Application of Wireless Sensor Network to Military Information Integration

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Abstract— **The purpose of this investigative study is to develop a model for a system of systems to improve situation awareness and targeting through a real-time aerially deployed wireless sensor network. The main hypothesis of this work is that scalable, affordable, real-time wireless network can contribute to the common operating picture. This network can be used to overcome targeting discrepancies and counter asymmetric threats in the new warfare paradigm that pertains to opaque environments. Surveys identified requirements for a system of systems to meet requirements for situation assessment. This paper describes 1. a model to support the hypothesis that this network can to improve response to asymmetric threats, and 2. a system architecture based on commercial-off-the-shelf technology for military operations in this new combat paradigm.**

I. Introduction

New and emerging technologies, such as networks, support military operations by delivering critical information rapidly and dependably to the right individual or organization at the right time, thereby significantly improving the efficiency of combat operations. New missions driven by world events and enabling technologies influence military operations. These new technologies must be integrated quickly into a comprehensive architecture.

The global war on terror features ill-defined, asymmetric warfare. For example, urban operations are difficult and casualty rich because of the opaque nature of the urban environment. Without remote sensing, human life is in danger, which is an unacceptable deficiency in sensor capability. A flexible and modular system is needed to detect threats and produce data in real time for the Common Operating Picture (COP) This paper describes engineering solutions to improve situation awareness.

This paper suggests a model that describes a system of systems. This model is based on fundamental tactical concepts, feasible technologies, conceptual doctrines, and capabilities required for the development of special-operations forces in air-power mission. This paper provides support and background for a dependable solution to sensor deficiencies through an aerially deployed wireless real-time sensor network connecting sensors to the COP through interoperable gateways via wireless technology.

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II. Methodology

A key component of the model is an aerial sensor delivery system similar to a sonobuoy acoustic-sensor system. To cover wide areas in opaque environments (OE) sensor networks must share and fuse data autonomously from multiple sensors into a coherent real-time COP to provide the knowledge necessary for situational awareness and target discrimination. Toward this goal, information was collected from past and current authoritative studies, reports, and related material including researcher experience. Conclusions were draw from supporting experiences emphasizing dependability and credibility. The methodology was divided into four phases.

In phase 1 the problem was defined. In phase 2, current techniques, technologies, and doctrine for complex targeting were researched. Technical literature, techniques, and doctrine on complex environments was reviewed. Qualitative requirements were derived from interviews of Special Forces with experience operating in the triple-canopy OE jungle and urban centers where insurgents mix with noncombatants. Users contributed insights that suggested the need for new technology and doctrine.

In phase 3, concepts were analyzed and a model was developed. A study of current technologies, doctrine, training, and current operations was completed. A conceptual model was developed that employs appropriate technologies, training, and personnel to accomplish the complex mission. Phase 4 consisted of analyzing the system requirements to develop an outline for system architecture and a path for future development. The result of this study is that a scalable, affordable, real-time targeting solution can be designed using an aerially deployed wireless sensor network.

A. *Technologies and implications*

Rapidly deployable sensor-net technology needs to be combined with real-time network technology and doctrine to produce the sensor network of the future. Ultra-wideband (UWB) sensor technology can sense reflected wideband electromagnetic energy then analyze, output, and display the results. The raw data can be processed to classify a target. Therefore, technology for highly sensitive

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and flexible sensors autonomously can produce target-discrimination data.

The Link-16 communication system is used to exchange data between platforms as illustrated in Fig. 1. This technology can enable reliable secure medium to pass sensor information. Moreover, National Security Agency (NSA) has approved wireless information technology, which supports a wireless Link-16-like capability.

