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GEOSPATIAL AND DATA FUSION TECHNOLOGIES FOR REAL TIME SITUATION AWARENESS AND DECISION MAKING

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Abstract

*A modern C4ISTAR (Command, Control, Communications, Computers, Intelligence, Surveillance, Target Acquisition and Reconnaissance) System requires **real time situation awareness,** derived from appropriate sensor data. The sensors must be geo-referenced with timing accuracy by using geospatial technologies and the sensors data must be fused in such a way that at the right time, the right piece of high-quality information relevant to a given situation is transmitted to the right user and appropriately presented. Only then can the data support **goal-oriented decision making** at all levels of decision hierarchy.*

By aggregating, organising, fusing & processing intelligence from multiple systems such as multispectral sensors, Synthetic Aperture Radar (SAR), optical, thermal, and geophysical sensors, Light Detection and Ranging (LiDAR), Geographic Information System (GIS) and Global Positioning System (GPS), also known as Geolocation systems, Common Operating Picture (COP) with relevant, accurate and timely intelligence is build up that can be used by decision makers for handling the threats efficiently and effectively.

Geospatial technologies were used fruitfully to establish the location of

Russian troops and equipment against Ukraine in 2014. However, that had been categorised under ***Digital forensic techniques.*** *In order to make these technologies as a component of C4ISTAR, these have to be fused with multi-domain, multi-sensor data obtained from varied sources so as to produce near-real-time situation awareness. C4ISTAR based on Geospatial and data fusion technology will act as a Force-Multiplier, providing multitudinous advantage over the enemy.*

Introduction

Although situation awareness is needed for many domains such as emergency/ disaster response, infrastructure monitoring etc., but it is extremely important for Armed Forces and in particular for Air Force. Situation awareness has been an integral part of military command and control (C2). Due to advent of modern technologies, ambit of C2 is now vastly enhanced to encompass C4ISTAR Systems. This acronym denotes computer-assisted functions for C4 (Command, Control, Communications, Computers), I (Intelligence), and STAR (Surveillance, Target Acquisition and Reconnaissance) in order to enable the coordination of defence-related operations. C4ISTAR systems aim at information dominance over potential opponents. Basic component of C4ISTAR, modular and flexibly designed as "systems of systems", is the combination of sensor systems and data bases with appropriate sensor data and information fusion sub-systems.[1]

The commanders at all levels of hierarchy as well as automated decision making systems have access to vast amounts of data. In order to optimize use of this high degree of data availability for various decision tasks, the continuous streaming of data should not overwhelm the human beings as also decision making machines involved. On the contrary, the data must be fused in such a way that at the right time, the right piece of high-quality information relevant to a given situation is transmitted to the right user and appropriately presented or in other words, requirement is to have **real time situation awareness.** Only then can the data support **goal-oriented decision making** at all levels of decision hierarchy.

The modern development of **sensor data fusion systems** has been made possible over the recent decades by substantial progress in these areas: **Advanced and robust sensor systems**; Communication links with sufficient bandwidths; Information technology for dealing with large data streams; Technical interoperability to build distributed "systems of systems" for sensor exploration and data exploitation; Mature navigation systems i.e., **Geospatial technologies** for providing common frames of reference for the sensor data based on precise space-time registration; and Advanced and ergonomically efficient Human-Machine Interaction (HMI) tools as an integral part of man-machine-systems presenting the results of sensor data fusion systems to the users in an appropriate way.[2]

An overview of 'real time situation awareness' required from armed forces perspective is pictorially depicted at Figure 1 below:-

