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LEVERAGING TECHNOLOGICAL ADVANCES IN C4ISR TO ENHANCE SITUATIONAL AWARENESS AND DECISION MAKING

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Abstract

C4ISR refers to technology that offer actionable intelligence for defence and strategic decision-makers to carry out command-and-control directives. Recent advancements in systems, techniques, and technologies have enabled enhanced Situational Awareness (SA) as well as in-depth understanding of an adversary's capabilities. Such enhanced SA will help to minimise the time between the initial perception of a threat and the subsequent decisions generated to mitigate the threat, thereby enhancing C4ISR capabilities. This paper provides a review of current and upcoming technologies that can be used to improve decision-making and SA.

Introduction

The 'nervous system' of the military, a collection of sub-systems used to make the best use of real-time Situational Awareness (SA), is referred to as C4ISR - command, control, communications, computers, intelligence, surveillance, and reconnaissance[1]. C4ISR is the backbone of any defence operation, ensuring battlefield transparency. It gathers and organises data from various sources, analyses them, and then disseminates it to all agencies concerned for coordinated and prompt action.

The value of C4ISR is drastically shifting from a static decision-making process, where commanders used to make decisions based on pre-determined criteria, to a dynamic decision-making process, where the flexibility is built into the system and enables commanders of various commands to interact more effectively in near-real-time and, if necessary, make mid-course corrections.

The quality of data has grown tremendously as a result of advances in electronics, IT, communication, compute power, etc., and this trend will continue. Due to these advancements, massive amounts of data are produced, which may place pressure on analytics to correlate data from many sources, evaluate them, and communicate useful discoveries in almost real-time.

The information used in C4ISR will come from a variety of sources and data types, including satellite and aerial images, pictures, text, audio, and video, sensor data, etc. Aspects to be considered in the implementation of C4ISR are:-

- Common standards and protocols must exist amongst all participating organisations
- Common data formats and data dictionary for seamless exchange of information
- Common GIS with geo-referenced data
- Common co-ordinate projection system
- Standard policies and procedures
- Joint encryption system

This article discusses the design of current and emerging technologies to keep C4ISR relevant and useful for the country.

Architecture for C4ISR

C4ISR receives data from a variety of sources, including services and intelligence organisations. The fact that all of these stakeholders might not want to disclose their internal architecture, including data and apps, is an important consideration in this case. As a result, the joint network centric architecture should be put in place that allows all agencies to share the identified data, when necessary or requested, while keeping other data private.

Each agency has its own secure network, like an ‘island’. The network architecture in a C4ISR implementation must be designed to include various ‘network islands’ with secure points of integration. Autonomy within a ‘network island’ and secure interoperability across several ‘network islands’ are key principles to be achieved. Every ‘network island’ has an Information Exchange Gateway (IEG) that is connected through a data diode. This IEG will only contain the data that has been identified, which will then be shared with the Theatre Shared Data centre (TSD) via a different data diode. This TSD will then transfer data to the Central Shared Data centre (CSD). The IEG of an organisation / agency will not simultaneously connect a ‘network island’ and a TSD, protecting the private data stored by the ‘network islands.’

C4ISR can be implemented in either a centralised or federated architecture. Figure 1 depicts a centralised architecture, in which all the TSD data are centrally stored, analysed, and published in the Client / Server (C/S) model.

In the centralised architecture, all entities will be bereft of ISR support if network communication to the CSD fails. The organisations / agencies shall continue to function in separate vertical silos, with integration between them only conceivable at the CSD level.