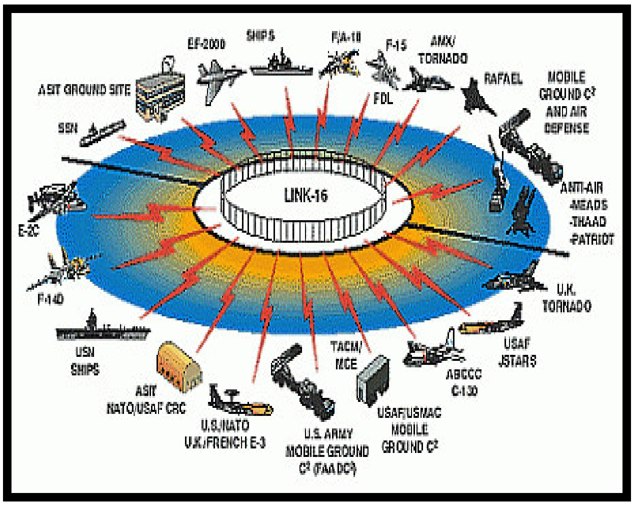

Fig. 1. Illustration of Link-16 interoperability

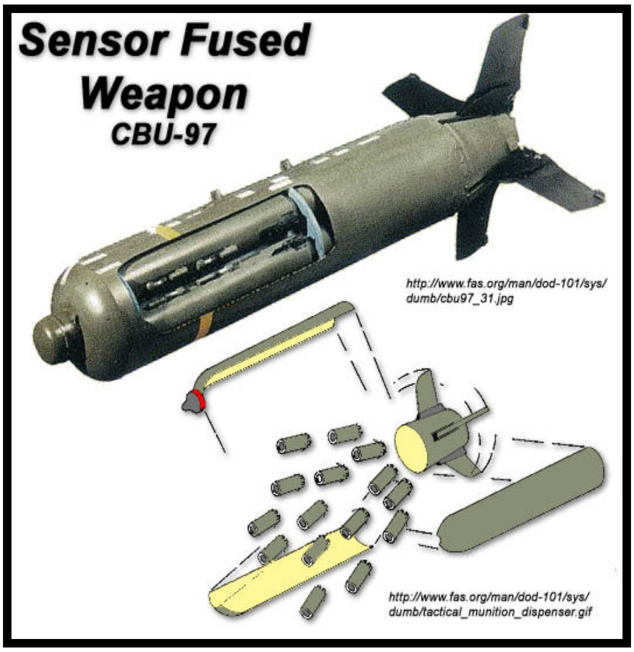

Fig. 2. CBU-97 sensor fused weapon

The aerially deployed unmanned CBU-97/CBU-105 Sensor-Fused Weapon (SFW) shown in Fig. 2 deploys munitions that hunt with IR sensors, hover, and fire into tanks. Rugged sensors can be deployed aerially in high-tempo operations. Commercial off-the-shelf (COTS) self-contained wireless communications networks using numerous self-organizing wireless mesh routing boxes [12] can deploy rapidly.

B. *Wireless communications nodes, sensor webs*

COTS technology is available for a self-contained wireless mesh communications network made from numerous self-organizing wireless mesh routing boxes [12]. Technology for a self-organizing rapidly deployable hastily formed transmission medium is available. Aerially deployed, environmental remote sensor can transmit surface environmental data to an aircraft. COTS technology is available to deploy remote and renewable solar-power and hydrogen-power sources. The U.S. National Oceanic and Atmospheric Administration and the National Aeronautics and Space Association have developed *Sensor Webs*, which are webs of adaptive, miniaturized pods that share environmental information, as shown in Fig. 3. Thus, wireless, sustainable, spatially distributed, miniaturized sensors can be networked with existing technology.

Fig. 3. Wireless Sensor Pod

C. *Network, aerial sensor, transmission nodes*

Fig. 4. Networked Rotomotion SR20 Vertical Takeoff and Landing (VTOL) mobile aerial sensor

Companies, such as Rotomotion LLC and Cyberdefense Inc. have developed networkable miniature unmanned aerial vehicles (UAVs) using the 802.11 wireless protocol. (See, for example in Fig. 4.) UAVs such as Rotomotion SR50 and CyberBug can include wireless sensors [2].

Static aerial sensors and transmissions nodes are integral parts of an aerially deployed sensor network. Similarly, tactical sensor-net tethered balloons have carried a payload of an internet protocol (IP) camera and a routing box [2]. The balloons operated as sensor and transmission-medium nodes at altitudes up to 4,000 feet. As an information medium, this provides an extended range that could link to additional sensor networks. Current sensor technology, policy, and doctrine are far behind potential technical capabilities to meet operational needs.