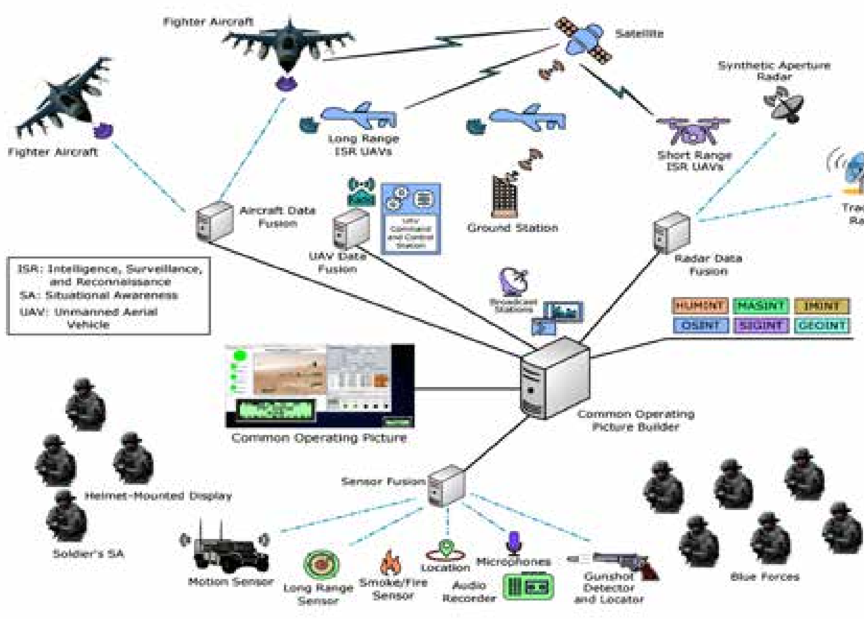

Figure 1: An Overview of Real Time Situation Awareness - Armed Forces Perspective (Source: Arslan Munir et al., Situational Awareness: Techniques, Challenges, and Prospects)[3]

The subject is being studied under the following heads:-

- Definition of Terms.
- A Model for Real Time Situation Awareness and Dynamic Decision-Making.
- Technologies Required for Situation Awareness.
- Utilisation of Geospatial and Data Fusion in the Indian Armed Forces.

Definition of Terms

Geospatial Technologies. It is a term used to describe the range of modern tools contributing to the geographic mapping and analysis of the Earth and human societies.[4] Geospatial technology enables us to acquire data that is referenced to the earth and use it for analysis, modeling, simulations, and visualization. The basic list of Geospatial technologies encompasses Remote Sensing (**RS**), Geographic Information System (**GIS**) and Global Positioning System (**GPS**).[5]

Data Fusion. It refers to combining data from multiple sources to improve the potential values and interpretation performances of the source data, and to produce a high-quality visible representation of the data. Fusion techniques are useful for a variety of applications, ranging from object detection, recognition, identification and classification, to object tracking, change detection, decision making, etc.[6]

The concept of data fusion is not limited to the fusion of data from different sources. A change analysis that occurs on the same type of spatial data over a period of time (multi-temporal data) can also be considered a form of spatial data fusion but in this case the fusion component is in time.[7]

Remote Sensing Data Fusion. It is one of the most commonly used techniques, aims to integrate the information acquired with different spatial and spectral resolutions from sensors mounted on satellites, aircraft and ground platforms to produce fused data that contains more detailed information than each of the sources.[8]

Situation Awareness (SA). Situation awareness is formally defined as "the perception of the elements in the environment within a volume of time and space, comprehension of their meaning and the projection of their status in the near future".[9]

SA (Armed Forces Perspective). SA refers to the capability to conceive the current and future disposition of friendly and enemy's aircraft and surface threats within a volume of space. SA comprises of three distinct stages or levels: perception, comprehension, and projection.[10]

A Model for Real Time Situation Awareness and Dynamic Decision-Making

Companies like Rolta and Mistral have developed C2 solutions, for connecting and managing disparate technologies, like variety of sensors including radars, GPS tracking, GIS mapping, and life critical systems. By aggregating, organising, fusing & processing intelligence from these systems, it builds Common Operating Picture (COP) with relevant, accurate and timely intelligence that can be used by decision makers for handling the threats efficiently and effectively. Following an alert, alarm, or event, the system provides multiple options, such as Notifications, escalations, or response plans to respond to a situation.[11] These systems are very useful for meeting the requirements of Homeland security or Emergency / Disaster response.

However, in the fast moving battle like air combat engagements, desired function of SA is for tracking the enemy's aircraft current move and predicting its future action, a fraction of seconds before the enemy himself observes his own aircraft's movement. SA can also be viewed as equivalent to "observe" and "orient" phases of the observe-orient-decide-act (OODA) loop. Since in the aerospace, pilots have to deal with many arduous situations such as: higher levels of aviation traffic, inclement weather (e.g., storms, fog), recently unmanned aerial vehicles (UAVs) in the air space, and locating and engaging the targets on ground; they need to be equipped with an advanced real time SA system to cope with these antagonistic conditions and provide dynamic decision-making.[12]

The information processing approach has been best represented by M. R. Endsley's (1995) theoretical three level model of situational awareness.[13] Situation Awareness and dynamic decision-making model shown in Figure 2 below has been adopted from Endsley's concept:-