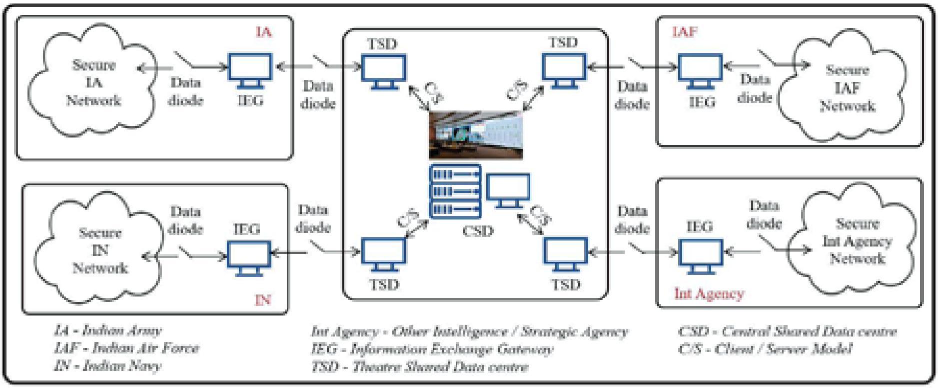

Fig. 1: Centralised Architecture for C4ISR

Figure 2 depicts a federated architecture, in which the TSDs of respective 'network islands' are connected in a Peer-to-Peer model. The IEG of any organisation or agency will gather data from other organisations via the Peer-to-Peer connected TSD. IEG synchronises data with its secure 'network island' whenever the connection to the data diode is established. Redundancy and survivability are better in a federated architecture, due to distribution of resources.

Furthermore, C4ISR architecture will cater for Information Push Model on 'need to know' basis for executors, and Information Pull Model on 'know all basis' for commanders at the decision-making level.

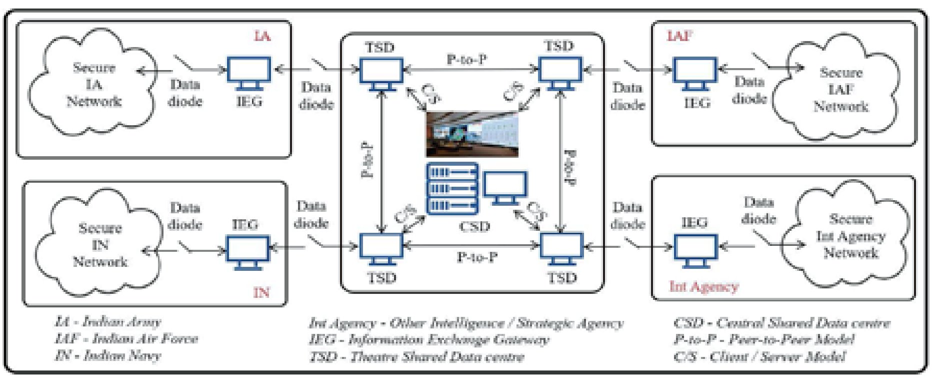

Fig. 2: Federated Architecture for C4ISR

The architecture's subsystems should have proper Sustenance Model, taking into account the centrally manageable Operating System, Compute requirements, scalable Storage, reliable Network, and Cyber Security.

Applications

Applications form the core of SA. Various technological innovations in the past decade have led to enhancements in SA capability. Whether at the services or agencies level or at the Central Command-and-Control Centre, applications are deployed to fulfil the requirements, augment the performance and help in timely and appropriate decision-making capability. Few technologies to improve SA are detailed below:-

- **Data Collection, Collation and Cataloguing.** The development of a significant amount of data at C4ISR, in Network Centric Warfare, is occurring at an accelerated rate, increasing the rate of data flow. This is due to advancements in technology, the deployment of more sensors, the conversion to digital data, among other factors. High-resolution, high-frequency data from satellite and aerial platforms, IoT sensors, surveillance assets, and other sources provide a vast volume of data in the form of images, videos, audio, radio signals, and other types of data. This large volume of data not only presents a challenge in terms of efficient processing, but it also needs high-performance computing systems to provide near-real-time retrieval and analysis of essential data for suitable and prompt decision making.
- Different sources of data collection or intelligence gathering which will help to improve SA are:-
- Human Intelligence (HUMINT)
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- Open-Source Intelligence (OSINT)
- Signals Intelligence (SIGINT)
- Image Intelligence (IMINT)
- Geospatial Intelligence (GEOINT)

Data is available in various categories and formats. Some of the data types for improving SA are:-

- Geospatial data, like image, which are available as satellite images (EO, SAR, IR, Hyper-spectral, etc.), aerial images (nadir, oblique), Vector data (Simple features, Point Cloud, 3D data models, time-series grided data, Data Cubes, etc.), Digital Elevation Models (DEM), Digital Terrain Models (DTM), portrait pictures, landscape images, etc.
- Textual data, like simple text, structured text data, structured database, unstructured text data, Graph database, etc.
- Audio data from audio recordings, phone / mobile call records, electro-acoustic sensors, etc.
- Video data from video cameras, web cameras, surveillance sensors, etc.

