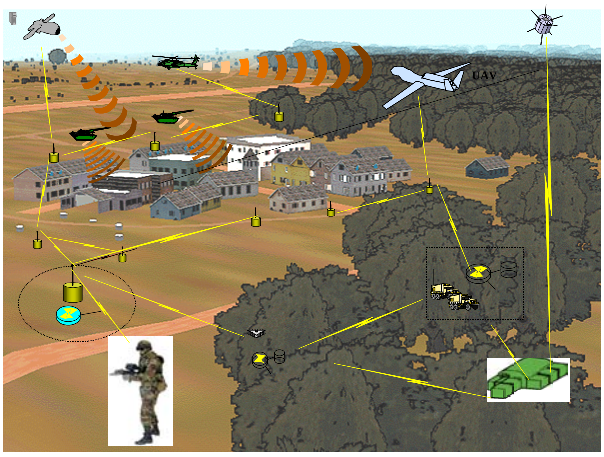

Figure 4 : Creating the Web

Advances in wireless communications and Information Technology in the commercial sector, worldwide, are dramatic and self-evident. Integration of discreet devices, such as **cellular phones, pagers, television, video cassette recorders, compact disc players, and video games**, will provide consumers with much greater access and control of the information they need or want in their daily lives. In this area of Information Technology, commercial investment and competition-driven innovation dwarfs the activities within the DoD. It is therefore critical that SSW leverage and embrace these capabilities in every appropriate way.

The Internet is another important example of technology growth in the commercial sector. This capability of real time access to unlimited amounts of information to an exponentially growing number of worldwide users is a key enabler and fundamental concept for the Sensor Web. Military users will access information from SSW via websites.

1.3 Making it ''Smart''

The web-centric network of large arrays of sensors will provide large amounts of data and imagery to users on demand. However, to effectively utilize this information, the web must become more intelligent, to intrepret and provide the right information in a timely manner, without cognitive overload.

We start with smart sensors. Imaging and non-imaging sensors can collect both battlefield environment information and target signatures and readily convert this to digitized imagery and information. This digitized information can be processed at the individual sensor level to accomplish first order interpretation. Image/signal processing can assist in target acquisition, classification, and in some cases, recognition and identification, depending on the type of target, unique signature data, and level of on-board processing.

Automatic Target Recognition (ATR) algorithms have matured significantly over the last several years and are now capable of on-board, model-based image processing, with less memory storage requirements than previous techniques, such as template-matching. Use of *neural-net processing* architectures will allow ATR algorithms to train and adapt to new target signatures in a wider variety of backgrounds, yielding

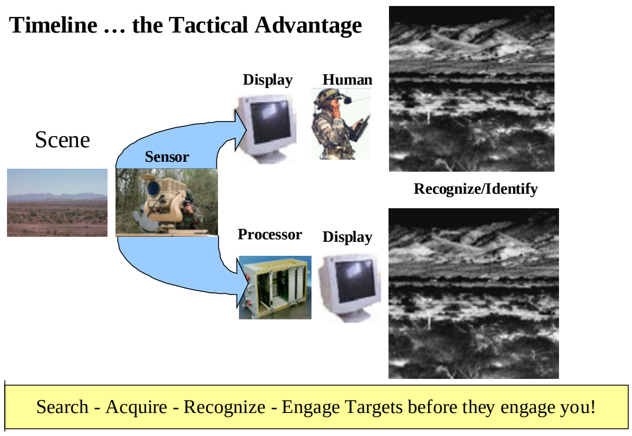

Figure 5 : ATR – critical to making Sensor Web *Smart*

more robust ATR capabilities with fewer false alarms. By linking local arrays of sensors with battlefield information of a particular area, the sensor web network can facilitate **multisensor fusion processing**, thereby increasing the value/confidence of the sensor information to the Warfighter. This could include **visible/near Infrared images (.4-1 micron), thermal images** from **Long-Wavelength (8-12 microns)** and **Mid-Wavelength (3-5 Microns)** and/or other orhthogonal signature data (**acoustic, seismic, magnetic),** thus allowing the sensor network to recognize/identify targets with increased confidence and lower false alarm rates.

Local area sensor networks can then provide target and battlefield environment information to the next higher level of **information fusion**, adding weather data, environmental day, terrain maps, and other contextual data from other databases. Linking these databases throughout the Sensor Web for smart routing of requests and intelligent fusion of this data will require **embedded intelligent agents** at each level. This will assure the proper tasking, processing, exploitation, and dissemination (TPED) of the information for each user request.

