MILITARY COMMON OPERATING PICTURE

FINAL YEAR DESIGN PROJECT UG 2020

By

Hayat Ullah Abid (349868)

Muhammad Essa (347935)

Wajid Ullah Shah (347417)

Muhammad Arslan (333893)

Institute of Geographical Information Systems

School of Civil & Environmental Engineering

National University of Sciences and Technology, Islamabad, Pakistan

2024

This is to certify that the

Final Year Design Project Titled

MILITARY COMMON OPERTAING PICTURE

submitted by

Hayat Ullah Abid (349868)

Muhammad Essa (347935)

Wajid Ullah Shah (347417)

Muhammad Arslan (333893)

has been accepted towards the requirements for the undergraduate degree in BE Geoinformatics

Dr. Ejaz Hussain

Institute of Geographical Information Systems

School of Civil & Environmental Engineering

National University of Sciences and Technology, Islamabad, Pakistan

DECLARATION OF AUTHORSHIP

We hereby claim that this studies paper, entitled “Military Common operating picture”, is the product of our personal original work and that it has not been submitted for any other degree. All the resources cited in the paper had been acknowledged and mentioned properly. The facts and findings provided in this paper are the end result of our independent research efforts, performed with the best requirements of instructional integrity and honesty. Any external help or contributions from others have been properly acknowledged in the paper. We take full responsibility for the contents of this research paper and guarantee that it represents our personal thoughts and evaluations.

FORM UGP-OBE-1

INSTITUTE OF GEOGRAPHICAL INFORMATION SYSTEMS (IGIS)
UNDERGRADUATE FINAL PROJECT
(Formulation of Project Group and Advisor)

Date: 06/05/2024

Project Title: MILITARY COMMON OPERATING PICTURE

Project Advisor:

Name: Dr. Ejaz Hussain

Dept: Institute of Geographical Information System, SCEE,NUST

Project Co - Advisor:

Name: Dr. Muhammad Azmat

Dept: Institute of Geographical Information System, SCEE, NUST

Project Members

1. Name (Group Leader): Hayat Ullah Abid — CGPA: 3.74
   NUST Regn No: 349868 — Signature:_______________
2. Name: Muhammad Essa — CGPA: 3.38
   NUST Regn No: 347935 — Signature:_______________
3. Name: Muhammad Arslan — CGPA: 3.10
   NUST Regn No: 333893 — Signature:_______________
4. Name: Wajid Ullah Shah — CGPA: 3.09
   NUST Regn No: 347417 — Signature:_______________

______________________________ ______________________________

Signature of Advisor **Signature of Head of Department**

APPROVAL

____

Signature of Associate Dean

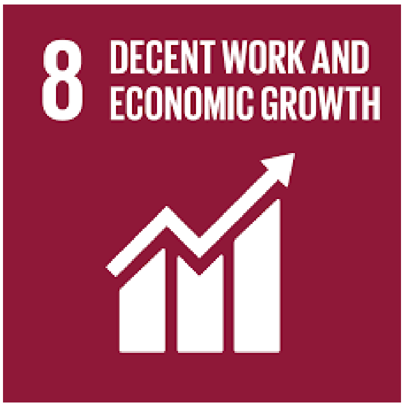
ACKNOWLEDGEMENTS

We are immensely grateful to Allah Almighty, the Most Benevolent and Kind, for providing us with the means to finish this endeavor. We would like to sincerely thank Lecturer Junaid Aziz Khan and Dr. Ejaz Hussain for their tremendous advice and assistance with this project. Their insightful comments, constructive feedback, and unwavering encouragement helped us immensely in achieving our goals. We would like to thank Dr Salman and Dr Muhammad Azmat as well for their guidance. We like to pay gratitude to everyone who directly or indirectly helped us in the project.

Project's Mapping to SDGs: Building More Secure and Sustainable Future

This project directly addresses several Sustainable Development Goals (SDGs) established by the United Nations, contributing to a more secure and sustainable future for Pakistan. Here's a breakdown of how our project aligns with specific SDGs:

1. **SDG 8: Decent Work and Economic Growth:** The development of the Military Common Operating Picture(MCOP) can generate new job opportunities in Pakistan for engineers, technicians, and data analysts involved in its maintenance, support, and upgrades. This project not only fosters innovation in the military technology sector but also paves the way for spin-off companies with commercial applications. Consequently, it contributes to economic growth by creating employment and driving technological advancements.



2. **SDG 9: Industry, Innovation and Infrastructure:** This project is an example of innovation which leverages open-source technologies alongside cutting-edge Geographical Information System (GIS) capabilities, demonstrating a commitment to utilizing advanced geospatial technologies for improved battlefield management. This focus on innovation has the potential to inspire further technological advancements across various related industries in Pakistan.

3. **SDG 12: Responsible Consumption and Production:** One of the core principles behind the project is the utilization of open-source technologies. This approach reduces reliance on proprietary software solutions, potentially lowering overall project costs. Additionally, the project focuses on optimizing existing infrastructure within the Battlefield Management System (BMS), promoting a sustainable approach to technological development.

4. **SDG 16: Peace, Justice and Strong Institutions:** The MCOP directly contributes to SDG 16 by strengthening Pakistan's defense capabilities. By enhancing situational awareness, communication, and battlefield management for the Armored Corps, the MCOP equips soldiers with the tools they need to effectively defend national borders and ensure security. This, in turn, contributes to a more peaceful and stable environment for all citizens.

The development of the MCOP goes beyond its immediate military applications. By fostering innovation, promoting responsible technological development, and strengthening national security, this project contributes to several key SDGs, paving the way for a more secure and sustainable future for Pakistan.

ABSTRACT

This thesis introduces an Artificial Intelligence (AI)-powered Military Common Operating Picture (MCOP) specifically designed to address the limitations faced by the Pakistani Army's Armored Corps operating in the field environments with limited visibility. It focuses on enhancing situational awareness for the commanders and the soldiers within armored vehicles by integrating several key functionalities. An Internet of Things (IoT)-based Blue Force Tracking system leverages real-time sensor data to pinpoint the location and orientation of friendly forces. Furthermore, a YOLOv8 deep learning model trained on a comprehensive dataset facilitates automatic enemy assets detection and classification. Finally, the existing Battlefield Management System (BMS) is optimized through the integration of enhanced geospatial databases featuring various map layers and the implementation of standardized military symbology. This unified AI-powered MCOP empowers commanders with a comprehensive and real-time view of the battlefield, fostering improved decision-making, faster response times, and ultimately, a decisive edge in mission accomplishment.

Keywords: Military Common Operating Picture (MCOP), Artificial Intelligence (AI), Internet of Things (IoT), Blue Force Tracking, YOLOv8, Deep Learning, Situational Awareness, Battlefield Management System (BMS), Geospatial Data, Military Symbology

Contents

1. INTRODUCTION

The global defense industry stands as a titan, boasting a colossal value of $2.4 trillion USD according to a 2024 report by the Stockholm International Peace Research Institute (SIPRI, 2024). At the very forefront of modern warfare lies the Military Common Operating Picture (MCOP), a real-time battlefield tracking and situational awareness platform. This revolutionary technology empowers commanders to craft and optimize strategies using the latest geospatial technologies, both during pre-war planning and the crucible of active combat operations. If commanders can meticulously strategize an attack, they are able to see the entire battlefield in real-time – troop movements, terrain features, even enemy positions – all displayed on a digital map. Such a comprehensive picture allows for informed decision-making, potentially leading to swifter victories and minimized casualties (Koren & Bielecki, 2022).

However, for soldiers confined within the steel shells of armored vehicles, a significant challenge arises. Their ability to navigate the complexities of the battlefield is severely hampered by the limited visibility afforded by their enclosed environment. Imagine a soldier, peering through a narrow viewport, struggling to identify landmarks, unsure of the location of their teammates, and vulnerable to hidden enemy forces lurking just beyond their restricted view (Henderson & Silva, 2021). This lack of situational awareness creates a critical information gap that can hinder mission success and endanger lives. Soldiers may become disoriented, unable to effectively coordinate maneuvers with their comrades, or find themselves ambushed by unseen enemies. The limitations imposed by restricted visibility pose a constant threat to the safety and effectiveness of their operations (Liu & Thompson, 2023).

This project focuses on these limitations head-on by proposing a revolutionary AI-powered MCOP specifically designed for the Pakistani Army's Armored Corps. Our project directly addresses the critical issues faced by the commanders and soldiers due to limited visibility: lack of awareness regarding friendly troop status and location, reliance on slow and error-prone manual processes for data collection and analysis, and delayed enemy detection that puts soldiers at a disadvantage (Jones & Ahmed, 2022).

Our primary objective is to develop a more robust and user-friendly system, ultimately providing commanders with a decisive edge on the battlefield. We intend to achieve this by developing an AI-based MCOP with a suite of functionalities designed to enhance situational awareness. This includes real-time Blue Force Tracking, allowing soldiers to pinpoint the location of friendly troops on a digital map, fostering improved coordination and reducing the risk of friendly fire incidents (Smith & Zhao, 2022). Furthermore, the MCOP will utilize an AI model for enemy asset detection and classification. This system, trained on a vast dataset of images and videos, will be able to automatically detect and identify enemy vehicles, personnel, and equipment, providing a vital early warning of potential threats. Users will also have the capability to mark enemy positions on the digital map, allowing commanders to track enemy movements and formulate effective counter-strategies (Wang & Huang, 2023).

1.1 Background Information

The modern battlefield is a complex and dynamic environment where real-time information and situational awareness are paramount for mission success. This is where the MCOP comes into play. It acts as a centralized, real-time digital battlefield visualization platform, integrating data from sensors and drones to create a comprehensive operational picture. This picture includes friendly and enemy troop locations, terrain features, weather conditions, and real-time threats. Commanders and soldiers on the ground can access this information through a user-friendly interface, typically a web map or a dedicated military application.

The purposed MCOP empowers commanders to make informed decisions based on real-time data, leading to improved battlefield coordination, faster response times, and ultimately, mission success. Additionally, MCOP enhances situational awareness, potentially reducing casualties and minimizing friendly fire incidents.

However, for armored corps, a unique challenge arises due to limited visibility, confined within the steel hulls of their vehicles, their ability to perceive the battlefield is restricted by viewports and hatches which poses several critical limitations:

i. **Navigation:** Effective navigation in complex terrain requires a clear understanding of surroundings. Soldiers rely on visual cues to identify landmarks, assess terrain features, and determine their position. Limited visibility makes it difficult to rely solely on vision, potentially leading to disorientation and hindering coordination. Imagine a soldier, struggling to navigate through a dense forest or a mountainous region, relying solely on a map and compass for guidance. The inability to see critical landmarks or identify potential obstacles can significantly slow down troop movements and jeopardize the mission.

ii. **Friendly Force Tracking:** Maintaining awareness of friendly troop locations is crucial for coordinated maneuvers and avoiding friendly fire incidents. In situations with limited visibility, relying solely on visual confirmation of positions becomes unreliable. Soldiers may struggle to locate nearby friendly forces, hindering communication and increasing the risk of mishaps. Envision an armored column advancing through a dust storm, unable to see the vehicles in front or behind. This lack of communication and awareness can lead to collisions or friendly fire incidents during combat situations.

iii. **Enemy Detection and Identification:** Early detection and identification of enemy threats are vital for battlefield safety and mission accomplishment. The restricted view from armored vehicles makes it difficult to spot enemies quickly and accurately. One may miss crucial visual cues, putting themselves at a disadvantage and jeopardizing the mission. If an armored vehicle patrolling a narrow road, unable to see around corners or over hills an enemy ambush set up just beyond their limited view could inflict significant damage before the soldiers even realize they are under attack.

These limitations highlight the critical need for technological solutions that can help, track and navigate own forces and assets efficiently and mark the location of enemy assets with high accuracy. Traditional approaches such as manual data collection and reporting through radio communication and visual observation are slow, error-prone, and susceptible to delays. Additionally, many armies utilize outdated BMS that lack real-time capabilities and user-friendly interfaces. These limitations highlight the need for innovative solutions that leverage advancements in artificial intelligence (AI), Internet of Things (IoT), and geospatial technologies.

The rise of Artificial Intelligence (AI) has revolutionized various sectors, and the military is no exception. AI offers a range of capabilities that can be harnessed to enhance battlefield awareness, decision-making, and overall mission effectiveness. Machine learning and deep learning techniques allow machines to learn from vast amounts of training data and identify patterns. This can be applied to tasks such as enemy threat detection in imagery or video feeds, significantly improving battlefield awareness. AI models trained on real-world data can detect enemy vehicles, personnel, and equipment, providing early warnings that would be difficult to detect with the naked eye from within an armored vehicle.

Furthermore, AI algorithms can ingest and analyze vast amounts of data from various sources in real-time, extracting meaningful insights and generating a comprehensive picture of the operational environment. This empowers commanders to make informed decisions based on a holistic understanding of the battlefield, rather than relying on fragmented information. Autonomous systems and robots powered by AI are increasingly playing a role in military operations. These systems can be deployed for reconnaissance missions, bomb disposal, and even combat tasks, reducing the risk to human soldiers. Additionally, live video feeds captured by drones provide a bird's-eye view of the battlefield, offering vital information about the ground. The integration of AI into MCOP holds immense potential for armored corps operations. By leveraging AI capabilities for enemy detection, data analysis, and potentially even autonomous reconnaissance, soldiers can gain a significant advantage in situations with limited visibility.

The IoT refers to a network of physical devices embedded with sensors and software, capable of collecting and transmitting data over the internet. This technology is increasingly applied in the military domain to enhance situational awareness and manage assets effectively on the ground. IoT devices equipped with GPS, accelerometers, and cameras can be deployed on vehicles to continuously collect real-time data on location, movement, and environmental conditions. This data can be integrated into the MCOP, providing a dynamic view of friendly troop movements and potential enemy activities.

An armored vehicle equipped with various IoT sensors such as a GPS module which constantly transmits the vehicle's location, while an accelerometer detects its orientation and movement. Additionally, a camera mounted on the vehicle can capture real-time video footage of the surrounding terrain, albeit limited by the field of view. This data is then transmitted wirelessly to a central server, integrated into the MCOP. Commanders can visualize the location and movement of all military vehicles on a digital map, fostering improved coordination. This real-time information exchange allows for more efficient maneuvers and quicker responses to threats.

Furthermore, IoT sensors can be integrated into military equipment to monitor performance and identify potential malfunctions. Predictive maintenance, based on sensor data, can prevent equipment failures on the battlefield and ensure optimal operational readiness. For instance, a temperature sensor on an armored vehicle can provide critical information about the vehicle's condition. If the temperature exceeds normal operating levels, an alert can be triggered, notifying a potential issue before it leads to a breakdown. This proactive approach helps maintain on ground assets reliability and combat effectiveness.