Data catalogues, like Spatio-temporal Asset Catalog (STAC), provide a promising solution for semantically classifying, indexing, and organizing data sources across different environments and enriching raw data with metadata[2]. Catalogues of data that include data descriptions may be made available as network services. Implementation of RESTful API discovers and uses data in applications to improve SA.

- **Geo-Spatial Applications.** Geospatial technology is the backbone of C4ISR applications. It offers geospatial image and map analysis capabilities. It also offers users the ability to understand the landscape, the location of the event, the deployment of the forces and their range, accessibility, changes in time and place, etc.

- **Geospatial Data Publishing.** Geospatial data can be published by following OGC standards (Fig. 3). Geospatial applications can consume the published data in standalone or network mode.

- **Geospatial Image Data Analyses.** Finding new targets, spotting changes, conducting surveillance, planning

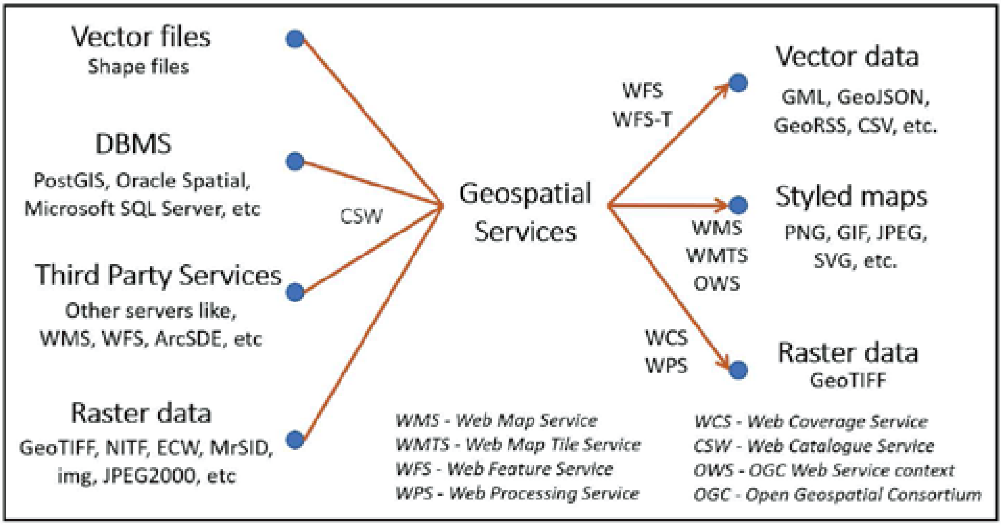

Fig. 3: Geospatial Services

missions, evaluating combat outcomes for Battle Damage Assessment (BDA), Order of Battle (OOB) analysis, etc., are the main goals of analysing geospatial image data from satellites and aerial platforms. They aid in estimating the adversary's military might, locating and tracking the adversary's forces, watching the positioning and disposition of the adversary's military units, keeping an eye on the enemy's primary supply routes, activity at their weapon storage facilities, course-of-action evaluations, etc.

Mastering the art and science of locating underground silos / bunkers / hidden facilities like ammo dump, will provide critical information for strategic and tactical planning. Geospatial image analyses will play a pivotal role in their identification.

Image interpretation tasks include – feature detection, localization, recognition, identification, comparison, interpretation, understanding, and prediction.

- **3D Terrain Visualization.** 3D landscape visualisation allows Commanders to better appreciate real-world scenarios, while sitting far away from the action. Employing modern 3D projectors / AR-VR / Holographic projections, instead of sand models, enhances their ability to make well-informed decisions.

  Terrain analysis includes numerous surface analysis capabilities, such as locating the highest and lowest points, assessing inter-visibility, determining line of sight, generating view sheds, path profile construction, elevation profile viewing, shaded relief creation, steepest path computation, creating color-coded images for elevation / slope / aspect, displaying slope contours and arrows, cut and fill volume analysis, planning tactical deployment, and 3D fly-through visualisation.