Intelligent, interactive displays will be required to provide the Warfighter with the information in a format tailored to his needs and requirements to make rapid and effective decisions on the battlefield. Real time access to local sensor arrays, coupled with **synthesized imagery** from other databases (adapted from **video-game technology and advanced visualization techniques**), can also provide the Warfighter with a ***Virtual Presence*** in a tactical area from a remote location, thereby aiding him in mission planning and rehearsals prior to conducting a military mission.

We start with data from local sensor networks (imagery, weather, weapon platforms), collect and process the digitized data, fuse it with data from other sources (synthesized data, intelligence data, logistics/utilities data, terrain/cultural data, etc), and display it to the Warfighter, upon demand, in the right way at the right time. This will allow the Warfighter to make faster and more effective battlefield decisions.

Thus, the **Information Superiority** achieved by the *rapid,, real time or near real time*, exploitation of an intelligent, web-centric architecture will lead to **Decision Dominance** on the battlefield.

2 Enabling Technologies

Smart Sensor Web is a vision and a thrust in Science and Technology ; it is not a specific program. But the capabilities of SSW will be realized through the application and integration of numerous enabling technologies currently being pursued by the defense S&T community, the commercial sector, and in Academia.

2.1 U.S. DoD activities

The DoD continues to make major investments in science and technology efforts directly relevant to SSW throughout the Services and Agencies.

The Services' requirements-based science and technology investment strategy is strongly focused on network-centric sensor and information technologies, with many being pursued as Joint efforts, such as the Advanced Concept Technology Demonstrations (ACTDs), sponsored by the Deputy Under Secretary of Defense for Advanced Systems and Concepts. For example, the Military Operations in Urban Terrain (MOUT) ACTD is evaluating numerous technologies with potential to improve urban warfighting, including small unit communication systems that provide location data for situation awareness.

The DUSD (S&T) is sponsoring a related initiative in **Cognitive Readiness** that has strong relevance to SSW. Cognitive Readiness will explore technologies to improve our understanding of human conditions and responses in the battlefield environment, to include information visualization, cognitive understanding, and advances in human behavior modeling.

Joint efforts are also being sponsored by the DUSD(S&T) in **Automatic Target Recognition (ATR) Technology Assessment**, with emphasis on **multi-spectral fusion** for improved clutter rejection and camouflage pentetration. This includes technology transition opportunities for advanced sensor sytems, such as the Long-Range Advanced Scout Surveillance Sensor System (LRAS3). In this case, ATR technology will aid the Scout in target search and track functions, with potential upgrade to target recognition capability via multisensor fusion. Target information from sensor systems such as LRAS3 can be linked to SSW via the network architecture.

Figure 6 : Long Range Advanced Scout Sensor System will incorporate ATR to aid in Search and Track

Service specific efforts such as the Army's **Warrior Enhanced Battlespace Sensor (WEBS)** effort strongly support the concept of web-based networked sensors. The Navy's and Marine Corps' **Extended Littoral Battlespace (ELB) ACTD** has validated the importance of providing information and more efficient sensor-to-shooter connectivity to small, dispersed Marine units. At the same time, the Navy's **Cooperative Engagement Capability (CEC)** effort demonstrates the value of efficient information flow and target tracking and hand-off in its Network Centric Warfare concept. Finally, the Air Force's **Joint Battlespace Infosphere (JBI)** is a scaled-up version of SSW concept that provides integrated, current, consistent, globally accessible information through the use of information centric JBI client applications and exploitation of relevant commercial technologies.

The Defense Advanced Research Projects Agency (DARPA) continues to seek radical innovation and make significant progress in advanced sensor technology, sensor networking, image/data fusion, target tracking, dynamic databases, and visualization technologies. Recent DARPA efforts are now being integrated into SSW, including the **Small Unit Operations Situation Awareness System (SUO SAS)** that provides mobile networking communication and situation awareness capability, and the **Video Surveillance and Monitoring (VSAM)** system which provides video-based ATR and target tracking and hand-off capabilities, utilizing a local array of sensors. For technical approaches to intelligent agent-based information visualization, SSW is also assessing DARPA's **Command Post of the Future (CPoF)** that deals with intelligent display and visualization technologies for command-level decision-making.

The Defense Modeling and Simulation Office supports the development of the tools (e.g., **High Level Architecture/Runtime Infrastructure**), models and databases (e.g., **multi-spectral environmental representations**) that together provide a synthetic environment for emulating live demonstrations and experiments of SSW. This provides a cost-effective means for assessing various implementations of the SSW concept. These same models and databases can also be used to support simulation-based decision support tools for optimizing sensor placement, and mission planning and rehearsal.