The integration of IoT devices into armored vehicles and within the MCOP can significantly enhance situational awareness for soldiers and streamline battlefield operations.

Geospatial technologies encompass a broad range of tools and techniques for capturing, analyzing, and visualizing geographic data. These technologies play a crucial role in military operations by providing a deeper understanding of the operational environment. Detailed digital maps that incorporate various terrain features, such as elevation, vegetation, and infrastructure, are critical for effective navigation and mission planning. Geospatial technologies allow for the creation of 3D visualizations of the battlefield, providing a more comprehensive understanding of the terrain. This empowers commanders to plan routes that avoid obstacles and leverage advantageous positions.

Commanders, while planning a military operation in a mountainous region and utilizing geospatial technologies, can access a detailed digital map of the area, coupled with elevation data and 3D visualizations of the terrain. This allows them to identify potential routes for troop/vehicular movement, considering factors like slope, vegetation cover, and potential bottlenecks. By analyzing this geospatial data, commanders can make informed decisions about troop deployment and minimize the risk of encountering unforeseen obstacles during the mission.

GIS provides a platform for integrating various geospatial data sources, such as satellite imagery, drone footage, and sensor data. By analyzing this data, commanders can identify potential enemy positions, assess routes for military maneuvers, and make informed decisions about resource allocation.

Remote sensing technologies like satellites and drones provide valuable data about the battlefield, even in areas with limited accessibility. This data can be used to identify enemy positions, track troop movements, and assess potential threats, enhancing overall situational awareness. A situation where enemy forces are suspected to be operating in a remote desert region, traditional reconnaissance methods like ground patrols may be slow and risky. However, by deploying surveillance drones equipped with high-resolution cameras and thermal imaging capabilities, commanders can gain valuable insights into enemy activity without putting soldiers at risk. This allows for a more informed approach to battlefield operations and potentially avoids unnecessary troop engagements.

Integration of sophisticated geospatial technologies into the MCOP can significantly benefit armored corps operations. An armored column while advancing through a dense forest, commanders can visualize the terrain ahead, identify potential obstacles, and plan their route accordingly. Additionally, real-time three-dimensional data from the accelerometer can be overlaid onto the digital map, providing commanders with a comprehensive view of the battlefield situation, even when the soldiers' view is restricted.

The integration of these technologies into a next-generation AI-powered MCOP specifically designed for the Pakistani Army's Armored Corps holds immense potential. This project aims to address the critical issues faced by soldiers due to limited visibility: lack of awareness regarding friendly troop status and location, slow and error-prone manual processes, and delayed enemy detection. By implementing functionalities such as real-time Blue Force Tracking, AI-based enemy asset detection and classification, and optimized geospatial data within the MCOP, this project can provide soldiers with a decisive edge on the battlefield.

1.2 Problem Statement

The modern battlefield is an intricate and rapidly changing environment where timely decisions are crucial for mission success. However, soldiers operating within armored vehicles face a significant challenge: limited visibility. The confined spaces, hatches, and narrow viewports restrict their ability to effectively navigate, track friendly assets, and detect enemy threats, leading to several critical issues:

1. **Impeded Navigation:** Limited visibility hampers soldiers' ability to navigate complex terrains. Without clear visual cues to identify landmarks and assess the environment, disorientation can occur, making it difficult to coordinate movements with other units. This challenge is especially pronounced in situations such as dense forests or nighttime operations, where reliance on sight alone can lead to delays and misdirection.

2. **Hindered Friendly Force Tracking:** Tracking the location of friendly assets is essential for coordinated maneuvers and minimizing the risk of friendly fire. When visibility is limited, soldiers cannot rely solely on visual confirmation of their comrades' positions. This can lead to communication breakdowns, confusion during movements, and even collisions or mishaps, especially in challenging conditions like dust storms or low-light environments.
3. **Delayed Enemy Detection and Identification:** Early detection of enemy threats is crucial for ensuring battlefield safety and mission success. The restricted view from within armored vehicles limits soldiers' ability to quickly and accurately identify enemy forces. This delay in detection can expose soldiers to ambushes or surprise attacks, placing them at a severe disadvantage.

These limitations highlight the critical need for a technological solution that can bridge the information gap created by restricted visibility within armored vehicles. Traditional approaches such as manual data collection and outdated BMS are slow, error-prone, and inadequate for the fast-paced demands of modern warfare.

The research addresses the challenge by developing an advanced AI-powered MCOP tailored for the Pakistani Army's Armored Corps. This MCOP utilizes open-source technologies for cost-effective development and customization, while integrating ArcGIS's robust geospatial capabilities. This integration provides decision makers with a comprehensive, dynamic battlefield overview.

1.3 Common Operating Picture for Battlefields

In war conditions, where information reigns supreme and clarity is a precious commodity, the MCOP emerges as a beacon of shared understanding, transforming the battlefield landscape from a fragmented puzzle into a unified tapestry. These optimized and intelligent evolutions of traditional Battlefield Management Systems, driven by the objectives of enhanced awareness, seamless communication, and intelligent decision-making, hold the potential to revolutionize warfare, empowering soldiers and commanders alike. Unlike traditional methods of data retrieval that rely solely on static maps, real-time information flows seamlessly through the MCOP, providing a dynamic and comprehensive operational picture. Soldiers can query data with intuitive ease, unearthing critical insights through advanced search functions in mere seconds. Detailed information on friendly forces, enemy positions, and terrain features is vividly displayed with a vast library of customizable symbols. Advanced object detection and classification algorithms act as tireless sentinels, automatically identifying and tracking enemy movements, providing commanders with an invaluable intelligence edge.

The true power of the MCOP lies in its ability to transcend individual awareness. This shared visualization, accessible to authorized personnel across various echelons, fosters unprecedented interoperability. Diverse units and command structures can exchange data and information seamlessly, ensuring everyone operates with the same up-to-date picture of the battlefield. This enhances situational awareness for every soldier, empowering them to navigate the chaos with clarity and confidence. Increased collaboration, fueled by real-time communication and decision-making across echelons, leads to faster and more effective response mechanism.

MCOP ensures that every soldier operates with the knowledge and tools they need to make informed decisions, minimizing casualties and maximizing their chances of returning home safely. It signifies a shift from individual heroism to collective brilliance, where technology acts as a force multiplier, not a replacement, paving the way for a future where information dominance translates to lives saved, missions accomplished, and a more secure world for all.

1.4 Current Manual System Used by The Army

The current system that is used in the Armor Regiment is purely mechanical and manual. The unit's Headquarter (HQ) staff maintains paper maps for planning and all possible theaters of conflict scenarios. When war does erupt, these maps are used to update plans, manage and execute armor operations. To get location of assets, the HQ staff uses the wireless set to obtain the location information and then manually adds pins and marks the paper-based maps present in the Command Headquarter. The commander then uses this updated map to give out further orders and commands. Currently, there is no use of advanced Geospatial tools and technologies in the field to help in planning and management. The paper maps offer limited visualization and map control. The location of other friendly and enemy forces is also handled manually by displaying it on the paper map at the Command HQ. Such updated information is gathered through wireless communication and is rarely ever used in plans at the speed that it can be used. Also this information is never transferred to the field commanders unless explicitly required. The status of the field assets is also gathered manually and is done so in a time consuming fashion. The fuel and ammunition count is sent manually over the wireless. Refill points and areas of safety and camouflage are pre-battle decided and cannot be changed as it is difficult to pass the changes to field commanders. Field commanders also have to rely on paper maps to navigate the battlefield. These maps are often outdated and at a very high scale to allow for good navigation.

1.5 Objectives

The limitations imposed by restricted visibility within armored vehicles pose a significant challenge. This project aims to address these limitations by “developing a next-generation AI-powered MCOP to:

a. Enhance Situational Awareness

b. Improve Navigation and Maneuvering

c. Enhance Enemy Threat Detection and Identification

d. Streamline Communication and Data Sharing

e. Optimize Battlefield Management System

with a set of well-defined objectives: the brief of these above mentioned sub objective is as follows:

1. **Enhance Situational Awareness:** The AI-powered MCOP will provide soldiers with a real-time, comprehensive view of their surroundings by integrating data from sensors, troop locations, and enemy threats, all displayed on an intuitive interface.
2. **Improve Navigation and Maneuvering:** Utilizing open-source technologies like QGIS and Leaflet, the MCOP will offer detailed digital maps and 3D visualizations, enabling effective navigation and strategic planning in complex environments.
3. **Facilitate Real-Time Blue Force Tracking:** The system will equip armored vehicles with IoT devices to track friendly forces in real time, reducing the risk of friendly fire and improving coordination on the battlefield.
4. **Enhance Enemy Threat Detection:** By leveraging AI and machine learning, the MCOP will analyze data from video feeds and other sources to automatically detect and identify enemy assets, providing early warnings to soldiers.

5. **Streamline Communication and Data Sharing:** The MCOP will serve as a central platform for real-time communication and information exchange between units, ensuring coordinated decision-making and rapid responses to battlefield developments.
6. **Optimize Battlefield Management System (BMS):** The project will build on existing BMS enhancements by:
    a. **Integrating Enhanced Maps:** Utilizing geodatabases with military, soil, trafficability, and navigation maps for a deeper operational understanding.
    b. **Updating Symbology:** Leveraging custom military symbology for clear and efficient asset marking.
    c. **Developing a Customized Toolbar:** Featuring tools like USB data loading and zoom level control to enhance operational readiness and focus on command areas.

By integrating with the already optimized BMS and leveraging its functionalities, the MCOP will provide a holistic and user-friendly platform for the Pakistani Army's Armored Corps. Soldiers will benefit from a superior level of situational awareness, improved capabilities, and ultimately, enhanced mission effectiveness.

1.6 Significance of Study

This research is pivotal as it pioneers the development of a next-generation common operating platform designed for the unpredictable and unavoidable circumstances faced by the military. Leveraging open-source technologies, it offers cost-effective and customizable solutions to enhance battlefield awareness, improve tracking and navigation of military resources, and provide a deeper understanding of enemy intent through movement pattern detection.

The study aims to create a prototype Geographical Information System (GIS) to enhance the existing decision-making system in the Armor Regiment. This system will provide improved tools and technologies, facilitating a more reliable and faster decision-making process by offering visual representation of the battlefield, locations of friendly and enemy assets, and strategic planning capabilities.

By advancing military technology, the project also stimulates local innovation and economic growth, creating job opportunities in engineering, technology, and data analysis. As future battlefields become more chaotic and complex, the need for advanced decision-making systems becomes more critical, ensuring better preparedness and response in dynamic combat environments.

1.6.1 Benefits Of Commercial IoT for Military Systems and Operations

A number of IoT-enabled military activities will be impacted by the coexistence and co-deployment of commercial and military IoT technology. This section examines the possibilities for the adoption of commercial IoT solutions in military settings and provides an overview of the state-of-the-art in order to demonstrate the effect of this revolution.

1.6.2 Object Detection Using YOLOv8 for Military Purposes:

In military operations, it is critical to quickly and accurately identify armament in order to protect soldiers and maximize mission success. These days, deep learning models have become reliable means of fulfilling item detection duties, making them invaluable tools for improving military protection. YOLOv8-Small, a more compact version of the well-known Look into the (YOLO) detection mechanism as soon as possible. The main goal of the examination is to use YOLOv8-Small's abilities for targeted weapon identification in military settings. With great care in its layout and extensive training, the suggested version proves its ability to accurately and efficiently recognize a wide variety of weapons. The trial findings demonstrate the effectiveness of YOLOv8-Small as a pressure multiplier on the battlefield and establish its capability application in supporting navy operations. Additionally, it explores the version's environmental adaptability, which is an important consideration in real-world army circumstances. The findings monitor the model's ability to keep constant performance throughout distinctive terrains, lights situations, and weather conditions. This adaptability significantly improves its operational viability and guarantees trustworthy weapon detecting abilities even in difficult situations. The findings of this study have implications for more general army tactics and procedures, wherein accurate and timely weapon identification might make all the difference in mission completion. YOLOv8-Small's capacity integration with existing military organizations shows potential for enhancing situational awareness and proactive risk reduction. In summary, our project leverages the performance and versatility of YOLOv8 to provide a groundbreaking addition to the field of weapon identification. The study's conclusions provide invaluable guidance for navy stakeholders looking for innovative ways to improve security and open the door to stronger and safer army operations.

1.6.3 Importance of terrain Military Operation:

The term "terrain" describes the overall layout of the land and is typically used to describe the slope, elevation, and feature orientation. It has an impact on weather patterns, climate, and water movement across a wide area. In the military, studying topography is crucial because it identifies places that are readily breached or through which supplies can pass freely. This information is utilized for both offensive and defensive operations. The ability of vehicles to go over a given region is determined by terrain variables. Operational planning heavily relies on precalculated traffic capabilities of military vehicles, such as tanks, etc.

Having knowledge of the geography both inside and outside of the borders is crucial for contemporary forces. For military purposes, gathering such critical data is essential. Terrain data is gathered through the use of remote sensing and photogrammetric techniques, yielding products such as DEMs, satellite photos, and vector data. After this information is obtained, it is crucial to preserve it effectively in databases. Spatial RDBMSs are widely available for storing and managing this kind of data.

Terrain Factors:

The major traffic ability factors which influence vehicle mobility are as follows:

i. Slope: Includes aspects with respect to direction of travel.
ii. Obstacle descriptions: Cross-sectional geometry; generic models acceptable.
iii. Surface materials: rocky, asphalt
iv. Soil Type
v. Soil strength: Characterized by several inter-related factors such as RCI: Remolding Cone Index, Cohesion: "C", Density, Moisture content, Freeze/thaw depths.
vi. Surface roughness.
vii. Surface slipperiness/wetness/ice/Snow.
viii. Non-woody vegetation: Vegetation with stem diameter less than 1.0 inch, includes bushes and crops.
ix. Woody vegetation.
x. Hydrology.
xi. Water Table.

i. Digital Elevation Models (DEMs)

Digital Elevation Models are a raster where each pixel contains information about a Continuous phenomenon that can be displayed in 3D. DEMs can be used to extract loT of information such as slope, aspect, depressions hills. The generalization of the digital elevation model (DEM), which attempts to shorten the time it takes to generate military passability maps (Dawid & Pokonieczny et al, 2023). The local standard deviations of the slopes in the examined region serve as the foundation for the generalization. It is assumed that the elevation points should be lowered in places with less terrain variety. This might greatly improve the process of creating military pass ability maps. The generalization was done using elevation data from LIDAR (Light Detection and Ranging), which is freely available from the Polish Head Office of Geodesy and Cartography. All elevation point coordinates (X, Y, and H) are contained in an ASCII grid file with data at a resolution of 1 meter.

ii. Digital Topographic Data

Digital topographic data are about the earth's topography contained in a digital format. As military mission planning and execution is shifting towards computer based systems, the need for digital data has increased. Topographic data includes:

i. Roads.
ii. Rail.
iii. Canals.
iv. Urban Areas.
v. Borders line.
vi. Points of Interests (Wells, Hospitals etc.).