- **Change Detection.** Multi-temporal satellite and aerial photos are examined to detect changes in strategic features. Specific objects identified in a given reference image are compared with features, discovered in the target image, to detect the appearance, disappearance, or change in placement of objects. Change detection offers useful insight into the behaviour and intentions of adversaries.

The process of automating change detection is currently in development stage. Automation will make it easier to quickly analyse numerous images.

- **Artificial Intelligence Applications.** Robotics and Artificial Intelligence (AI) is the combination of technology and cognitive intelligence for simulation, processing of information, and knowledge to build capability in a machine to imitate human behaviour[3]. Unmanned systems are expected to dominate future wars, and artificial intelligence will be a key factor. On July 11, 2022, the Defence Minister of India launched 75 newly-developed AI products/technologies, at the 'AI in Defence' (AIDef) Symposium, in New Delhi. To modernise defence services and strategic agencies, efforts are currently under way to fully utilise AI's potential. In this perspective, various AI-based applications are explored below:-

    - **NLP Search, Language Support and Sentiment Analysis.** Natural Language Processing (NLP) use Deep Learning (DL) to comprehend the meaning and relationships between words. Intelligence experts employ HUMINT, OSINT, and other types of intelligence data in NLP to derive relevant topic discovery, sequence mapping, and generative summarisation. NLP will provide SA in the context of C4ISR and will improve decision-making.

    - NLP with geospatial technologies may assist agencies comprehend and appreciate the coordination and correlation of events in time and space.

- The technical study and examination of a language form, its meaning, and its environment is known as linguistics. AI plays a critical role in interpreting linguistics in the context of the computer, which will aid in the development of intelligence. Language AI models are available for a variety of tasks such as translation, transliteration, speech to text, text to speech, image to text, and so on.
- Information that circulates through print, electronic, and social media is very valuable to intelligence agencies. Analysis of such data may provide intelligence agencies with important insight into the undercurrents and sentiments of certain groups and/or the general public. Organizations may use NLP to assess public mood, monitor social media, news, and so on, and to categorise online interactions based on emotions such as sadness, grief, joy, rage, and so on. NLP can be used to spot risks, keep an eye on behaviour, and prevent a crisis.
- **O**bjec**t Identification and Classification in Images.** The type of object recognised, its class, and its relative change over time, in a geospatial image, give critical information for C4ISR Commanders, in planning their strategy. AI is a tried-and-tested technique to solve a problem. Of course, the scale of the images and/ or photographs have a strong association with the classification of an object. The object should be clearly visible in the image or photograph in order to be classified. Convolutional Neural Networks (CNN) are one of the most used techniques to analyse geographical images. The majority of modern AI detection systems have been trained to recognise pre-defined objects. The future belongs to pre-trained models that will improve SA by

automatically classifying and identifying defence objects and assisting with decision-making.

- **Facial Recognition.** Facial Recognition is a biometric solution that was specifically created and built to recognise the human face, without any physical contact. It can help to improve the security of any organisation or vital facility. The primary goals of facial recognition are to recognise, categorise, confirm, and, if necessary, neutralise any identified threats.

- **Automatic Event Recognition in Video Streams.** Video streams from UAVs, IoT devices, and CCTV cameras are critical sources for surveillance and SA. Automatic video data analysis from diverse sources can aid in the timely analysis of large amounts of data with higher output quality.

  Hidden Markov Models (HMMs) and CNNs require volumes of training data for configuring the network to recognize events. On the contrary, Bayesian networks can be utilized for event recognition when training video data is scarce[4].

- **Super Resolution.** In defence applications, one of the major challenges is to extract information from low resolution images. Super-Resolution can solve this problem. Super-Resolution (SR) is the process of deriving image of higher resolution (HR) by applying an algorithm to low-resolution (LR) images[5].

  In general SR needs multiple images of different resolutions to generate HR images. In defence applications, many times it becomes difficult to get multiple images. Single Image Super-Resolution (SISR) has fundamental low-level vision problems. The SISR aims to recover the High-Resolution images from a single Low-Resolution image[6].