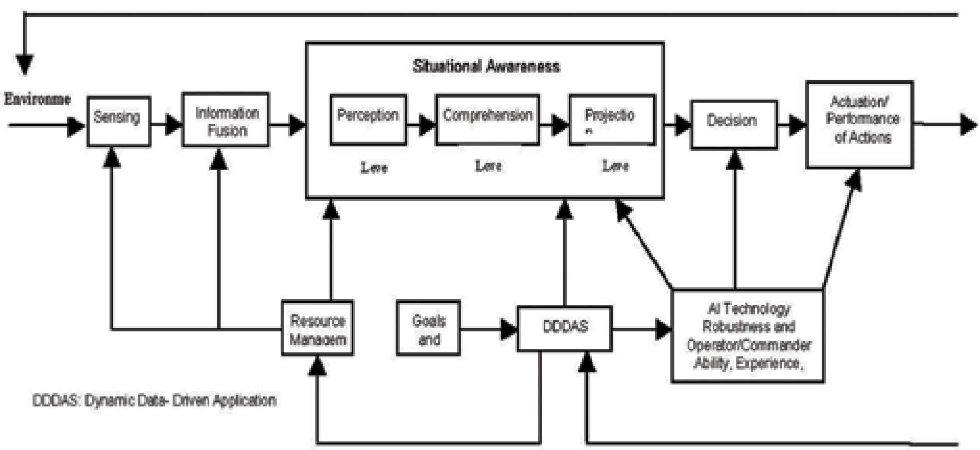

Figure 2: Situation Awareness and Dynamic Decision-Making Model (Source: Source: Arslan Munir et al., Situational Awareness: Techniques, Challenges, and Prospects)[14]

The model has an **SA core** whereas **sensing and decision-making elements** are built around the SA core. A multitude of sensors sense the environment to acquire the state of the environment. The sensed information is fused together to remove the redundancies in the sensed data, such as multiple similar views captured by different cameras or quantities sensed by different sensors in close locality, and also to overcome the shortcomings of data acquired from a single source, such as occlusions or change in ambient lighting conditions.[15] The fused data is then passed to the SA core, which comprises of three levels or stages:-

- **Perception – Stage 1 SA.** The first stage of acquiring SA is the perception of the status, attributes, and dynamics of the relevant elements in the surroundings. For example, a pilot needs to discern important entities in the environment such as other aircraft, UAVs, terrain, ground targets, and warning lights along with their relevant characteristics.[16]

- **Comprehension – Stage 2 SA.** The second stage of SA is the comprehension of the situation, which entails understanding the entities (acquired in Stage 1) and integrating them together, in relation to the operator's objectives. For instance, a pilot must understand the significance of the perceived elements in relation to each other.

- **Projection - Stage 3 SA.** The third stage of SA is prediction or estimation of the status of entities in the surroundings in future, at least in the near future. For example, from the perceived and comprehended information, the experienced pilots/operators predict possible future events (Stage 3 SA), which provides them knowledge and time to determine the most befitting course of action to achieve their objectives.[17]

The SA core also receives input from the commanders at strategic or operational levels, which can be supplemented by artificial intelligence (AI) assisted decision-making. Perception is organised through the standard information fusion and resource management loop. However, to better manage the resources according to changing situations, a dynamic data-driven application systems (DDDAS) module is established to provide input to the resource management module, which in turn manages the sensors sensing the environment and computing resources in the SA core. In the DDDAS module, the computation and instrumentation facets of an application system are dynamically assimilated in a feedback control loop such that the instrumentation data can be dynamically fused into the executing model of the application. The executing model can in turn control the instrumentation. The DDDAS module can help guide and reconfigure sensors to increase the information content of the sensed data for enhancing SA of the activities of interest in the environment.[18]

Due to the recent advancements in AI, AI has become an integral part of SA core and dynamic decision-making. AI assists operators/pilots in comprehending the situation (Stage 2 SA) and then making projections about the future actions of entities in the environment (Stage 3 SA). Based on the acquired comprehension and projection, decisions are recommended by the AI models to the commanders and then the commanders make the appropriate decisions taking into account the input from the AI and the assessed situation. Finally, the decisions are implemented at the tactical level by the operators. The decisions to be implemented have a vast range including, for example, the positioning of personnel and equipment, firing of the weapons, medical evacuation, and logistics support etc.[19]

Technologies Required for Situation Awareness

Improving sensor data fusion and its consequent SA has been an ongoing process in the field of the armed forces. However, with the speedy development of emerging and disruptive military technologies under the Fourth Industrial Revolution, variety and quality of sensors have increased manifold, providing real time or near real time SA and with AI, Machine learning, Big Data Analytics and exponentially enhanced computational speed, dynamic decision-making from commander to operator level is increasingly being realised. Various technological advancements are either under consideration or have already been employed by military to improve SA. Some of these are elaborated in the succeeding paragraphs.