The US National Laboratories and Federally-Funded Research and Development Centers (FFRDCs), closely linked with the academic community, are also playing a major role in the pursuit of Smart Sensor Web. Significant research is continuing in advanced sensor technology and micro, electro-mechanical systems (MEMS) and micro, electro-optical- mechanical systems (MEOMS). Lincoln Laboratory, at the Massachusetts Institute of Technology (MIT), is playing a major role in the overall integration of technologies for SSW, as well as pursuing leading-edge research in numerous supporting technologies, including : advanced sensor/processing technology, multispectral fusion, hypserspectral imaging technology, and information fusion.

2.1 Commercial technologies

Numerous technology advances in the non-DoD commercial sector and the rapid advances of the uses of the Internet are being leveraged in the pursuit of the SSW initiative.

The communications network of SSW will exploit advances in **mobile, wireless networks** supporting cell phones, interactive pagers, and laptops with PCMCIA communication cards. The miniaturization of powerful processors coupled with novel user interface technologies (e.g., voice, touch screen, gesture recognition, heads-up displays, etc.) supports the development of personal data systems that fit in the palm of a hand or on the back of a wrist, as well as hands-free computers. These devices are significant for linking the individual combatant to the power of the SSW.

Commercial wristwatches now provide **Global Positioning System (GPS)** information, **weather information,** and even **remote sensing** (e.g., sensors that can determine the temperature of a remote object). A remote connection through the **Internet** provides **real-time control of cameras** (pan, tilt, and zoom), an important step toward the real time, *Virtual Presence* that SSW will provide the Warfighter.

Figure 7 : Leveraging commercial Technologies

Commercial security systems, burglar alarm systems, multi-mode sensors for law enforcement activities and **thermal imagers for firefighters** all provide a commercial base for large networked arrays of cheap, throwaway sensors. Even high resolution **satellite-based imagery** is now affordable and available through the Internet for general public use.

2.2 Multidisciplinary University Research Initiatives

The **Multidisciplinary University Research Initiative (MURI)** is a multi-agency DoD-sponsored program that supports multidisciplinary university research teams whose efforts intersect more than one traditional science and engineering discipline. Multidisciplinary team efforts can accelerate research progress in areas particularly suited to this approach by cross-fertilization of ideas and expertise, hasten the transition of basic research findings to practical applications, and help to train students in science and/or engineering in areas of importance to DoD. By supporting these team efforts, MURI complements other DoD programs that support university research principally through single-investigator awards.

For example, of the numerous MURI efforts, two are particularly relevant to SSW:

- *Data Fusion in Large Arrays of Micro-sensors (SensorWeb)* -- The objective of this initiative is to develop a quantitative basis for information processing in large arrays of distributed micro-sensors under strong limitations on the capabilities of each sensor and severe constraints on communication.

- *Adaptive Mobile, Wireless Networks for Highly Dynamic Environments* -- Develop new adaptive wireless network technologies applicable to the distributed, dynamic, mobile, multi-hop military environment based on a rich exchange of information between the various system layers.

The DoD also sponsors significant research at universities and private research laboratories throughout the US through Small Business Innovative Research programs. In gnereal, the Basic Research areas include : Nanoscience, Biomimetrics, Mobile, wireless communications, Smart structures, Intelligent systems, and Compact power sources. Each of these areas has potential value to the realization of Smart Sensor Web.

3 Technology Challenges

Because SSW is a multi-disciplinary thrust, there are numerous technology challenges covering a broad area of disciplines, including : communications, bandwidth, signal processing, robust, self-organizing networks, power sources and power management, and sensor deployment. Further discussion in this paper highlights those technology challenges dealing with image fusion exploitation and visualization.

3.1 MultiSensor Fusion

Smart Sensor Web will be able to link and exploit both imaging and non-imaging sensors. Imaging sensors will include : visible/Near Infrared cameras (EO), thermal imagers (IR) in the mid-wave (3-5 microns) and long-wave (8-12 microns), Laser Radar (1-2 microns), and Synthetic Aperture Radar (SAR). Multisensor imaging also includes multispectral imaging (processing simultaneous images from a single sensor in multiple spectral bands) and hyperspectral imaging (processing simultaneous images from a single sensor in a larger number of narrow spectral bands). Non-imaging sensors include : acoustics, seismic, magnetic, ground moving target indicators (GMTI), and other cueing sensors, as well as numerous micro-weather sensors.