It is however necessary that the dataset follows some requirements in terms of data consistency, interoperability, and accuracy etc.

The Engineer Topographic Laboratories (ETL) conducted a study in Vicksburg, Mississippi, USA and assessed the Digital Topographic Data (DTD) needs of the United States Army. The objective was to define Army DTD requirements for the Defense Mapping Agency (DMA). The evaluations were performed on testing the dataset to support terrain analysis, the analysis community, and existing and emerging Systems/programs covering tactical, combat modelling, simulation, training, testing, aid developmental applications. In the same study DTD requirements were defined and evaluated in terms of format, data content, resolution, accuracy and a database Specification for DTD, encompassing the requirements for terrain analysis, and other programs.

iii. Military Geographic System

One of the technologies that are used to manage all sorts of information is Geographic Information Systems (GIS). This technology links the various types of information in a computing environment to provide analyzing tools for decision makers and save their time as compared to not using a GIS. If spatial and non-spatial information are linked together with a geographic model, the use of such information and the analysis becomes easier, and the information can be used in many useful ways. A typical GIS will provide functionalities to store, query and analyze geographic information.

Liao in 2001 proposed a system architecture that basically considered the military. geographical intelligence system as a problem-solving procedure for supporting the military operations as well as the situational analysis and also generating a planning process at the tactical level.

The data collected from surveillance and reconnaissance missions can be usefully. manipulated through GIS and integration and incorporation of its tools. Attribute database, spatial database, rule base as well as knowledge repository can greatly help. for the development of a knowledge-based decision support system specially to manage the Battlefield environments. For example, it can help identify the position of targets and possible threats, the combination of such information along with terrain and other useful knowledge can help plan missions and operations and provide greater analysis capabilities.

Uses of GIS in Military:

There are many different uses of GIS in military, some of these are:

i. Command, Control, Communication, Information Operations and Intelligence Systems: The map data that the military usually maintains is used for various purposes and functional applications at military CCIS systems. All of these systems rely on locational information and maps; thus they make use of GIS.
ii. Unit/Troop Tracking Systems (GPS): The units, organizations and even troops are tracked via GPS embedded equipment on different levels of maps.

iii. Intelligence and Operations systems: For intelligence systems, it is required that the information should be collected from maps that are current and have detailed topographic and cultural information. The currency of information is of prime importance, together with the ability to associate the information within an appropriate position referencing system. Where possible, maps are supported by photographic or other imagery. In other words, the most up-to-date geographic information is essential, together with the ability to relate it back to the standard products used by the operators. The requirement for military operations is that detailed map and chart information be available, in sufficient quantities, for all forces concerned. These maps and charts must be current, contain standard navigation and position information (in the form of a grid or graticule) plus detailed topographic and hydro graphic information. Interoperability and standardization of information is of prime importance.

iv. Logistic Information Systems: Such information systems require such capabilities like route definitions, distribution models, shortest path analysis, query and display of the facilities and logistic infrastructure and other related issues that assist in planning for logistics. These fundamental capabilities are provided by GIS Logistic Information Systems.

v. Electronic Warfare Systems: All electronic warfare systems require terrain data either for analysis or for display.

vi. Radar Coverage and Frequency Analyses Systems: For the site selection of the radars and radio antennas, coverage area analysis, propagation analysis, weapon and or missile corridors, flight corridors etc. are analyzed and displayed via GIS tools.

vii. Common Operational Picture (COP), Land/Maritime/Air Recognized Picture: This is totally a new concept in GIS.

viii. 3D Terrain Modelling, Drape and Fly through Systems: It is important to model the terrain and evaluate it before the operation. Draping of various accurate maps and imagery on the terrain also is very helpful for intelligence. This technology is also used for flight simulation.

Military Map Browsing Systems: Together with the central use of GIS data, increase in the performance of GIS data usage with multi-user environment, it has been very popular to browse the maps on the web. As mentioned above the maps are very intensively used for various purposes and the high performance access to the maps is very important now with easy to use browsing capabilities.

iv. Vehicle Performance

Vehicle e Performance in this context is defined as the speed, power, durability and capabilities of land vehicles with regards to terrain, slope, vegetation, etc.

- **MODSAF/SIMNET Vehicle Performance**

Modular Semi-Automated Forces MODSAF and Simulation Network SIMNET are military training and analysis simulation systems that are mainly used for vehicle performance evaluation. MODSAF provides a framework simulating military operations that gives a clear basis for integrating different platforms and systems. This makes any training scenario seemingly real by creating an illusion of units' behavior in a virtual environment. On the other side, SIMNET is a networked simulation system that interconnects a series of simulators and provides large-scale exercises in joint training. All things considered regarding performance of vehicles, MODSAF, similar to the example of SIMNET, brings out the ableness for military planners and analysts to examine performance of various types of vehicles under different conditions pertaining to speed, maneuverability, and operational effectiveness in combat scenarios. They include optimization of missions in vehicle design, improvement of tactics, enhancement of mission effectiveness, and overall improvement with the consideration of valuable input data and techniques for modeling in real-time simulation. This in turn informs better decisions and resource allocation in the military operations. (DTIC.milt)

1.7 Military And Defense Symbology

A military symbol is a graphic representation of units, equipment, installations, control measures, and other elements relevant to military operations. As a part of doctrine, these symbols provide a common visual language for all users.

- **Allied Procedural Publication 6A (APP-6A)**

This is a North Atlantic Treaty Organization (NATO) defined military symbology. APP-6A recognizes five broad sets of symbols, each set using its own SIDC (Symbol identification coding) scheme:

i. Units, Equipment, and Installations.
ii. Military Operations (Tactical graphics).
iii. METOC (Meteorological and Oceanographic).
iv. Signals Intelligence.
v. MOOTW (Military Operations Other Than War).

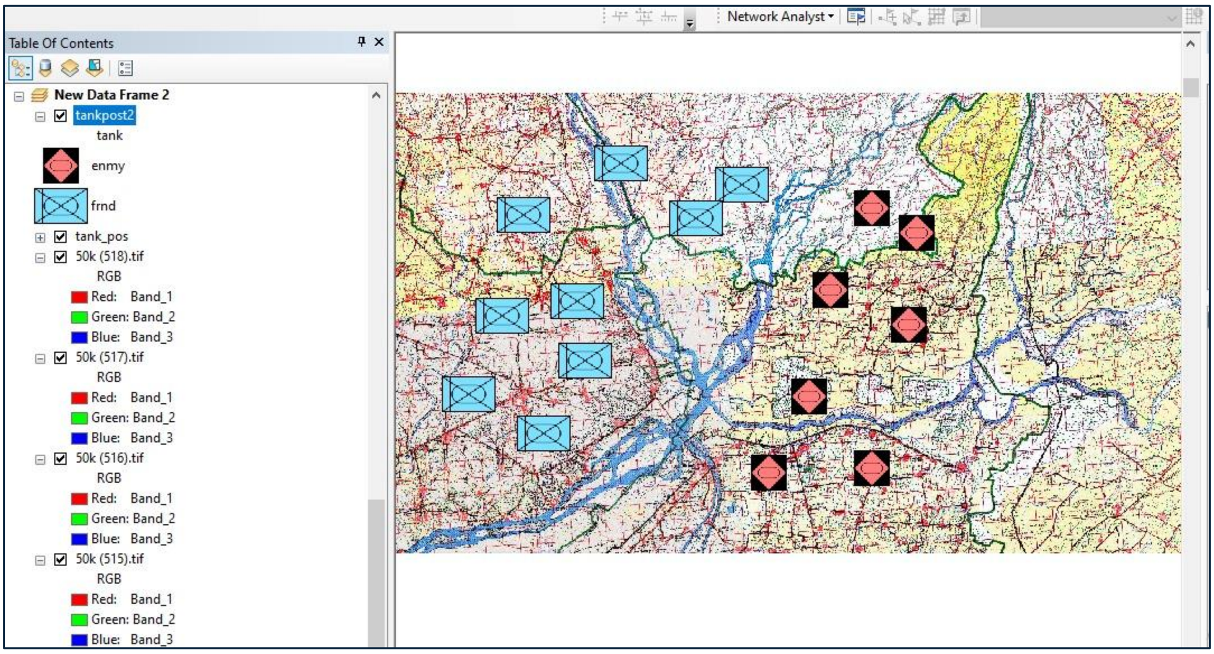


Figure 1: Military Symbology Shown on Military Map

1.8 Tactical Assault Kit

Indeed, the TAK (Tactical Assault Kit) component plays a pivotal role in enabling real-time tracking of both friendly and enemy positions on the battlefield. This capability is crucial for facilitating dynamic collaboration among military units and providing commanders with up-to-date information for informed decision-making. By integrating TAK into the Military Geographic Information System (MGIS), commanders gain enhanced situational awareness, allowing them to monitor troop movements, identify potential threats, and coordinate tactical maneuvers more effectively. Additionally, TAK enables seamless communication and data sharing among military personnel, fostering a cohesive and synchronized approach to mission execution. Overall, the integration of TAK enhances the operational capabilities of the user, enabling them to adapt and respond swiftly to changing battlefield conditions.

Figure 2: Tactical Assault kit

1.9 Rehbar Integrated Battlefield Management System (IBMS)

This system is developed for the user, installed in tanks and used to track friendly and enemy positions similar to that of US Army's Blue Force Tracking. The Al-Sakb, Al-Khalid and Al-Zarrar tanks are being equipped with this system. It allows the vehicles to work together and plan attacks and other battlefield movements, the vehicles exchange information for this purpose. IBMS uses VHF and UHF communications, and each vehicle can act as a relay.

2. LIETRATURE REVIEW

This section of the document will provide details of similar projects or works being carried out in other armies of the world. It should be noted here that most of the data and papers on military applications of GIS and geospatial tools and technologies are kept secret by the armies, this results in a shortage of available literature on how to develop such a system. The research work done in the military domains is not published due to reasons which makes it difficult to know about technologies being used by different military organizations and what future areas are being explored. As far as the project and use of geospatial technologies is concerned, publicly available literature is usually in a very basic form. The establishment of such a basic form of GIS and use of geospatial technology is merely an advancement of the GIS used for civilian purposes. Armies in different parts of world are using much more complex GI Systems for operational planning and their efficient execution. Different software companies especially those working in the geospatial domain though usually extend their research from the civil to military domain to attract more clients e.g. ArcGIS military analyst. Such companies usually publish their research in different journals to attract military clients and this research is extensively covered in the literature review. For the purpose of this literature review, the papers which have contributed usually come from the domain of research of Geospatial software companies rather than the military itself.

2.1 Situational Awareness

The observation of environmental factors within a volume of time and space, the understanding of their semantics, and the projection of their state in the near future are all considered components of situation awareness, or SA. Furthermore, situation awareness is closely related to environment perception, which is crucial for decision-makers in intricate, dynamic systems like military command and control. As previously said, situation awareness is attained by C4I system functionality. Advanced technologies for data collection, data mining, and decision support processes enable the creation of data sets that paint a picture of the current fighting zone.

One of the main causes of mission failure has been recognized as human mistake, specifically the lack of recent situation awareness or insufficient information. The concept that is being presented is significant in fields where the flow of data and information might result in major repercussions (force losses) due to poor (inadequate) decision-making.

2.2 Geo-Intelligence

Effective networked mechanisms: enhancing information exchange and data flow in the battlespace across all organizations operating within the operational scope while taking efficiency and security constraints into account, Improved data availability and quality through information sharing leads to a broader understanding of scenarios and faster, more accurate development of situational awareness. Shared situational awareness involves customized, non-retrained data sharing among all scenario participants. Processes improve operational synchronization between sensors, actors, and command centers by enabling and guaranteeing collaboration (data sharing). This lowers communication delays, which speeds up decision-making and boosts mission efficiency.

2.3 Realized Positioning Techniques in Defense Intelligence:

The integration of GPS, 2G and beyond mobile networks, RFID, and GIS offers a robust toolkit for defense and intelligence operations. These technologies, whether used individually or in combination, provide critical location-based information essential for strategic decision-making. From precise coordinates to nearest transmission stations, they offer diverse data relevant to both outdoor and indoor environments. Spatial data visualization through GIS enhances situational awareness and aids in gaining tactical advantages. Defense strategies have long emphasized the importance of positioning techniques, now amplified by digital advancements. Automation underscores the need for accurate spatial awareness to achieve military objectives and ensure national security.

2.4 YOLOv8 for Military Object Detections

Due to the excellent performance and advanced features of the YOLOv8 model, it is applied in military object detection scenarios. For instance, UAV-YOLOv8, a variant of YOLOv8, enhanced the quality of detection of small objects in aerial images by proposing a fast feature processing module called FFNB and a dynamic sparse attention mechanism called BiFormer within the backbone network in 2023. It improves the model's attention to crucial information, optimizes the performance of small object detection, and reduces the missing detection rate.

Modified 2023 YOLOv8 detection network for UAV aerial image recognition, incorporating a Bi-PAN-FPN concept and optimizing the backbone network and loss function, enhances the ability to detect small targets. The approach reduces parameters but remains highly accurate and solves the problem of far-distance information loss; anchor balancing during prediction is predicted (Wang & Huang, et al 2023). Improvements to YOLOv8 have been on the frontline towards enhancing the performance of these models for military applications in the way they recognize and track different objects effectively and efficiently.

2.5 Recognized Operational and Utility Pictures:

1. Recognized Air Picture (RAP) – containing all available objects within particular airspace supplemented with affiliation, type, evidential records and performed tasks.
2. Recognized Maritime Picture (RMP) – describing all relevant and available maritime objects within defined naval area supplemented with object features, conducted tasks and activities.
3. RGP (Recognized Ground Picture) – containing all available objects (installations, units, warfare, obstacles) within particular area supplemented with affiliation, type, evidential records and tasks, operational responsibilities, etc.
4. Recognized Logistics Picture (RLP) – defining, underlining available aspects of logistics operations supporting all battlespace domains.
5. Recognized Cyberspace Picture (RCP) – combining available data describing cyber and info space with regard to communication networks, protocols and systems.
6. Results of decision support algorithms – for environment (e.g. terrain) and operational elements characteristics evaluation – enriching the overall picture and supplementing SA.