D. Ultra-wideband and visual sensors

UWB was determined to be able to operate as a 'security fence' in tactical operations [7]. Due to its wide frequency spectrum and the different ways unique frequencies reflect from different materials, the UWB sensor system can indicate the location of a firearm on a war fighter's body [9]. The UWB sensors are covert [7]. Their signal is difficult to detect because it falls below the typical noise threshold at most distances and has a low probability of intercept. UWB signals (Fig. 5) that act as a reflecting form of radar can encode the information necessary for communications, which is an asset to sensor nodes that must self organize, and output information.

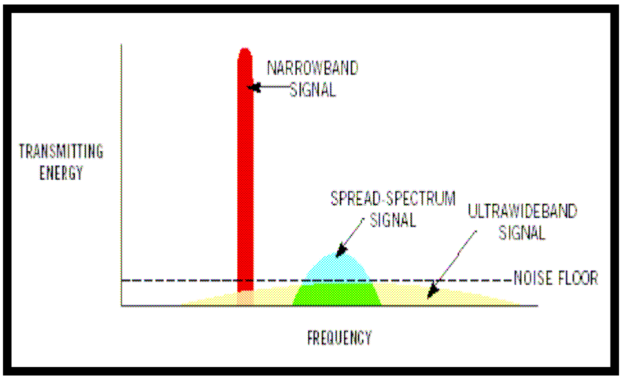

Fig. 5. Signal comparison against noise

UWB technology can be used for effective geolocation where coordinates cannot be derived from the Global Positioning System (GPS), such as in thick forests or artificial structures [11]. UWB is the ideal medium for the physical layer of network operations [7]. Coupled with the capability to detect, classify, and output data, UWB provides a multi-use technology that could simplify sensor operations, combining the sensor and the transmission medium into the same node [1], [6]. UWB is the leading candidate sensor for full-spectrum coverage [7].

Sensors with ad-hoc networking capability could provide rapidly deployable, failsafe, inexpensive, and early threat detection. Sensors that produce a visual output from emissions or reflections (e.g. IR, near IR, UWB, or even acoustic) are also essential in a real-time sensor network for command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) [3], [5].

F. Sensor deployment and data streams

Rapid airborne deployment of the system is necessary for sensor-net operations as the only foreseeable solution at this time for high-tempo operations requiring a sensor net. The sensor net should be deployed from an aircraft, or several aircraft. The deployment design should conform to the terrain of operations. For instance, if operating a jungle, UWB sensors should be deployed from aircraft via a parachute system that will entangle them and point them downward from the trees. In other terrain, sensors could deploy like the device that collects surface-environmental data. Aerial deployment implants this device in the ground.

UAVs that provide the sensor net should be launched in highly redundantly to ensure the fidelity of the net and to avoid a single point of failure. UWB sensors should be deployed as primary ground sensors. If they can be ruggedized sufficiently they should be deployed in a cluster fashion similar to that of the SFW. IR, near-IR, and visual passive sensors should be in the payloads of static aerial devices as they provide the majority of wide-area coverage.

UWB frequency patterns can help recognize hostile equipment. The target can be located with any sensor available and the sensor data output can display as a grid coordinate. An operator can discern hostile stance by screening a real-time visual sensor data stream. The output can be augmented with a layer of additional sensor data.

With respect to grid coordinates, visual-, IR-, near -IR-, and acoustic-based sensors can acquire a set of targets passively. Active acoustic sensors also can locate targets. Operators require target-discrimination data layered on the coordinate outputs. Candidate targets can be filtered with UWB active-reflection data to discriminate hostile targets. Targets can be localized with data, either from UWB device geospatial orientation or from a GPS output fused with range data combined with the device's position.

IR, near-IR, and UWB sensors can produce a real-time visual data stream. UWB-type sensors have the added advantage of penetrating through opaque environments. The output must be layered with Target-Discriminating Data (TDD) for the operator interface. Real-time data can come from ground sensors; however, the most effective sensor for maintaining a passive IR, near-IR or visual data stream is a mobile or static aerial sensor. TDD must be stored and correlated to maintain fidelity in case the target moves out of range of the UWB sensors into the coverage area of long-range passive sensors.

III. Data Interoperability

Requirements and features of the new system are described in this section with a view toward data interoperability. Sensor-data fusion centers provide TDD prioritization and queuing, as well as the maintenance of a database of targets. These centers also produce and maintain the COP, which includes the following layers: maps, overlaid target from sensors and TDD. Personnel in fusion centers prioritize and layer real-time sensor data of TDD on top of video streams. Examples include custom static aerial nodes that function as servers to fuse information and provide it to users. Interoperability is enhanced further when standard user interfaces display the COP. The interfaces also provide access to prioritized and fused sensor data for situational awareness.