Fusion of multisensor information will provide significant benefit for robust ATR capabilities for search, recognition, and tracking of targets, even in the presence of camouflage and decoys.

3.2 4-D Image Fusion

Three-dimensional image fusion requires accurate image registration and geolocation from each sensor acquiring information. In order to fuse imagery from a multisensor array, fusion algorithms will need precise locations and viewing angles as well detailed performance parameters (magnification, range, etc.). Image processing can then provide the necessary image transforms for image registration and fusion of multisensor imagery, particularly of fixed assets.

Dynamic battlefield conditions require a four-dimensional fusion space. Moving targets, changing environments, mobile sensors and tactical battlefield events require rapid updates and image fusion in time as well as space. Major technical efforts are continuing in this area and multisensor fusion capabilities are anticipated for SSW in the near term.

Figure 8 : Multispectral Color Fused Imagery, Monterey, CA

3.3 Information Fusion and Visualization – the ultimate pay-off to the Warfighter

The real pay-off of SSW for the Warfighter will likely be in the Information Fusion and Visualization area. Here, the challenge is to fuse the massive amount of sensor data available into the right information at the right time. This will involve significant advancements in intelligent agents, integration of live and virtual imagery and information, multi-level resolution and fidelity, and interactive displays that present the necessary battlefiled information without inducing cognitive overload.

Three-dimensional, immersive displays are needed to provide the Warfighter with the capability to be anywhere on or above the battlefield at anytime, in real time, giving him *Virtual Presence* on demand.

4 Achieving Smart Sensor Web…a Testbed Approach

4.1 Testbeds and Sub-Webs

To translate the vision of the SSW into reality, OSD is sponsoring a Testbed to demonstrate state-of-the-art hardware and software technologies, from on-going

DoD efforts and from the commercial sector; and to use experiments to assess technical and operational utility of these technologies. The other aspect of the Testbed is to determine technical needs (power sources, bandwidth, etc.) and operational requirements (information needs, presentation capabilities, sensor employment, etc.).

For the first 2-3 years of the effort, OSD will utilize the Military Operations in Urban Terrain (MOUT) site at Fort Benning, Georgia, for testbed integration and demonstration. This site was selected particularly because local situation awareness is most difficult and most critical in built-up, urban areas. The MOUT site is fully instrumented for collecting experimental data can leverage the site personnel knowledge gained from many Joint and Service exercises and technology demonstrations over the past several years.

Figure 9 : MOUT Site, Ft. Benning, Georgia

To identify the major SSW components and provide a framework for this multi-disciplinary effort, "Sub-Webs" were established. Initially, there were five Sub-Webs : Image, Weather, Weapons, Simulation, and Information Integration. Physio-Med Sub-Web was recently added and additional Sub-Webs are being considered, as additional capabilities (e.g., chemical and biological sensing) are included in the experiments and demonstrations.

The SSW Testbed activitiy is a joint, DoD-wide, effort, involving all the Services, including : the Air Force Research Laboratories (AFRL), the Army Research Laboratory (ARL), the Army Night Vision Electronics and Sensors Directorate (NVESD), the Office of Naval Research (ONR), and other Service Labs and Research Centers throughout the U.S.

The elements of the current SSW Sub-Webs include:

- **Image Web** – visual and infrared imagery, coupled with ATR; acoustic, magnetic, seismic, infrared, and laser beam sensors, coupled with solution models for target identification and alerts; personal sensors on individual Warfighters for observing around corners or through windows; and a host of sensor platforms, including ground, tree, and building mounts, as well as robotic ground and aerial vehicles.

- **Weather Web** – temperature, humidity, pressure, wind, visibility, and other weather sensors coupled to micro and macro weather models to provide current (nowcasts) and predictive (forecasts) local weather information.

- **Weapons Web** – initial focus on integrating the data from the laser radar sensor and on-board ATR of the Air Force's Low Cost Autonomous Attack System (LOCAAS) into the SSW database, thus utilizing valuable intelligent sensor data that would normally be lost when the LOCAAS self-destructs during its attack phase.

- **Simulation Web** – advanced models, simulations, and associated databases (e.g., Paint the Night database of multi-spectral environmental data) to fulfill two roles within the SSW effort: (1) as a c omponent of SSW, visualize information and provide virtual presence for mission planning and rehearsal, and (2) as a component of the Testbed, support the simulation-based experimentation and assessment of the SSW concept and its technology.