The major difficulty while designing unified COP rendering environment comes from the specificity of graphical (symbols) elements and background GIS information. The geoinformation varies depending on the battlespace dimension or in case of cyberspace even limits such relationship (Bélanger & Allouche, et al 2017).

2.6 Joint Battle Command Platform

Ihe U.S. Army and Marine Corps are developing next-generation observational software for an army of platforms, including handheld devices under the program of Joint Battle

Command-Platform. "In o an effort to improve situational awareness down to the squad leader level, the U.S. Marines Corps and Army intend to provide the next-generation situational awareness software on ruggedized handheld platforms similar to smart phones or personal digital assistants." (Guyan, 2010).

It is extremely important that a commander both in the field and at headquarters be aware of how the situation is developing around them. This awareness of ones surrounding can be critical to the success on the battlefield and can make or break an operation. The information has to be timely and precise.

"Finally, we design a feature processing module named Focal FasterNet block (FFNB) and propose two new detection scales based on this which makes the shallow features and deep features fully integrated. The proposed multiscale feature fusion network substantially increased the detection performance of the model and reduces the missed detection rate of small objects." (Wang et al. (2023).

According to (Guyan, 2010), the technology and software have now gotten to the development level where they can be employed in military applications because they possess the processing power and communication protocols to function successfully in the battlefield.

"The Recognized Maritime Picture (RMP) is essential for naval command-and-control, integrating data from multiple sources such as The Automatic Identification System (AIS), ship- and shore-based radar, and remote sensors." (Wang et al., 2023).

As stated above, it has now become feasible to use hardware and software tools with the assets in order to incorporate e it into a network of fighting nodes which can then be commanded and controlled.

2.7 IoTs in Military Common Operating Picture:

Several facets of military operations will be profoundly impacted by the broad use of IoT technology. Thanks to capillary and high density personal and environment sensor systems, an increasing number of battlefield assets will soon become networked entities. The precise and detailed data collected may be highly advantageous for automated supply chain logistics, urban operations in mega-city settings, and military intelligence, surveillance, and reconnaissance activities. Research must address a number of issues in order to meet these objectives, including resolving discrepancies between military and commercial IoT architectural patterns, ensuring interoperability across various IoT systems, handling data and information management, and realizing resource efficient IoT middleware solutions.

IoT development has been further spurred by recent advancements in miniaturization, Radio Frequency Identification (RFID), low power computing, and machine-to-machine communications. The commercial and industrial sectors have already given the area a great deal of attention. IoT is a mostly commercial technology, although its advancements fall under the more general topics of embedded computing and cyber-physical systems, and they are beneficial to the military. But because of its ties to commercial and industrial partners and processes, the military will be more and more impacted by developments in commercial IoT. (Li, S., 2024)

We anticipate that the military will be greatly impacted by the IoT's widespread adoption in at least four important areas:

1. New platforms for sensing and computing that are integrated into military operations.
2. Developments in the underlying IoT enablers.
3. Accessibility to a greater amount of information.
4. Modifications to doctrine concerning the availability and capabilities of IoT.

3. MATERIALS AND METHODS

Methodology flow chart

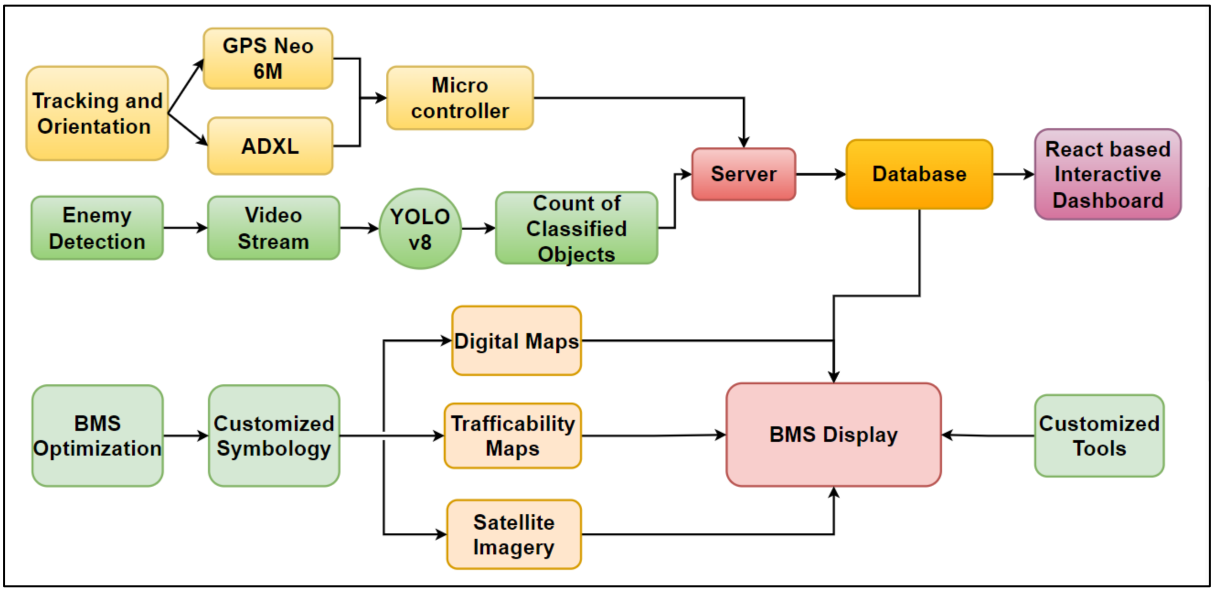


Figure 3: Methodology Flow chart

This project has taken a comprehensive and multifaceted approach to develop a next-generation AI-powered Military Common Operating Picture (MCOP) specifically designed for the Pakistan's Army's Armored Corps. Here's a breakdown of the key methodologies employed:

1. **Integration of Open-Source Technologies:**
   a. To ensure cost-effectiveness and foster future customization, the project leveraged open-source technologies for core functionalities. This involved the selection and integration of well-established open-source libraries and frameworks tailored to meet the specific needs of the MCOP.

b. A meticulous evaluation process was undertaken to identify open-source solutions that met stringent security requirements for military applications. This ensures the integrity and reliability of the MCOP while remaining cost-effective.

2. Optimizing the Existing Battlefield Management System (BMS):

a. The project acknowledged the advancements already made to the Pakistani Army's Armored Corps BMS. The MCOP seamlessly integrates with the optimized BMS, leveraging its existing functionalities for a more holistic solution.

b. Integration with the existing geodatabases within the BMS allows the MCOP to utilize comprehensive map layers, including military overlays, soil data, trafficability information, and navigation maps. This provides soldiers with a deeper understanding of the operational environment.

c. The MCOP capitalizes on the custom symbology already implemented within the BMS. This standardized symbology facilitates rapid identification of friendly and enemy assets on the digital map, promoting efficient communication and decision-making.

3. Development of a Customized User Interface (UI):

a. A user-friendly UI was developed specifically for the MCOP, ensuring soldiers can access and interact with critical information intuitively. This interface is optimized for use within armored vehicles, considering the limitations of space and visibility.

b. The UI is integrated seamlessly with existing BMS functionalities and display information from various sources, including real-time sensor data, AI-powered threat detection, and friendly troop locations. This centralized platform streamlines information access and fosters situational awareness.

4. Integration of AI and Machine Learning:

Artificial intelligence (AI) and machine learning algorithms play a pivotal role in the MCOP. These algorithms is trained on real-world data to perform tasks such as:

a. Enemy Threat Detection: By analyzing video feeds from cameras mounted on armored vehicles, AI systems will automatically identify enemy vehicles, personnel, and equipment. This provides early warnings of potential threats, giving soldiers a critical advantage on the battlefield.

b. **Real-Time Blue Force Tracking:** Data from ADXL, GPS and NodeMCU Microcontroller (ESP8266) are the devices mounted on armored vehicles will be fed into the AI algorithms, enabling real-time tracking of friendly troop locations. This minimizes the risk of friendly fire incidents and fosters improved coordination.

5. **Rigorous Testing and Evaluation:**
   a. The developed MCOP is rigorously tested and evaluated to ensure that it meets the specific needs and operational requirements of the Pakistani Army's Armored Corps. This testing will involve simulations, field trials, and soldier feedback.
   b. The project team is committed to continuous improvement and will refine the MCOP based on the gathered feedback. This iterative approach ensures the final product is a reliable and effective tool for soldiers on the battlefield.

By employing this multifaceted methodology, the project has developed an MCOP that addresses the critical challenges faced by the Pakistani Army's Armored Corps due to limited visibility. The integration of open-source technologies, ArcGIS, AI, and a user-friendly UI will empower soldiers with superior situational awareness, enhanced communication, and ultimately, a significant advantage in safeguarding Pakistan's borders.

3.1 Optimizing The Battlefield Management System (BMS) For Enhanced Integration with the MCOP

The project recognized the crucial foundation laid by the Pakistani Army's existing Battlefield Management System (BMS). However, to fully unlock the potential of the new Military Common Operating Picture (MCOP) and provide soldiers with a seamless information experience, several optimizations were implemented within the BMS framework.

3.1.1 Enriching the Geospatial Landscape: Integration of Enhanced Maps

One key optimization involved the integration of enhanced maps within the BMS. Existing geodatabases, meticulously maintained by the Pakistani Army, were leveraged to create a comprehensive set of digital maps. These maps go beyond basic terrain representations. They incorporate a rich tapestry of information layers critical for battlefield decision-making. This includes:

1. **Military Overlays:** These overlays provide crucial information about friendly troop locations, enemy dispositions, and designated areas of operation. By visualizing this data on the digital maps, soldiers gain a clear understanding of the overall tactical situation.
2. **Soil Data:** This layer provides detailed information about the composition and characteristics of the terrain. This is vital for assessing vehicle maneuverability, particularly in challenging environments like deserts or mudflats.
3. **Trafficability Information:** This layer indicates the ease or difficulty with which different terrains can be traversed by armored vehicles. With this information readily available, commanders can plan routes that optimize speed and minimize the risk of getting bogged down.
4. **Navigation Maps:** These detailed maps provide soldiers with clear guidance for navigating complex environments. They can be layered with other information, such as enemy positions and friendly troop locations, to create a comprehensive picture that facilitates efficient movement.

The hierarchical organization of these map layers within the BMS ensures soldiers can access the specific data they need quickly and efficiently. This reduces cognitive overload and allows them to focus on the critical tasks at hand.

3.1.2 Standardization and Clarity: Updated and Customized Symbology

Building upon the existing strengths of the BMS, the project capitalized on the custom symbology developed by the Pakistani Army. This symbology offers a standardized set of symbols for representing friendly and enemy assets on the digital map. Each symbol is carefully designed to be easily recognizable, even in situations with limited visibility. This standardization facilitates rapid identification and clear communication between soldiers.

Everyone on the battlefield has a shared understanding of the symbols, ensuring a unified response to evolving situations.

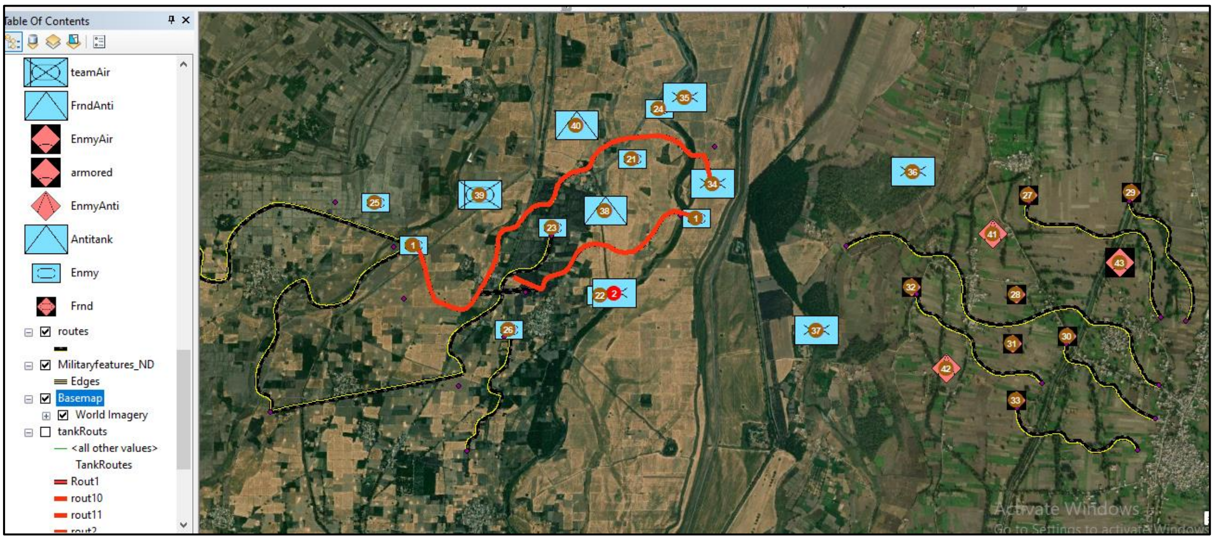


Figure 4: Custom Symbology with Adjusted Scale

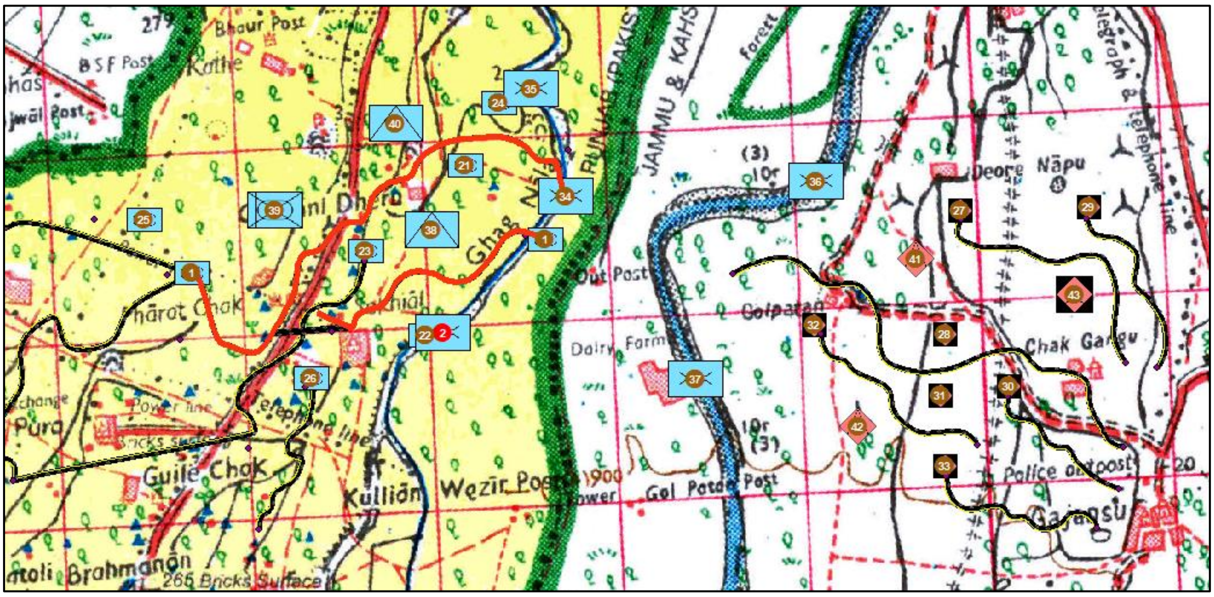


Figure 5: Custom Symbology on Military Maps

3.1.3 Tailored Functionality: Development of a Customized Toolbar

Recognizing the specific needs of the Pakistani Army's Armored Corps, a customized toolbar is being developed using the ArcGIS Add-in Python Wizard. This toolbar goes beyond the standard functionalities offered by ArcGIS, providing features specifically tailored for military operations which include:

1. **USB Data Loading Tool:** This innovative tool streamlines data access in the field. Soldiers can seamlessly load critical data from a USB drive directly into the ArcGIS environment within the MCOP. This eliminates the need for complex data transfer procedures and ensures soldiers have access to the latest information, even in remote locations or situations with limited internet connectivity.