Layered COP will be generated through complete sensor fusion on site inside the payload of a persistent aerial sensor or onboard a tethered static aerial sensor. This portion of the system should be highly redundant. Tethered static unmanned aerial nodes should be equipped with payloads capable of autonomous sensor-fusion operations to support the prioritizing, queuing, and layering of data. Airborne fusion centers can supply layered sensor data.

The payloads also should provide data transmission to a forward-operating base, airborne platform, or other COP gateway outside of the local area. These nodes could be either a tethered balloon or a persistent airship, as in the case of sensor fusion. The payloads must be compatible with various transmission media including UHF, satellite communications (SATCOM), and Link-16. Transmission nodes will utilize UWB for communication as it is the most secure and robust for operations in opaque environments. These data will support the COP for commanders.

Ground operators need autonomously filtered TDD, prioritized sensor data via the COP for targeting. The interface will be wearable, possibly a heads-up display helmet or a wearable device, preferably on the forearm. The device must utilize a full-spectrum interface that can accept voice and keyed commands. User experimentation and survey help to determine the optimal user interface.

Data delivered to the ground operators on the sensor net will include a map with overlaid targets. The TDD on each target should be hidden but accessible to the operator through the graphical-user interface (GUI). Moreover, real-time sensor data should be available to the operator in a prioritized fashion with field-of-view (FOV) selection. If airborne mobile sensors are deployed, the operator should be able to control their FOV coordinates. The system will have preset TDD prioritization algorithms for various rules of engagement, deployment payloads, deployment patterns, and operating environments.

System will be interoperable with Link-16, UHF/VHF/HF bands, SATCOM and other transmission media to pass precise targeting data to war fighters. This capability will be deployed onboard the static aerial sensors to ensure fidelity and access. Static aerial nodes are required at various altitudes for persistent real-time data coverage, wide-area transmission and redundancy.

IV. Model Requirements Analysis

This section defined user requirements and describes a model recommended for resolving the targeting problem. Solutions and the model architecture are described with particular attention to the need for real-time targeting solutions. Asymmetric security threats, such as terrorism, continue to increase [10]. Current tactical systems cannot deploy rapidly due to the lack of a common information environment among air and land entities. Using current operational applications, an autonomous network cannot be generated. Whereas some technologies could assist in this endeavor, most do not meet stringent US Department of Defense and coalition requirements for the global war on terror and other security missions. An effective real-time targeting force needs to include target detection, classification, and identification leading to situation and threat awareness, as well as fused data for decision makers.

A. End-user survey

The survey showed that the most significant challenges for operators prosecuting targets in OE are: (1) opaque barriers that obscure targets, such as jungle foliage or artificial structures and (2) discrimination of hostile targets from noncombatants. The following deliverables are required from sensor operations to input into weapons operations according to the survey:

- Highly accurate grid coordinates in Military-Grid-Reference-System format for situational awareness
- Data on whether targets are armed or unarmed
- Queuing of targets prioritized by threat magnitude
- Proper fusion of the sensor data
- Generation of an accurate COP
- Secure and reliable transmission of the COP

At the tactical level, real-time ground sensors provide data equivalent to that of human intelligence (HUMINT) and an RQ-11 Raven UAV. At the operational level, a wide area of sensor coverage must provide operators the situational-awareness equivalent of a RQ-1 Predator UAV.

B. Sensor-net operations

Software applications have enabled self-organizing real-time sensor networks [4] and [8]. The real-time targeting architecture suggested here consists of elements functionally separated into categories of sensor, information processing, dissemination, and prosecution. This could be automated and not always require humans in the loop.

C4ISR operators require several objects layered with sensor data for situational awareness. The first consists of visually represented positional data, such as a map or an overhead image with an updating overlay of the FOV (Fig. 6). The second consists of simplified target-classification data, which could include a rendered box (Fig. 7) overlaid onto the real-time data to indicate a target's position. The target then can be mapped to the COP. Otherwise in a congested area of operations the target will be lost in the noise. In UAV and sensor-net operations, visual data alone do not provide adequate situation awareness. Sensor-data overlays should take advantage of UWB capabilities by indicating improvised explosive devices and firearms on persons or targets. Operator interfaces must enable access to multiple data sets to prioritize the data streams that provide the most targeting information to the COP. An overlay or map display with the FOV rendered in real time can give the user adequate situational awareness to transform a raw-data stream into knowledge upon which decisions and action can be based.