Intelligence Collection. Different sources of intelligence that assist in improving SA include human Intelligence (HUMINT), open-source intelligence (OSINT), measurement and signature intelligence (MASINT), signals intelligence (SIGINT), imagery intelligence (IMINT), and geospatial Intelligence (GEOINT). The intelligence acquired from multiple sources is required to filter the discrepancies reported from a particular intelligence source.[20]

Sensors. Technological advancements have led to the development of a multitude of sensors many of which have found applications in surveillance and SA systems. Some of the key sensors are:-

- **Multispectral sensors**. A standard visual sensor collects red, green and blue wavelengths of light. Multispectral sensors collect these visible wavelengths as well as wavelengths that fall outside the visible spectrum, including near-infrared radiation (NIR), short-wave infrared radiation (SWIR) and others. Comprising of three-to-five spectral bands, multispectral sensors fall into two common categories: modified and multiband.[21] Modified sensors are created when a special filter is placed on a standard visual sensor. Multiband sensors are manufactured specifically for multispectral data collection. Each band is collected by a dedicated sensor so there is no need for multiple flights. Multiband sensors mix different band combinations to meet different needs.[22]

- **Radar Sensors.** Radar sensors utilize longer wavelengths at the centimeter to meter scale, which gives it special properties, such as the ability to see through clouds. The spatial resolution of radar data is directly related to the ratio of the sensor wavelength to the length of the sensor's antenna. For a given wavelength, the longer the antenna, the higher the spatial resolution. From a satellite in space operating at a wavelength of about 5 cm (C-band radar), in order to get a spatial resolution of 10 m, one would need a radar antenna about 4,250 m long. An antenna of that size is not practical for a satellite sensor in space.[23]

- **Synthetic Aperture Radar (SAR)** has been developed, wherein a sequence of acquisitions from shorter antenna are combined to simulate a much larger antenna, thus providing higher resolution data.[24] SAR systems provide high-resolution, microwave brightness images of the earth's surface, typically in the 1GHz–10GHz frequency (1cm–60 cm wavelength) range. These images are sensitive to the roughness, geometry and dielectric properties of targets, and thus provide geophysical measurements of the surface.[25]

- Other remote sensing instruments, such as **optical, thermal, and geophysical sensors** measure targets in different regions of the electromagnetic spectrum or through other physical processes (e.g., gravity, magnetism). These sensors are sensitive to different target properties than the SAR, and thus provide information, which is complementary and may be usefully combined with SAR. The data fusion exploits the different information content about a target captured by SAR and other sensors in order to improve the recognition and discrimination of features in the scene. The end-product of fusion through enhancement is typically a colour image in which the SAR and other data have been combined in to an attractive, interpretable scene.[26]

- **Light Detection and Ranging (LiDAR)** is a popular remote sensing method used for measuring the exact distance of an object on the earth's surface. Even though it was first used in the 1960s when laser scanners were mounted to airplanes, LiDAR didn't get the popularity it deserved until twenty years later. It was only during the 1980s after the introduction of GPS that it became a popular method for calculating accurate geospatial measurements.[27]

Geospatial Technologies encompass Geographic Information System (**GIS**) and Global Positioning System (**GPS**), also known as Geolocation systems:-

- An important aspect of GIS is its ability to assemble the range of geospatial data into a layered set of maps which allow complex themes to be analysed and then communicated to wider audiences. This 'layering' is enabled by the fact that all such data includes information on its precise location on the surface of the Earth, hence the term 'geospatial'.[28]
- GPS when embedded in remotely located sensors provide less than 1 m ranging accuracy in open terrain and less than 2 m ranging accuracy inside buildings.
- The geolocation systems, when utilized for military equipment integrate measurements from complementary sensors to provide a fused solution that is more precise than any individual sensor.[29]
- Through "geolocating" process, locations of places, where videos and photographs are taken, are verified. Geolocation differs from "geotagging". Geotagging is the automated

process of adding geographical identification data to various media such as photographs and videos. Only a fraction of photographs and videos recorded on smart phones, digital cameras, and tablets that are posted online contain an embedded “geotag” of their location. Geolocation techniques, however, allow an investigator to firmly establish the location of recorded images even without an embedded geotag. Using photographs posted on various social media sites, in combination with satellite imagery and “street view” images from services such as Google Earth and Yandex Maps, investigative geolocation techniques pinpoint the coordinates of where photographs were taken.[30]