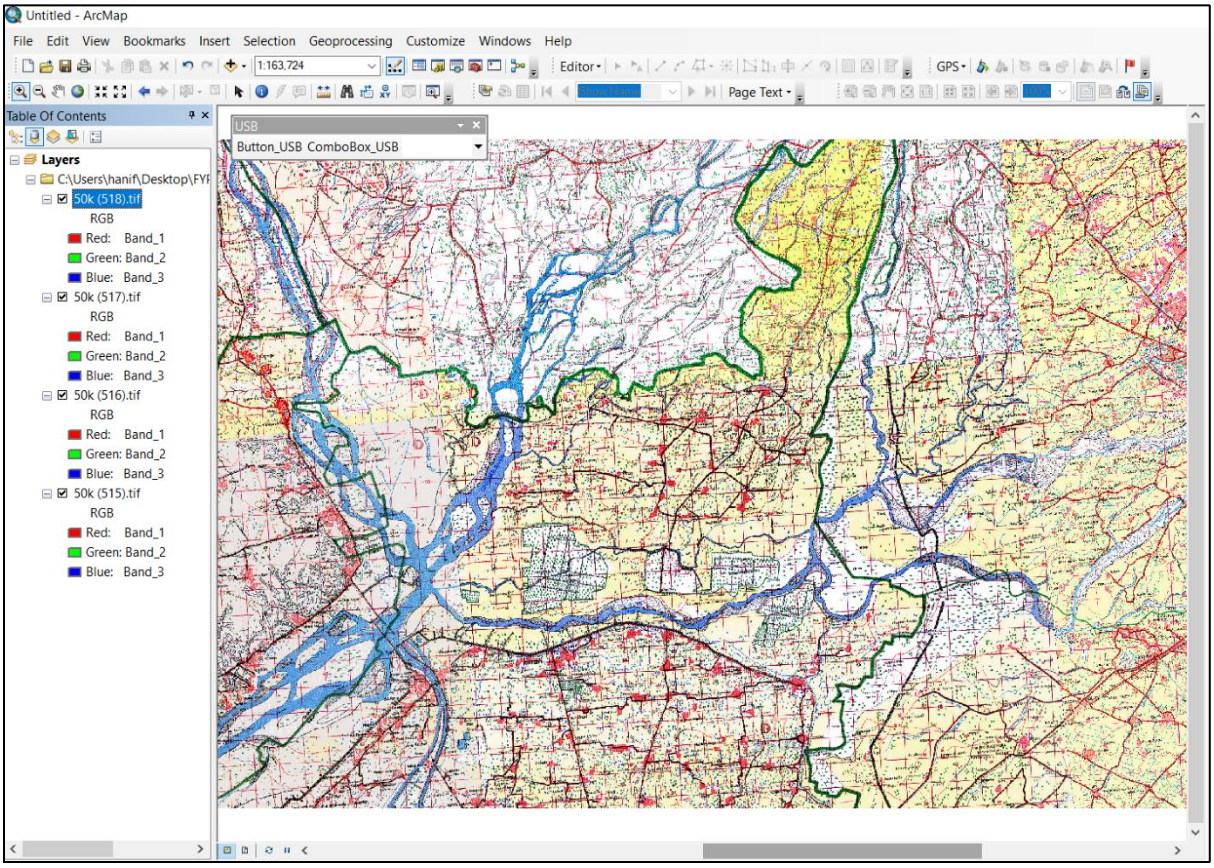


Figure 6: Adding data on ArcMap directly through USB Tool

2. **Zoom Level Control for Commanders:** This empowering feature allows commanders to set and maintain specific zoom levels within the MCOP. This ensures they can focus on their assigned area of command (brigade or regiment) with optimal detail. By having a clear view of their operational zone, commanders can make informed decisions and effectively coordinate their troops.

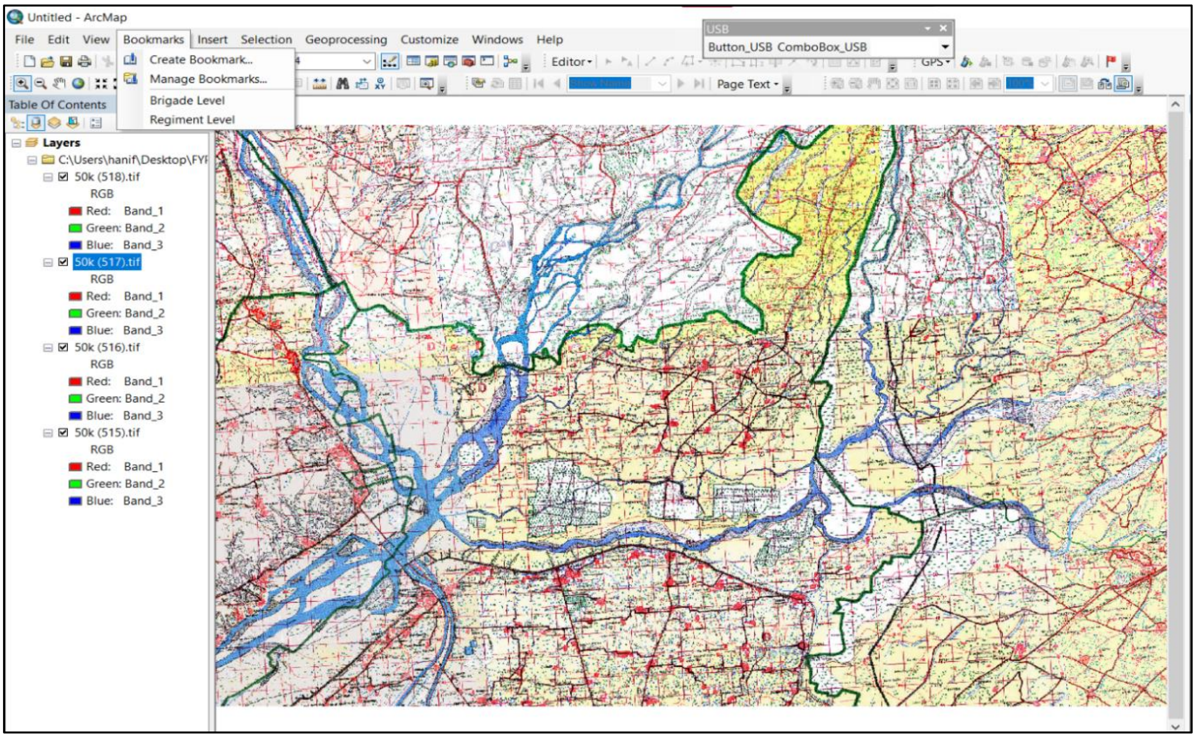


Figure 7: Customized Scale Tool for Brigade commander

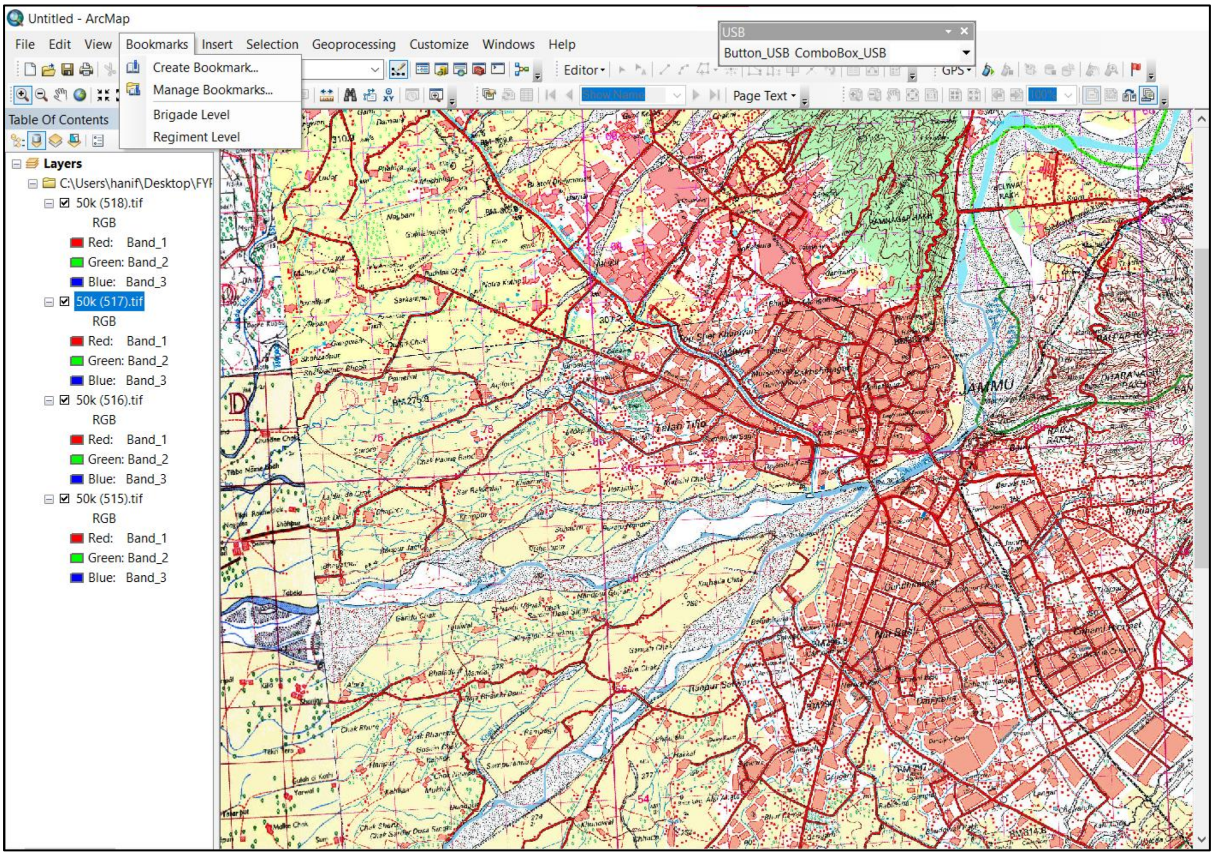


Figure 8: Customized Scale Tool for Regiment Command

These optimizations to the BMS, coupled with the advanced functionalities of the new MCOP, represent a significant leap forward in battlefield information management for the Pakistani Army's Armored Corps.

3.2 Blue force Tracking

Blue force tracking is a system used to track friendly forces. It uses sensors to track the movement of soldiers and other military personnel. The data is then transmitted to a server where it's stored in a database and visualized on a web map.

Here's a step-by-step breakdown of how blue force tracking works:

These sensors are attached to soldiers and vehicles, showing the prime role in taking readings with respect to their position and condition in real-time. It includes data related to the GPS coordinates and orientation information along the x, y, and z axes. It is, therefore, obvious that the sensed data would be transmitted from the sensor to the server via an IoT device, ensuring information reception within the timeframe. Upon reception of this data by the server, it is stored in the hosted database for future analysis and retrievals. The data is, therefore, put on a web map to facilitate effective decision-making that can be accessed by commanders and whoever needs it. This would help them view in real-time the location and status of their forces, greatly improving situational awareness and operational effectiveness in the field.

Blue force tracking can be used for a variety of purposes, including:

BFT offers a great number of advantages to military operations in terms of raising situational awareness, improving safety, better coordination, and optimizing logistics. BFT provides the real-time visibility of troops' locations; the commanders can now make knowledgeable decisions about force deployment, thereby drastically reducing the risk of friendly fire incidents. Friendly force identification on the battlefield is also clearly identified, which contributes to improved safety in general since soldiers can recognize their fellow comrades to avoid misidentification with possible threats. In addition, BFT enhances coordination between different units due to the fact that commanders may track the movement of their forces to ensure planning and performance of operations that are much more effective and coordinated with each other. Besides personnel tracking, BFT can also be used for supply and equipment movement, thereby optimizing the logistics function to ensure that resources get to the right places at the right time.

Further considerations

i. The impact of Blue Force Tracking on military operations

ii. The cost of implementing and maintaining Blue Force Tracking systems

iii. The potential for Blue Force Tracking technology to be adapted for civilian use

3.2.1 Development of our IOT Device for blue force tracking

The device is designed to track the location and orientation of friendly forces and transmit that data to a central server and stored it in the PostgreSQL database which is hosted on AWS cloud. The data can then be displayed on a web dashboard that can be accessed by commanders and other authorized personnel. This can help to improve situational awareness, reduce the risk of friendly fire, and improve coordination between different units.

3.2.2 Device Components

The device is comprised of the following key components:

i. ADXL345 Accelerometer: This sensor is used to determine the orientation of the device along the x, y, and z axes. This data can be used to track the movement of the device, such as whether it is stationary, moving, or accelerating.