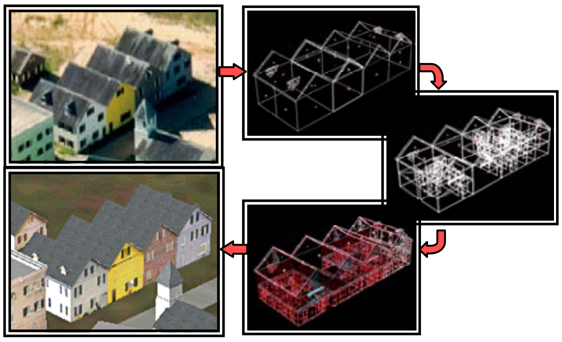

Figure 10: ***Virtual Presence*** via Live/Virtual Image Fusion

- **Information Integration Web** – intelligent agents, knowledge bases, and smart networks to integrate and present information obtained from SSW sensors, models, and databases, and appropriate external databases (e.g., maps, blueprints, higher echelon sensors, location data, etc.) in an interactive mode (information push and pull) to the Warfighter.

- **Physio-Med Web** – temperature, blood pressure, heart rate, hydration, and other physical and medical sensors and associated models that aid in identifying physical (overheating, needs hydration, etc.) and medical (heat exhaustion, wounded, etc.) problems. Will evaluate configurations for performing triage, medical diagnostic aid, and use for Personnel Recovery.

In addition to the Sub-Webs, there are other DoD agencies who will participate in the SSW Testbed experiments. This will include the Special Operations Command (SOCOM), utilizing the Testbed to evaluate technologies for web-centric sensor systems.

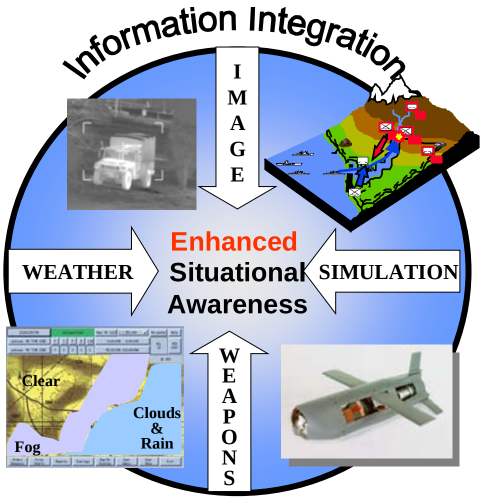

Figure 11 : Situational Awareness via Information Fusion

4.2 Technology Transition Opportunities

Experiments and successful **Advanced Technology Demonstrations (ATDs)** from the SSW Testbed can be transitioned to on-going development and acquisition programs within the Services and can be introduced as Product Improvements to fielded equipment, where appropriate.

Maturing technologies that offer important advanced capabilities in Situational Awareness for the Warfighter can also be integrated and evaluated for military utility via **Advanced Concept Technology Demonstrations (ACTDs),** and rapidly transitioned to the field.

SSW is being pursued as a multi-year S&T Testbed effort, with the intent of transitioning to an ACTD(s) for military utility evaluations by joint warfighter units in actual field conditions. Successful outcome of these evaluations will result in early fielding and further transition opportunities to acqusition programs.

International collaboration with NATO allies is in its early stages and is also being pursued. This will provide further opportunities for accelerated development and expanded applications for fielding.

5 Smart Sensor Web ends with Operational Utility for the Warfighter

Smart Sensor Web is a vision of revolutionary capabilities for the Warfighter. For the first time, battlefield commanders - company commanders, platoon leaders, squad leaders and fire teams - will have access and connectivity to essential battlefield information *in real time*, *on demand*. The recent technological advances in low-cost microsensors, microelectronics, signal/image processing, information technology in both the military and commercial sectors are allowing this vision to be realized. Smart Sensor Web will be achieved incrementally through the integration and demonstration of these enabling technologies via the **SSW Testbeds.** Rapid transition to the field will be accomplished through military user evaluations via **Advanced Concept Technology Demonstrations (ACTDs)** and acquisition programs.

Just as the Internet began as a small network to link a specific technical community at DARPA and grew to its massive, ubiquitous, state, revolutionizing our society, so too may be the evolution of **Smart Sensor Web** and its contribution to the survivability and military effectiveness of the **Warfighter in the New Millennium.**

"Seeding" the Battlefield with a network of distributed sensors

The Sower, Artist, Lee Hodges Ventura, CA

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