- Employing Super Resolution on satellite images will enhance the analysis capabilities of C4ISR systems for identification, classification, and change detection of defence targets.
- Advance Applications. Modernization of defence forces and intelligence agencies is headed toward automation, with robots equipped with powerful algorithms analysing available data, applying AI techniques, and making decisions:-
- **Information Fusion.** Surveillance applications use a plethora of sensors, such as motion detectors, proximity sensors, biometric sensors, and a range of cameras, such as colour cameras, night vision imaging cameras, thermal imaging cameras, and so on, to monitor defence targets from various angles and resolutions. Information fusion contributes significantly to SA by helping to extract insightful knowledge from observed data. SA combines low-level information fusion (tracking and identification), high-level information fusion (threat- and scenario-based assessment), and user refinement (physical, cognitive, and information tasks). Information fusion minimizes redundancy between the data captured by different sensors, such as the same or similar views captured by various cameras. Furthermore, information fusion also assists in performing hand off between cameras when an object being tracked by one of the cameras, moves out of its field-of-view and enters into the field-of-view of another camera. In the fog / edge computing paradigm,

information fusion at sensor / IoT nodes reduces the data which are transmitted to the servers[7].

- **Automatic Image Registration / Ortho rectification.** Information extraction with specific geographic location begins with image registration of multi-temporal and/or multi-sensor images. However, the procedure is time and labour-intensive. Automation of the procedures for the near-real-time extraction of meaningful information from satellite and other aerial images is required due to the increasing volume of data coming in.
- Image registration and orthorectification are utilised in defence and security applications such as target detection, recognition, and tracking, vehicle navigation, and surveillance, among other things.
- **IoT and Sensors**
- With the development of new technology, new sensors are developed and used for defence. Soldier health monitoring sensors, autonomous vehicle sensors, gunshot acoustic sensors, and other technologies are being developed to modernise defence systems. They deliver a range of data in various formats to the command-and-control centre, for quick analysis and decision-making.
- **Drone / UAV Data Processing.** Unmanned Aerial Vehicles (UAVs) / drones can greatly assist in enhancing SA because they are capable of gathering intelligence in situations that are regarded dull, unclean, or dangerous. Next-generation UAVs will process the gathered data, perform information fusion, and carry out high-level analytics on board as a result of technological developments. Context-aware UAVs with cameras are

able to produce a high-level description of the scenario seen in the video and pinpoint potentially dangerous circumstances.

The application of drones in novel ways has gained momentum during grey-zone warfare in peacetime. Miniaturization of electronics, new generation navigational tools, and fast computers have resulted in the development of smart weapons, superior sensors with long stand-off ranges, and precise terminal guidance. Loitering munitions, originally developed as anti-radiation drones, have proven to be more dangerous than armed drones.

- **Cyber Warfare.** Cyber warfare refers to the actions of a nation or state or international organisation to attack and attempt to harm another nation's computers or information networks using, computer viruses or denial-of-service assaults. Cyber warfare can take many different forms, including espionage, sabotage, denial-of-service attacks, attacks on the electrical grid, propaganda, economic disruption, and surprise cyber attacks.

  Threat intelligence on the most recent cyber threats, cyber attacks, and zero-day occurrences must be obtained and tracked because they are essential pieces of knowledge for cyber warfare.

  The components of cyber warfare include connecting to the adversaries' network and preventing access to one's own network.

- **Research Areas.** The advancement of technology is a dynamic phenomenon. To keep the system updated, time, money, and resources should be put in researching emerging / futuristic technology. To gain an advantage over our adversaries, IT development should evolve at a rate that keeps up with global advancement. Below are a few emerging technologies, that are important to defence:-

- **ISAR.** Inverse Synthetic-Aperture Radar (ISAR) is a microwave data processing technique that uses Radar imaging to generate a two-dimensional high-resolution image of a target. It is analogous to conventional SAR, except that ISAR technology uses the movement of the target rather than the emitter to create the synthetic aperture. ISAR radars have a significant role aboard maritime patrol aircraft, which provides them with radar images, for target recognition purposes, like ships and other objects. In situations where other radars display only a single unidentifiable bright moving pixel, the ISAR image is often adequate to discriminate between various missiles, military aircraft, and civilian aircraft[8].