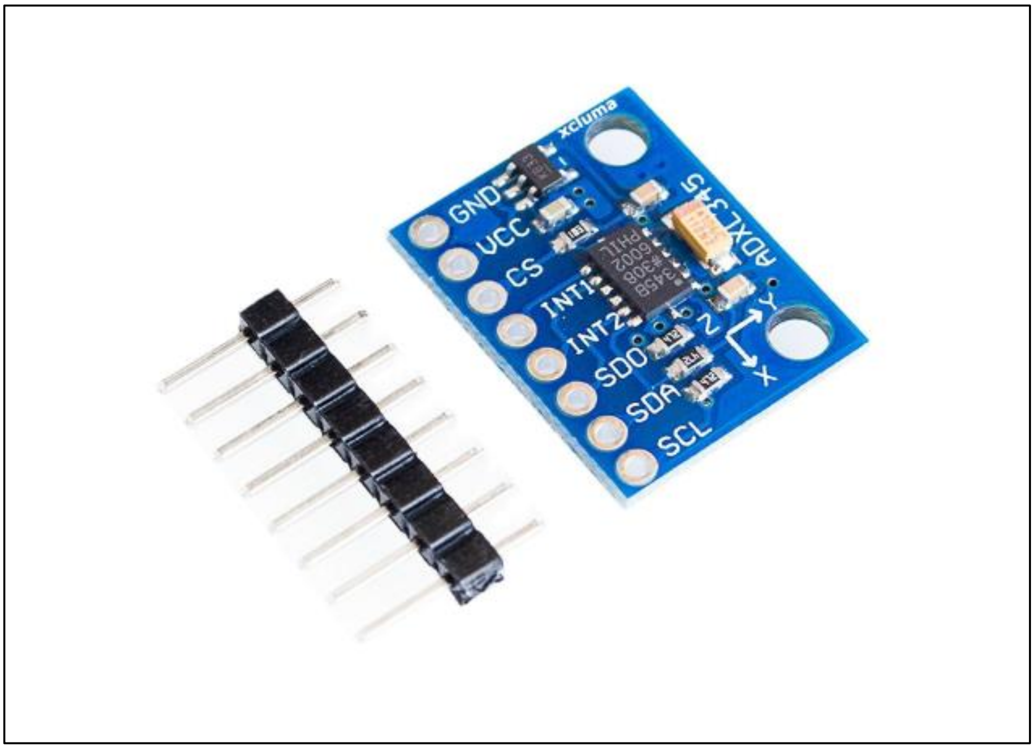


Figure 9: Adxl345 accelerometer

ii. **GPS Module:** This module receives signals from GPS satellites to determine the device's latitude and longitude coordinates. This data is essential for tracking the location of the device.

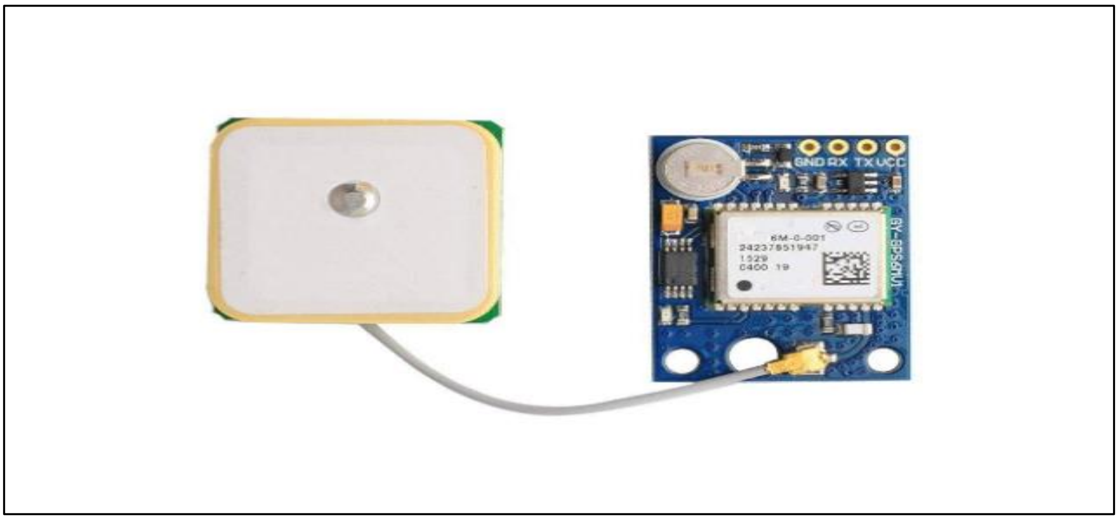


Figure 10: GPS

iii. **Microcontroller (ESP8266):** This programmable chip collects data from the accelerometer and GPS module and transmits it to a central server via a cellular or Wi-Fi network. It also manages the power consumption of the device.

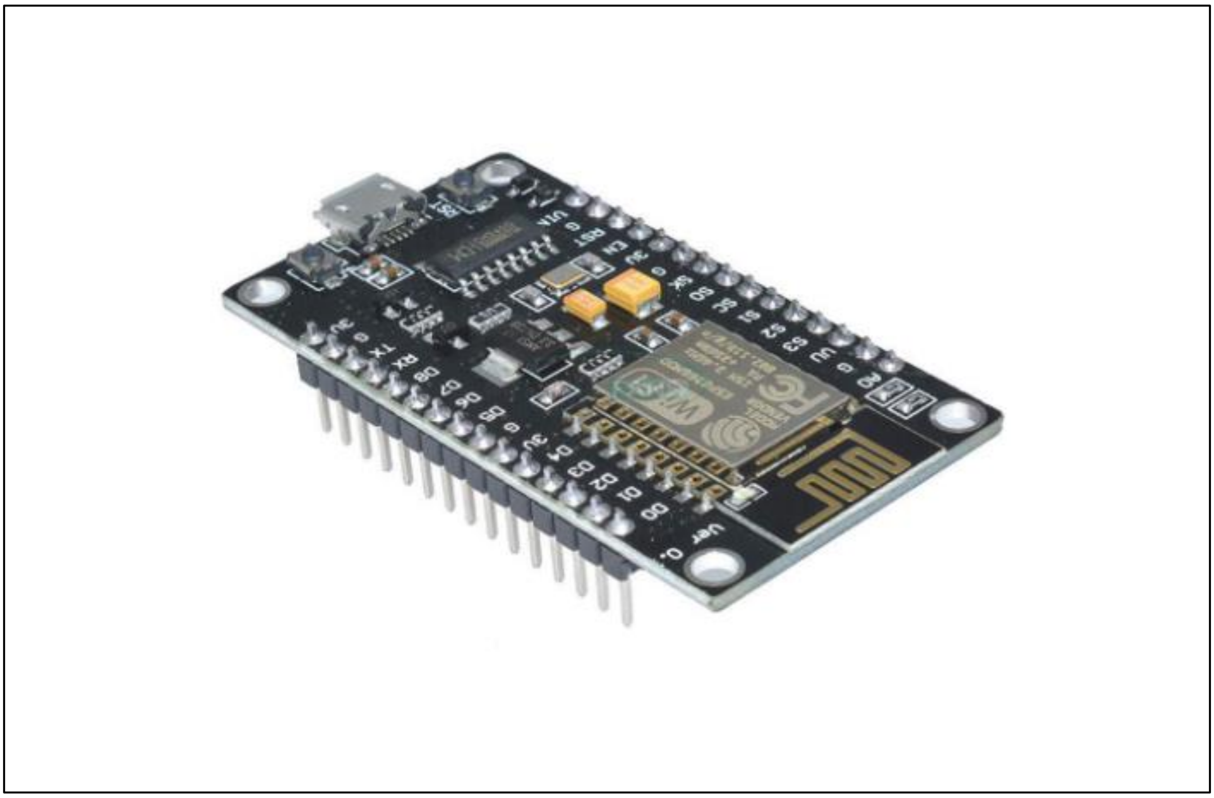


Figure 11: NodeMCU microcontroller

iv. **Power Supply:** This component provides power to the other components of the device. It can be a battery or an external power source.

3.2.3 Functionality of Device

The device operates as follows:

The GPS module continuously collects location data from GPS satellites.

1. The ADXL345 accelerometer collects data on the device's orientation and movement.
2. The microcontroller collects data from both sensors and formats it for transmission.
3. The microcontroller transmits the data to a central server via a cellular or Wi-Fi network at regular intervals.

4. The central server stores the data and makes it available to authorized personnel on a map display.

3.2.4 Benefits of Device

The device offers several benefits for Blue Force Tracking applications:

i. **Compact and Portable:** The device is small and lightweight, making it easy for soldiers to carry.

ii. **Low Power Consumption:** The device is designed to be energy-efficient, which means it can operate for long periods on a single battery charge.

iii. **Durable Construction:** The device is built to withstand the harsh conditions of military operations.

iv. **Accurate Tracking:** The combination of GPS and accelerometer data provides accurate and reliable tracking of the device's location and movement.

v. **Secure Communication:** The device can be configured to use secure communication protocols to protect the confidentiality of the data being transmitted.

3.2.5 Application of the Device

The device can be used in a variety of Blue Force Tracking applications. It is capable of tracking the location of individual soldiers or units, allowing commanders to monitor their precise positions on the battlefield. Additionally, it enables real-time monitoring of the movement of friendly forces, ensuring that commanders have up-to-date information on troop movements and deployments. This real-time tracking capability is crucial for identifying potential friendly fire incidents, as it provides clear and accurate data on the positions and movements of all friendly units. The device also plays a key role in coordinating the movement of troops on the battlefield, facilitating better synchronization and execution of tactical maneuvers. Furthermore, it provides situational awareness to commanders by offering a comprehensive view of the battlefield, including the positions and movements of all friendly forces. This situational awareness is essential for making informed decisions and responding effectively to changing battlefield conditions.

The Blue Force Tracking device developed is a valuable tool that can improve situational awareness, reduce the risk of friendly fire, and improve coordination between different units. The device is compact, portable, and energy-efficient, and it provides accurate and reliable tracking of the device's location and movement. The device has a wide range of applications in military operations.

3.2.6 Future Considerations

Future improvements for the device include several key areas. Integration with other military systems, such as communication systems and command and control systems, would allow for a more comprehensive view of the battlefield situation, enhancing overall situational awareness and coordination. Additionally, the security of the device could be further enhanced by employing more advanced encryption techniques and authentication protocols, ensuring the confidentiality and integrity of the transmitted data. The battery life of the device could be extended by utilizing more energy-efficient components and optimizing the power consumption of the device software, allowing for longer operational periods in the field. Furthermore, the device could be miniaturized even further, making it more portable and easier for soldiers to carry, thus improving its practicality and ease of use in various operational scenarios.

3.2.7 Data Pipeline for Web-Based Blue Force Tracking

The data pipeline for the web-based Blue Force Tracking (BFT) system is designed to collect data from sensors deployed with assets on the field and display it on a web mapping dashboard accessible to commanders and other authorized personnel.

3.2.8 Data Pipeline Overview

The data pipeline for Blue Force Tracking consists of several stages. First, data collection occurs as sensor data is gathered from devices carried by soldiers on the ground. These devices typically include a GPS module for location data and an accelerometer for movement data. Next, the collected sensor data is transmitted to a central server via cellular, Wi-Fi, or satellite networks. Once the data reaches the central server, it undergoes processing and formatting, which involves filtering out errors, correcting inaccuracies, and combining data from multiple sensors to ensure accuracy and reliability. The processed data is then stored in a database, making it accessible for future queries. Finally, data visualization takes place as a web mapping application retrieves the data from the database and displays it on a map. This map can be enhanced with various features such as terrain data, imagery, and symbols representing friendly forces. Users can interact with the map by zooming in and out, panning around, and viewing different map layers, providing a comprehensive and dynamic view of the battlefield situation.

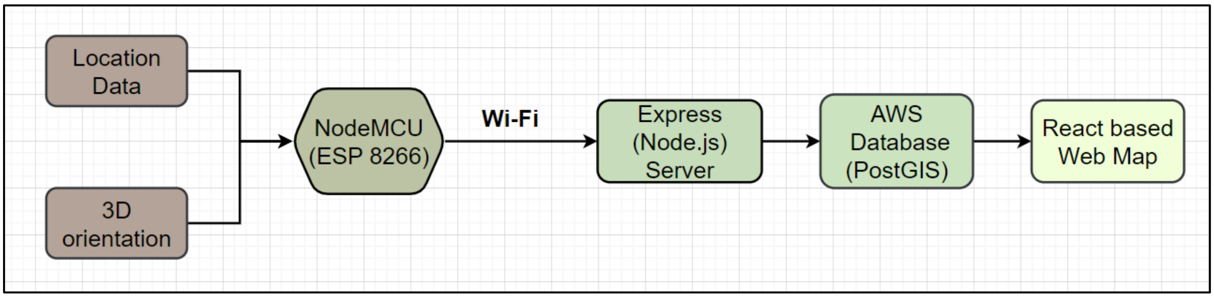


Figure 12: Data Pipeline: From Sensors to Web Map

i. Data Collection Devices

The data collection stage is performed by Blue Force Tracking devices carried by soldier’s vehicles on the ground.

components:

i. **Microcontroller (NodeMCU ESP8266):** This programmable chip collects data from the other sensors and transmits it to a central server via a cellular or Wi-Fi network. It also manages the power consumption of the device.

ii. **GPS Module (GPS Neo 6M):** This module receives signals from GPS satellites to determine the device's latitude and longitude coordinates.

iii. **Accelerometer (ADXL345):** This sensor is used to determine the orientation of the device along the x, y, and z axes. This data can be used to track the movement of the device, such as whether it is stationary, moving, or accelerating.

iv. **Power Supply (AA Battery):** This component provides power to the other components of the device.