- Geolocation is thus a powerful and effective tool for tracking individuals and the images they produce. The geolocation methodology was used by combining multiple sources of open domain information to track the movement of soldiers, vehicles, and cross-border shelling from Russia to Ukraine in 2014.
- Geolocation methods enable pinpointing of each piece of equipment to its exact location coordinates using a combination of sources. This includes using satellite and/or ground imagery of the area and matching it with landmarks visible in the media images. For example, in July 2014,a video was uploaded to YouTube showing the movement of a military convoy (carrying 2S19 Msta-S, a self-propelled 152 mm howitzer system) in Rostov-on-Don, Russia, heading west. The coordinates were verified through geolocation, using satellite and ground imagery available through a Russian online map service. Later in September 2014, an Al Jazeera news crew filmed the movement of Msta-S system through Novoazovsk in Ukraine, again heading west.

Comparison of a number of distinctive features in both these videos strongly suggested that the unit was same in both the places and that the unit would have been transferred across the border.[31]

Utilisation of Geospatial and Data Fusion in The Indian Armed Forces

The Governments of India and the United States signed the Basic Exchange and Cooperation Agreement (BECA) on October 27, 2020. The BECA agreement focuses on exchange of Geospatial intelligence (GEOINT) for use by the governments for defence and other purposes. BECA will help India get real-time access to American GEOINT that will improve the accuracy of automated systems and weapons like missiles and armed drones. Through the sharing of information on maps and satellite images, it will help India access topographical and aeronautical data, and advanced products that will aid in navigation and targeting.[32]

In today's Network centric warfare, which is highly dependent on a Multi-platform Multi-sensor data Fusion (MPMSDF) engine, the weapons are launched at a future position of the target. For a dynamic target, errors can lead to serious consequences since the fast-moving hostile fighter jets or incoming missiles may not give a second opportunity to intercept them. Geo-data referencing framework and timing accuracy (via an Atomic clock) are essential for Real-time computation of Air, Surface and Sub-surface warfare functions to achieve a successful missile impact. European nations are employing their Regional Satellite-based Augmentation Systems (SBAS) e.g. EGNOS (European Geo Stationary Navigation Overlay Service) to further improve GPS accuracy and reliability. India too shall have a similar capability when ISRO's PNT (Position, Navigation and Time) services are available using Indian satellite constellations as part of NavIC system.[33]

Geospatial technologies were used fruitfully to establish the location of Russian troops and equipment against Ukraine in 2014. However, that had been categorised under **Digital forensic techniques.**[34] In order to make these technologies as a component of C4ISTAR, these have to be fused with multi-domain, multi-sensor data obtained from varied sources so as to produce near-real-time situation awareness. In July 2020, the U.S. Air Force has reportedly awarded Descartes Labs a contract that will allow them to use the company's geospatial analytics platform for data fusion from multiple sensors including satellite sensors, to provide near-real-time analytics. The contract was awarded by the U.S. Air Force to spark innovation through non-traditional vendors.[35]

Indian Armed Forces should draw a leaf from the U.S. Air Force and engage our emerging start ups along with Indian Space Research Organisation (ISRO) to create / strengthen its C4ISR.

Conclusion

The data collected by a multitude of intelligence, surveillance, and reconnaissance (ISR) sensors enhance the situation awareness of decision makers and help them to better understand their environment and threats. However, this enhancement of situation awareness for end users is impeded by a variety of factors such as: incompatible data formats; bandwidth limitations; sensor persistence (ability of a sensor to sense continuously); sensor revisit time, particularly applicable to satellite or other airborne sensors; and multi-level security. Furthermore, with increasing amount of sensor data, challenge is to identify the most significant pieces of information, fusing that information, and then presenting that information to the end user in a suitable format.

Geospatial technology is now playing a vital role in matters that affect national security, as the professionals working for defence intelligence can now make use of data sharing to their advantage. Geospatial technology now utilises artificial intelligence (AI) and machine learning (ML) to rectify data processing and analysis issues. These systems allow agencies to gain valuable battle space situational awareness more rapidly and precisely. AI-powered investigation systems also provide forces with a safe and economical way to survey and analyse the hotspots and battlefields in real-time. C4ISTAR based on Geospatial and data fusion technology will act as a Force-Multiplier, providing multitudinous advantage over the enemy. Situation awareness based on Geospatial technology has found great usage in Gray Zone or Hybrid warfare, to detect and identify an adversary, who intends to conceal the identity of its troops and equipment to deny attribution.

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Endnotes

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