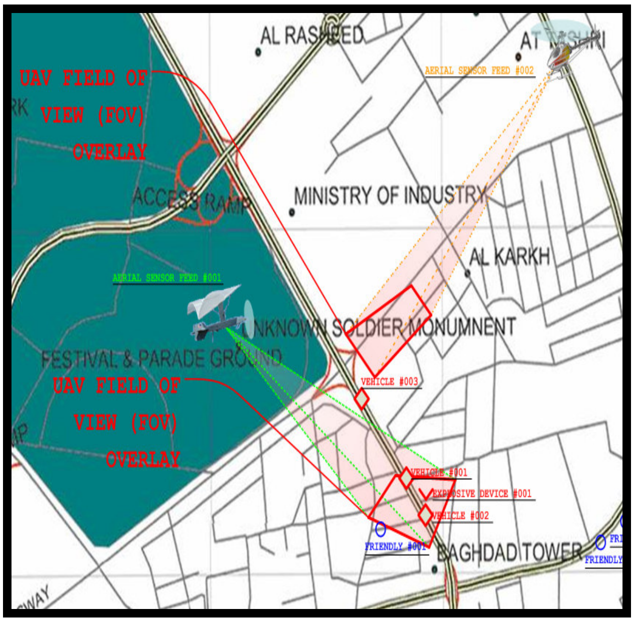

Fig. 6. COP UAV: Sensor data FOVs, TDD, and friendly overlay

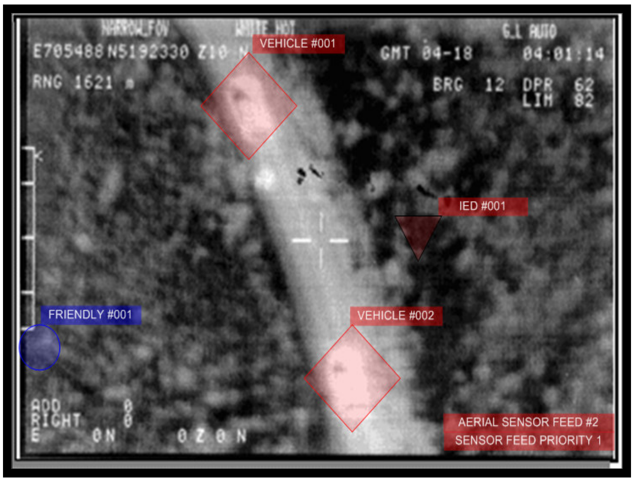

Fig. 7. Aerial sensor data overlaid with TDD

V. System Architecture

A. *Overview of the model*

The system architecture calls for the sensor net to be deployed utilizing the sensor in-depth doctrine for integration into joint and coalition operations. This doctrine specifies multiple sensor layers from a strategic level to provide global coverage to a tactical level. The strategic level includes national intelligence assets, such as imagery intelligence, signals intelligence, and other global assets that can thus localize the area of operations (AO).

Sensors are deployed for passive patrolling of the AO to identify local operating areas containing possible targets of interest. Examples of patrolling elements at the operational level include RQ-1 Predator UAVs, RQ-4 Global Hawk UAVs, and HUMINT. When these localizers identify an active target area they pass information to the COP where operators can increase surveillance at the sensor-net level. This will be a high-tempo operation requiring real-time tactical targeting in a pre-defined area.

The system, including gateways, should be tested after deployment. When fidelity and security are assured, the operator can discriminate, classify, and monitor targets in real time. All components of the sensor net should be highly redundant to avoid a single point of failure.

B. *Sensor-network components*

Real-time sensors can be aerial or ground, mobile or static. Mobile aerial sensors provide flexible coverage of local AOs. Examples includes the RQ-11A Raven, the RQ-1 Predator RQ-4A Global Hawk. Static aerial sensors provide persistent coverage of wide areas, including passive visual real-time sensors, such as the tethered balloon payload of visual, IR, and near-IR sensors.