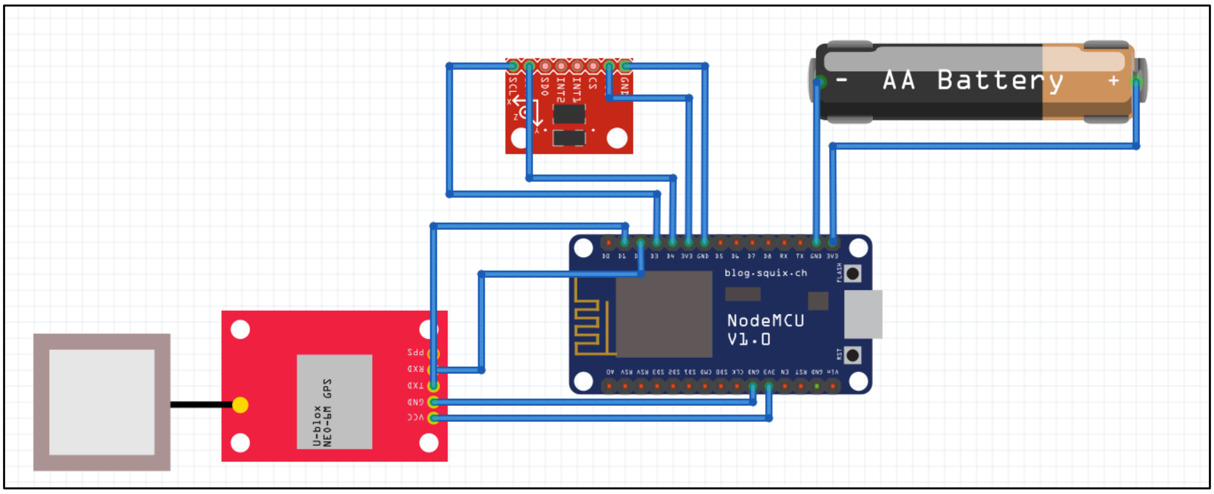


Figure 13: IOT Device for blue force tracking

ii. Data Transmission

The data collected from the Blue Force Tracking devices is transmitted to a central server. The method of transmission will depend on the capabilities of the devices and the available infrastructure. Some common options include:

i. **Cellular Network:** Cellular networks provide a wide-area coverage for data transmission. However, they may not be available in all areas, and they can be expensive to operate.

ii. **Wi-Fi Network:** Wi-Fi networks can provide high-speed data transmission over a short range. However, they are limited to areas with Wi-Fi coverage.

iii. **Satellite Network:** Satellite networks can provide data transmission from almost anywhere on the globe. However, they can be expensive to operate and may have latency issues.

iv. **Software-Defined Radio (SDR):** In scenarios where traditional networks are unavailable, SDRs are employed for data transmission. SDRs are versatile and can adapt to various frequencies and protocols, making them ideal for use in war zones where network infrastructure is compromised or nonexistent. Their flexibility allows for reliable communication in challenging environments, ensuring that critical data reaches the central server.

iii. Data Processing and Storage

Once the sensor data is received by the central server, it undergoes a series of processing and formatting steps. This process includes error correction, where data processing algorithms identify and rectify errors caused by factors such as noise, interference, or malfunctioning sensors. Data filtering is also performed to eliminate extraneous information that is not relevant to Blue Force Tracking (BFT) applications, ensuring that only necessary data is retained. Additionally, data aggregation is carried out to combine information from multiple sensors, providing a more comprehensive view of the battlefield. For instance, GPS data can be integrated with accelerometer data to discern whether a friendly force is stationary, moving, or engaged in combat. Following these processing steps, the refined data is stored in a database, which can then be queried by the web mapping application to access the most current location and movement information of friendly forces. The processed data is then stored in a database. This database can be queried by the web mapping application to retrieve the latest location and movement data for friendly forces.

3.2.9 Web Dashboard for visualization of Data

The web dashboard provides a user-friendly interface for visualizing real-time blue force tracking data.

i. **Map View:** The map view displays the real-time location of friendly forces as icons or symbols on a digital map. This allows commanders to see the overall disposition of their troops and track their movements.

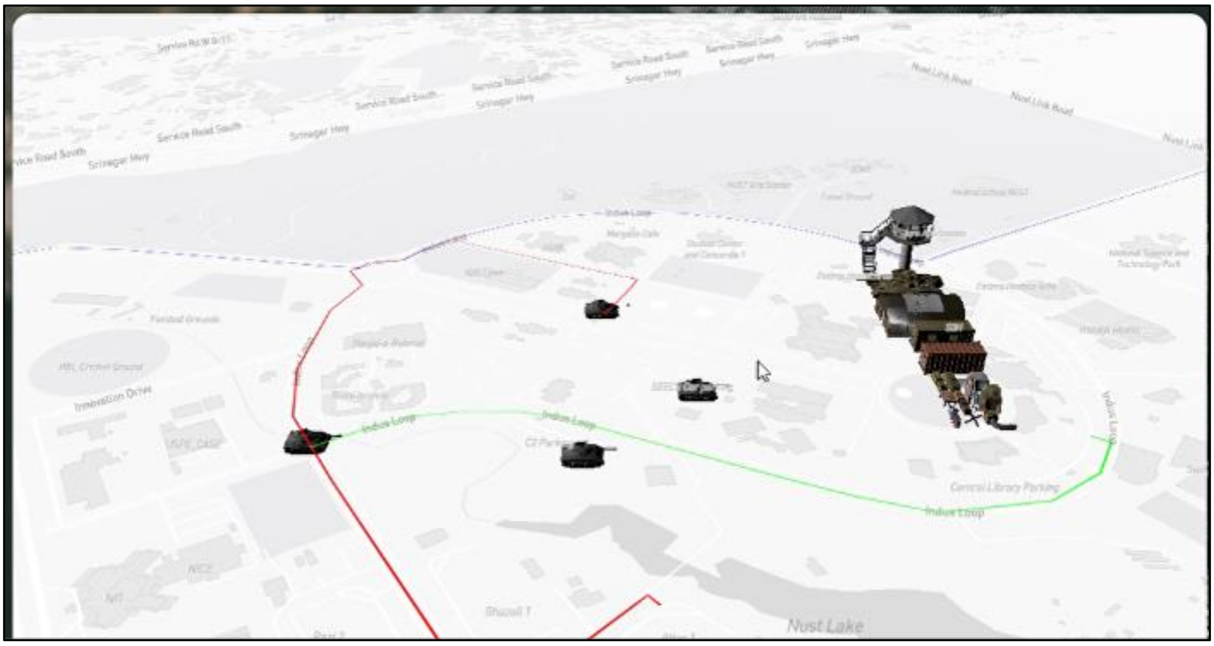


Figure 14: Real time IOT Device data visualization on the ground

Figure 15: Real time data visualization on the ground

ii. **Speedometer Display:** The speedometer-like display utilizes the x, y, and z data from the accelerometer (ADXL345) to depict the movement of the device. It likely translates these values into a visual representation of speed or movement intensity.

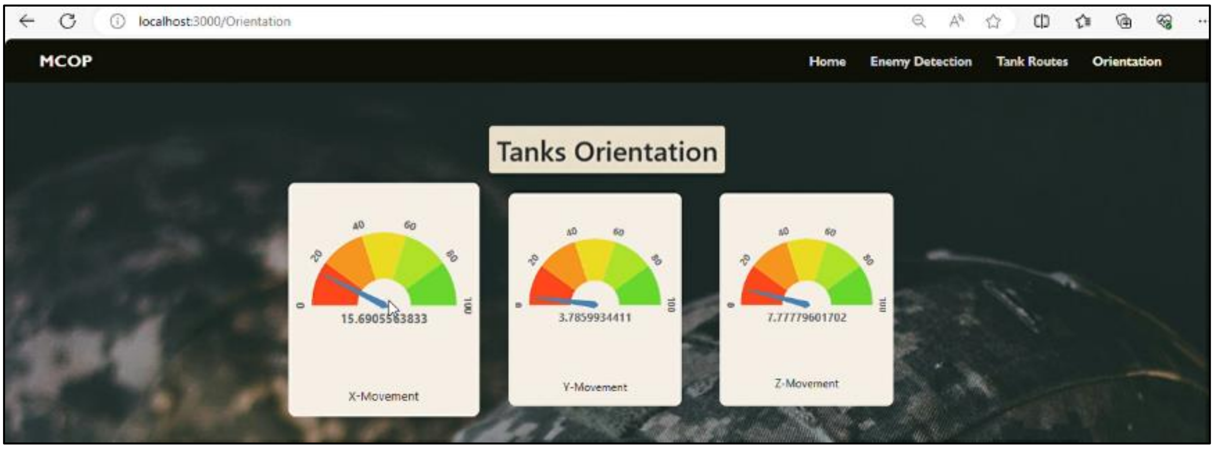


Figure 16: X, Y, Z axis data on speedometer

3.2.10 Benefits of the System

The system offers several significant benefits for military operations. First, it provides real-time visibility, allowing commanders to see the location, orientation, and movement of friendly forces as they happen. This capability greatly enhances situational awareness on the battlefield, ensuring that commanders have up-to-date information at their fingertips. Additionally, the system helps to reduce the risk of friendly fire by clearly depicting the positions and orientations of friendly forces, thereby minimizing the chances of accidental engagements. Enhanced coordination between different units is another key advantage, as the system enables commanders to track troop movements and communicate more effectively, ensuring synchronized operations. Finally, the availability of real-time Blue Force Tracking (BFT) data supports improved decision-making by empowering commanders to make quicker and more informed decisions in the midst of dynamic battlefield conditions.

3.2.11 Applications

The web-based BFT system can be used in various military operations, including:

i) Tracking individual soldiers or unit movements.

ii) Monitoring the overall battlefield situation.

iii) Identifying potential friendly fire risks.

iv) Coordinating troop movements and maneuvers.

v) Providing real-time situational awareness to commanders at various levels.

3.2.12 Accelerometers in Blue force tracking

Accelerometers are critical components in Blue Force Tracking (BFT) devices, measuring acceleration along multiple axes—typically X, Y, and Z. These sensors play a vital role in detecting movement by monitoring changes in acceleration, allowing the BFT device to determine whether it is stationary, moving, or accelerating. This capability not only supplements GPS location data but also provides insights into the type of movement occurring, such as identifying if a vehicle is starting up due to sudden acceleration. Additionally, accelerometer data is instrumental in identifying the device's orientation in three-dimensional space. Understanding the tilt or pitch of a vehicle, for instance, can be crucial in certain scenarios, providing a clearer picture of the vehicle's positioning and its movements within the field.

3.2.13 Interpreting a Line Graph of Accelerometer Data

While the specific graph you sent lacks labels and context, a line graph showing X, Y, and Z accelerometer data over time would likely depict the following:

a. **X-axis:** Time (seconds, minutes, etc.)
b. **Y-axis:** Acceleration values along the X, Y, and Z axes (g-force or arbitrary units)

The randomness or fluctuations in the X, Y, and Z data over time would likely reflect the movements and vibrations experienced by the BFT device. Here are some scenarios:

(1) **Random fluctuations around zero:** This could indicate the device is stationary or experiencing minimal movement.
(2) **Spikes or dips in one or more axes:** This could indicate the device is being jostled, tilted, or accelerated in a particular direction. For instance, a sustained increase in Z-axis data might suggest the device is experiencing upward acceleration, possibly due to a bumpy ride.

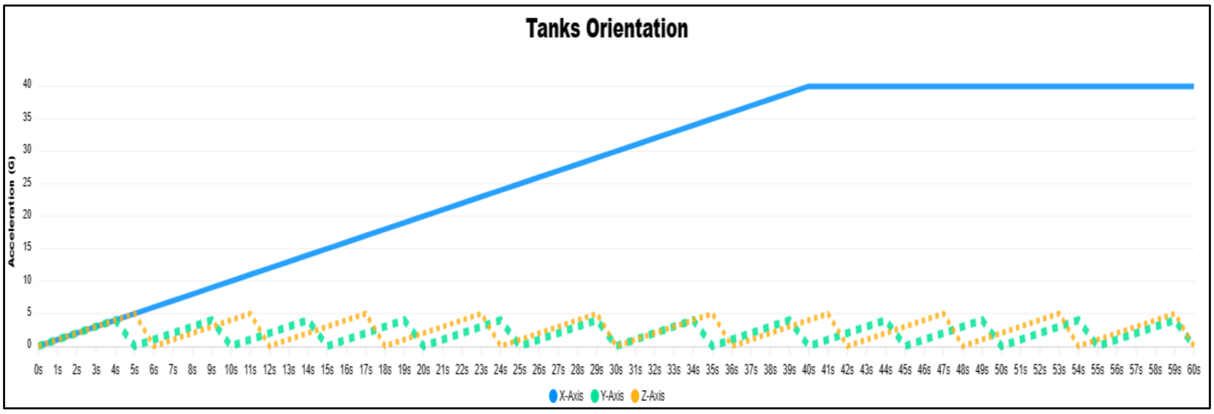


Figure 17: Orientation graph

3.2.14 How this Information is Useful in BFT

The X, Y, and Z data from the accelerometer, combined with GPS data, can provide a more comprehensive picture vehicular movement and status in the field. This can be beneficial in several ways:

- **Improved Movement Classification:** By combining movements detected by the accelerometer with location data from GPS, the system might be able to differentiate between different types of movement. For example, the BFT system might be able to distinguish between a stationary vehicle, a vehicle idling, and a vehicle traveling at high speed.

- **Potential for Additional Insights:** In some cases, the accelerometer data might provide supplementary information that can aid in situational awareness. For instance, a spike in Z-axis data coupled with a change in GPS location could indicate a soldier jumping over a wall or entering/exiting a vehicle.

3.2.15 Limitations to Consider

While accelerometers provide valuable data, their effectiveness can be limited without additional context. The accuracy of accelerometer readings can be influenced by various factors, such as the placement of the BFT device. The way the device is attached to a user or vehicle can significantly impact the sensor's ability to accurately measure acceleration. Additionally, environmental factors like external vibrations from rough terrain can be misinterpreted by the accelerometer as movement, leading to potential inaccuracies. To enhance the accuracy and utility of accelerometer data, it is essential to integrate it with data from other sensors, such as GPS. Combining this information and processing it through algorithms designed to account for these influencing factors can provide a more reliable and comprehensive understanding of the device's movements and orientation.

3.2.16 Historical Data Analysis for Future Optimization

In addition to real-time visualization of Blue Force Tracking (BFT) data, our web dashboard also offers the capability to store historical data in a hosted database. This archived data can be an asset for post-operation analysis and mission planning.