- **Predictive Modelling.** Predictive analytics is a form of advanced analytics that uses current and historical data to forecast activity, behaviour, and trends. It applies statistical analysis techniques, data queries, and ML algorithms to data sets for creating predictive models. Predictive Modelling looks for patterns in data and projects them forward to help the defence sector mitigate risks and capitalize on opportunities[9].

  In the dynamic battle scenario tagging and tracking of defence units like, artillery and armoured columns, in images can enable intelligence units with valuable inputs regarding adversaries planning and motives.

- **5G Network.** 5G network provides ultra-low latency, which means faster response times when moving data like video and AR/VR for immersive experiences. Its high reliability makes it ideal for supporting mission-critical applications and services. Its massive connectivity capabilities enable faster aggregation of network-connected endpoints, sensors, devices, and data to power IoT connectivity[10].

- **Robotics.** Robotics is a vital tool for executing risky tasks in a defence context, as well as for training, simulating, modelling, and modelling. Robots are being redefined as physically embodied AI entities as a result of continuing technological advancements.

  Robots can be equipped with technologies such as RADAR, electro-optical/infrared, sonar, LiDAR, and others to gather crucial data. Despite being outfitted with sensors and radios, the robots are supposed to be resistant to electronic warfare and cyber-attacks.

- **Quantum Computing.** The field of quantum technology is new and has the potential to be disruptive. The use of quantum technology in the defence, opens up new possibilities while enhancing efficiency and boosting precision, resulting in ‘quantum warfare’.

  The ‘must-have’ technology is the implementation of post-quantum cryptography. The possibility that foreign intelligence is gathering encrypted data with the anticipation of future decryption using the capability of quantum computers is real, high, and present. Few quantum-resilient algorithms can provide not only a new mathematical method challenging enough even for quantum computers, but also a new paradigm for working with encrypted data.

Interoperability, Standardization and Backward Compatibility

The perspectives of interoperability between two or more system components include information exchange, information understanding, and collaborative coordination between system elements. System interoperability factors such as architectural rationality, security of information exchange environment, operation efficiency, and management maintenance are a few viewpoints to be considered[11].

Integrating diverse platforms from various defence equipment manufacturers employed by each defence / strategic agency is a significant interoperability problem in C4ISR.

Interoperability can be seen from different levels, such as device interoperability, networking interoperability, syntactic interoperability, semantic interoperability, and platform interoperability. These levels, combined with interoperability approaches, openness, connectivity, application protocols, and security / privacy metrics, are required to handle C4ISR Interoperability issues.

Following defence / industry standards in every component is critical to attaining full interoperability. As technology develops, it's possible that outdated hardware and software won't function with new data formats and interfaces. When the hardware, software, or application is upgraded, the existing data should not be lost and should be ready for reuse. Backward compatibility is possible by adhering to standards like ISO, OGC, etc.

Collaboration

It is recommended that agencies collaborate with professional institutes, for research and development of quality applications. Long-term partnerships with academic institutions will assure future technology research, whilst partnerships with government laboratories and businesses will boost C4ISR by providing cutting-edge applications to run the show.

Conclusion

During a conflict, forces' knowledge of the enemy and the regions where it operates typically decides whether they succeed or fail. In the 1970s, Soviet military strategists invented the phrase 'reconnaissance-strike complex' to explain a networked system that incorporated the modern concept of generating 'kill chains' on the fly by joining an array of sensors to many shooters. Most of the computing power needed by these sensors and networks is already accessible today. Furthermore, additional information may be obtained via the cloud and fed into AI systems, resulting in newly accessible and affordable ways of seeing and techniques for bringing together and analysing the data collected and presenting the information as and when needed. AI systems also address stealth, electronic warfare, cyber attacks, and other forms of deceit that hiders can use to remain undiscovered. As a result, the reconnaissance-strike complex has grown in sophistication. Modern day architects are merging technologies to develop a system that can quickly eliminate a large number of potential targets while passing information about them to the essential locations.

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