Mobile ground sensors, such as manned local-area operator sensors (e.g. visual, IR, and near-IR), provide flexible ground-situation awareness that can be augmented with overlaid FOV and TDD. Examples include terrestrial vehicle-mounted sensors, maritime sensors, and wearable sensors. Static ground sensors provide situational awareness and augmentation with overlaid FOV and TDD. Examples include passive visual, IR, and near-IR imagery data and UWB active sensor reflections transformed into visual-imagery data for environmental transparency.

Static aerial and ground sensors provide area coverage and prioritization in the form of alerts when the threshold of passive emissions is detected. Examples include magnetic, acoustic, IR, near-IR, and visual sensors. Active transmitters provide location data on friendly units for situation assessment.

C. *Transmission-medium elements*

Transmission-medium elements include mobile or static ground and aerial nodes, gateways, and sensor-data-fusion centers. Mobile nodes provide flexible situation awareness and a data-gathering intelligence center if necessary. Command and control functions provide interoperable gateway functions as well as UAV data integration and operation. Examples include network-operation centers.

Aerial nodes act as flexible network extenders. Mobile examples include the Predator UAVs and the Rotomotion SR20 Vertical Takeoff and Landing (VTOL) as well as miniature UAVs. Static nodes function as wide-area access points for network coverage. Network-mesh connectors provide aerial connectivity where the network cannot be connected on the ground. Static-aerial nodes on balloons at high altitudes can provide static-aerial gateways to UHF, VHF, and Link-16 communications.

D. Rapid-system deployment

Deployment is divided into three categories: a) cluster deployment of ground sensors; b) anchor deployment of gateways and static aerial nodes; and c) on-platform and/or external deployment of mobile aerial nodes and sensors. Cluster deployment of ground sensors from a number of different platforms is both robust and modular. Examples include sensors deployed from a C-130 airplane in a manner similar to the deployment of humanitarian rations. Anchor deployment of gateways and static aerial nodes tether the nodes to the ground. Examples are modeled after the deployment of sonobuoys coupled with aerial deployment of jungle-penetration anchors. Deployment of mobile aerial nodes and/or sensors is flexible and reliable.

VI. IMPLEMENTATION

The following technologies can reduce the cost of an aerially deployed real-time sensor network.

- Rotomotion SR20 VTOL UAV helicopter system for C4ISR, network extension, and sensor deployment.
- Crossbow wireless ad-hoc sensor network to provide IR and magnetic-anomaly sensor coverage.
- Open-standard internet-protocol router; Cisco voice-over-internet protocol; and wireless, satellite, and land mobile-radio-over-internet Protocol.
- Secure voice and data communication up to 60 MHz
- XACTA deployable wireless-mesh nodes
- Balloons equipped with Mesh Dynamics antennas.
- IEEE 802.11. 802.16, and 802.20 wireless protocols

Moreover, a real-time wireless sensor network requires other tasks and activities summarized below.

- Fuse sensor data from multiple layers and UAVs.
- Deploy aerial nodes with quick- inflating balloons.
- Integrate IR and near-IR sensor data.
- Deploy static ground sensors as clusters like SFW.
- Evaluate UWB to penetrate opaque environments.
- Use airborne sensor-data fusion centers for TDD layering.
- Integrate GPS into all sensor nodes and UAVs.
- Develop an efficient COP GUI in a layered display of top-level data with drill down of underlying data.
- Develop software to help operators recognize hostile-stance imagery in real-time sensor data.

VII. FUTURE RESEARCH AND DEVELOPMENT

The following topics need to be investigated.

1. Prioritization and queuing of TDD and algorithms for prioritizing targets and/or local-operating areas by AO types (urban vs. jungle, etc.)
2. Whether and to what degree the network can improve situational awareness and help prosecute targets.
3. The network capacity as well as the best approach to integration with the products of sensor-data fusion to predict when overload will occur.
4. Linkage of gateway nodes, e.g. forward operating bases and intelligence centers.
5. Information reliability and the degree of interoperability that UAV links offer to the COP.
6. Optimal aerial deployment pattern for the sensor net, determined experimentally.

COP interfaces need to accept input commands from human operators including acoustic, conventional tactile, and motion-pattern input methods. In conclusion, an aerially deployed real-time targeting sensor network can help overcome current targeting discrepancies and counter asymmetric threats in opaque environments.

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