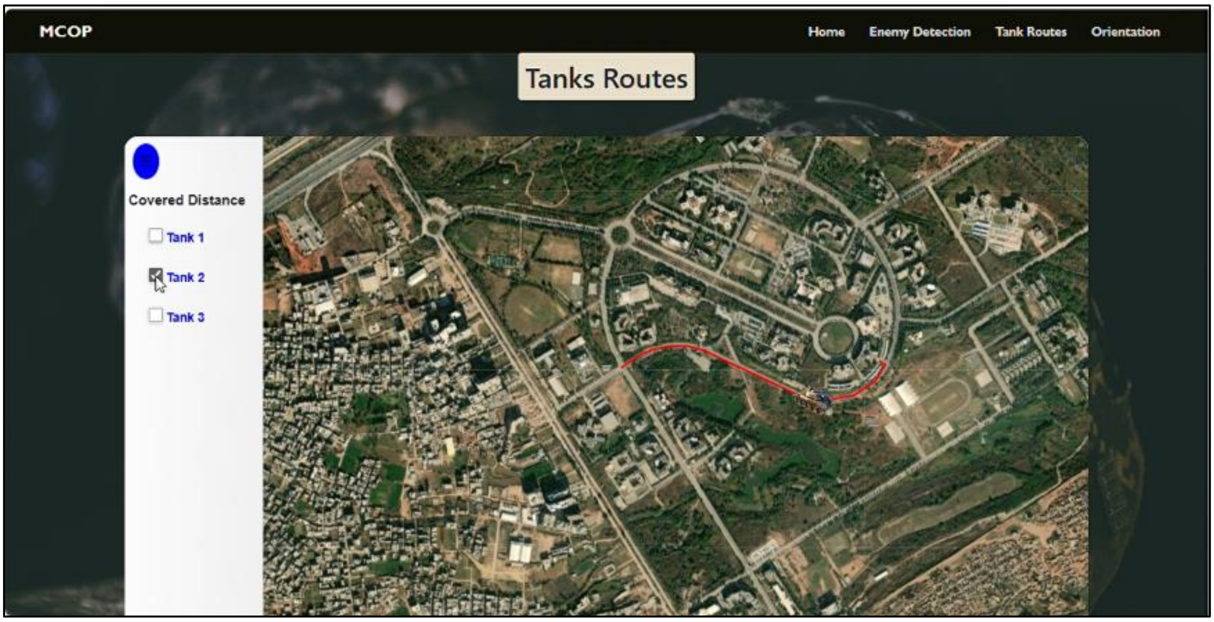


Figure 18: Stored data path visualization

3.2.17 Benefits of Historical Data Analysis

Analyzing historical data offers several key benefits for improving military operations. By examining data from past operations, commanders can identify trends and patterns in troop movements, vehicle usage, and other critical factors. This insight allows for the development of more effective strategies and tactics for future deployments. Historical data is also valuable for evaluating the performance of Blue Force Tracking (BFT) systems, enabling analysts to assess aspects such as data accuracy, device reliability, and battery life based on previous experiences. Additionally, reviewing historical data on troop movements in specific regions aids in risk assessment, helping commanders to evaluate potential risks and make informed decisions regarding troop deployment, route planning, and resource allocation. Furthermore, historical data can be utilized to create realistic training scenarios that mimic the challenges encountered in past operations, thereby enhancing the skills and preparedness of soldiers and commanders for future missions.

3.2.18 Historical Data on the Web Dashboard

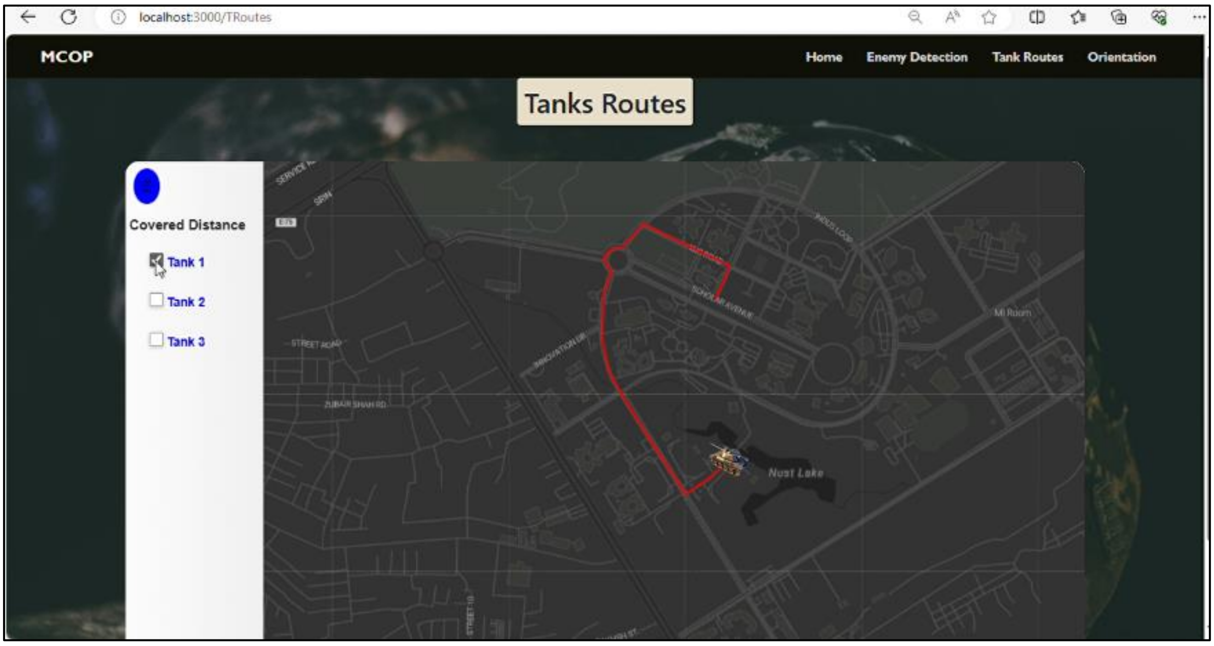


Figure 19: stored data path visualization

By leveraging the historical data stored in the database and visualized on the web dashboard, commanders can gain valuable insights to inform future decision-making and optimize the effectiveness of their Blue Force Tracking operations.

3.3 Red Force Detection

As mentioned above VOLOv8 model is used for enemy assets detection. Customization and implementation of the model are being discussed below:

3.3.1 YOLOv8 Architecture

In our project, we utilized the YOLOv8 (You Only Look Once version 8) architecture, a state-of-the-art model designed for real-time object detection tasks. This model builds upon the strengths of its predecessors while introducing several innovations to improve accuracy and efficiency. Figure below shows the detailed breakdown of its architecture, for a clear visual understanding.

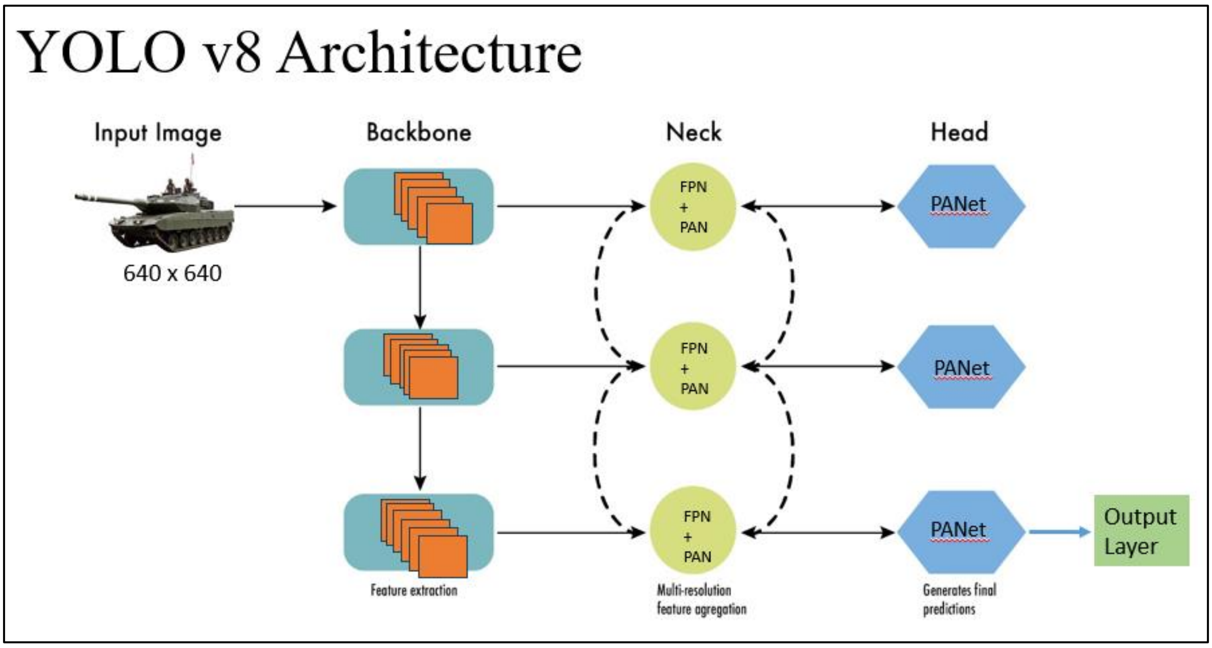


Figure 20: YOLO v8 Architecture

Overview

The YOLOv8 architecture consists of three main components:

1. Backbone
2. Neck
3. Head

Each of these components plays a crucial role in the detection pipeline.

1. Input Image: Our model begins with an input image, typically of size 640x640 pixels. This image is processed through various stages to detect and classify objects within it.
2. Backbone (Feature Extraction): The backbone is responsible for extracting features from the input image. It consists of several convolutional layers that progressively

capture spatial hierarchies of features, ranging from edges and textures to more complex patterns.

3. Convolutional Layers: Convolutional layers apply filters to the input image to detect different features.
4. Activation Functions: ReLU (Rectified Linear Unit) is used to introduce nonlinearity.
5. Pooling Layers: These layers reduce the spatial dimensions of the feature maps, retaining the most critical information while reducing computational complexity.

3.3.1.1 Neck (Multiresolution Feature Aggregation)

The neck is designed to aggregate features from different layers of the backbone to produce a multiscale representation. This is crucial for detecting objects of varying sizes. In our project, YOLOv8 employs a combination of Feature Pyramid Networks (FPN) and Path Aggregation Networks (PAN).

1. FPN (Feature Pyramid Network): This network helps in building high-level semantic feature maps at different scales, improving the model's ability to detect small objects.
2. PAN (Path Aggregation Network): PAN enhances the feature hierarchy by adding bottom-up paths to improve localization capabilities and accurate detection of large objects.

The neck in the diagram above shows how we connected different layers of the backbone, aggregating features at multiple resolutions.

3.3.1.2 Head (Final Prediction)

The head of the YOLOv8 architecture is responsible for making the final predictions, which include object classification and bounding box regression. Our project uses PANet (Path Aggregation Network) in the head for further refining the features and generating precise outputs.

1. Classification: This part of the network predicts the class of the object present in the bounding box.
2. Bounding Box Regression: This part predicts the coordinates of the bounding boxes surrounding the detected objects.

The head outputs the final detections, represented as bounding boxes along with class labels and confidence scores.

Output Layer: The output layer consolidates the predictions from the head and presents them in a structured format. This layer typically includes:

Bounding Boxes: Coordinates of the boxes that tightly enclose the detected objects.

Class Scores: Probability scores for each detected object, indicating the likelihood of the object belonging to a particular class.

Class Labels: The predicted labels for the detected objects.

3.3.2 Innovations in YOLOv8

In our project, we leveraged several enhancements introduced in YOLOv8:

1. Improved Backbone: We used more efficient and deeper backbone networks for better feature extraction.
2. Advanced Neck Designs: By combining FPN and PAN, we achieved superior feature aggregation.
3. Enhanced Head: Optimized for better classification and localization accuracy.
4. Optimization Techniques: We incorporated newer techniques such as anchor-free detection, better loss functions, and regularization methods to enhance performance.

3.3.3 Data Preparation

To efficiently make use of the extensive object detection capabilities of the Yolov8 model, data preparation is a crucial step in this process.

This section will cover the dataset used, the importance of data augmentation, and the process of data annotation using Roboflow. By systematically organizing and annotating our data, we ensured the foundation for training an accurate and efficient model.

3.3.3.1 Training Dataset

For this project, we compiled a training dataset consisting of 4,500 images. These images encompass a diverse range of scenes and objects to ensure that our model can generalize well in real-world scenarios. Specifically, we focused on detecting four classes of objects:

1. Tanks
2. Soldiers
3. Military Trucks
4. APCs (Armored Personnel Carriers)

These classes were chosen due to their relevance in military contexts, which is the focus of our detection task.

3.3.3.2 Importance of Data Augmentation

We implemented data augmentation, a critical process in machine learning, especially in computer vision. Data augmentation involves creating new training samples by applying various transformations to the existing images. The primary goal of data augmentation is to increase the variability and diversity of the training dataset. This process helped to make our model more robust and less prone to overfitting. Here are some common augmentation techniques we used:

1. Rotation: We rotated images to different angles to make the model invariant to orientation changes.
2. Scaling: We changed the size of objects within the image to help the model detect objects at various scales.
3. Translation: We shifted the image along the X and Y axes to make the model robust to object positions.
4. Flipping: We horizontally and vertically flipped images to increase variability.
5. Cropping: We randomly cropped parts of the images to simulate different viewing angles and distances.

3.3.3.3 Sources of Training Data

To ensure diversity and comprehensiveness, we sourced the images for our training dataset from a variety of platforms:

1. Open Source Platforms: Such as Google Images, provide a vast array of images from different contexts and environments.

2. Games: Video games with realistic graphics served as a good source of varied and challenging images.
3. Kaggle: A platform offering numerous datasets contributed by the data science community.
4. Roboflow: A tool that not only provides datasets but also helps in organizing and augmenting them.

These diverse sources ensured that our dataset covered a broad spectrum of scenarios, enhancing the model's ability to generalize to new, unseen data.

3.3.3.4 Annotation of Training Data

Annotation Environment**: Roboflow**

We utilized Roboflow, an efficient and user-friendly platform for data annotation, a critical step in preparing our training dataset. The annotation process involved labelling each object of interest in the images with bounding boxes and corresponding class labels. Here's a detailed explanation of how we annotated our data in Roboflow:

1. Upload Images: We began by uploading the collected images to the Roboflow platform, which supports bulk uploads, making it easy to handle large datasets.

2. Annotation Interface: Roboflow provided us with an intuitive interface for annotating images. We drew bounding boxes around objects and assigned the appropriate class labels (e.g., Tank, Soldier, Military Truck, APC).

3. Pretrained Models: We utilized Roboflow's pretrained models to provide initial bounding boxes and labels, which we then finetuned manually. This feature significantly sped up the annotation process.

4. Collaboration: Roboflow allowed multiple annotators to work on the same project simultaneously, enabling efficient and scalable annotation workflows. Each annotator's work was saved in real-time, ensuring that the dataset was consistently updated.

5. Quality Control: Roboflow included tools for quality control, such as annotation review and validation processes, to ensure that our annotations were accurate and consistent.

6. Augmentation: After annotation, Roboflow provided built-in augmentation tools to automatically apply various transformations to the images, increasing the size and diversity of the training dataset.

7. Export Formats: Once the annotation was complete, we exported the dataset in YOLO format.

By following these detailed steps in data preparation and annotation, we ensured that our dataset was robust, comprehensive, and well-annotated. This thorough process was critical in training our object detection model to achieve high accuracy and reliability in real-world scenarios.

3.3.4 Model Training Workflow

The model training workflow is a structured process that outlines the steps involved in training an object detection model using the YOLOv8 algorithm. The workflow ensures that the model is trained, validated, and tested effectively to achieve high accuracy and robustness. The diagram below illustrates the key stages of this process.

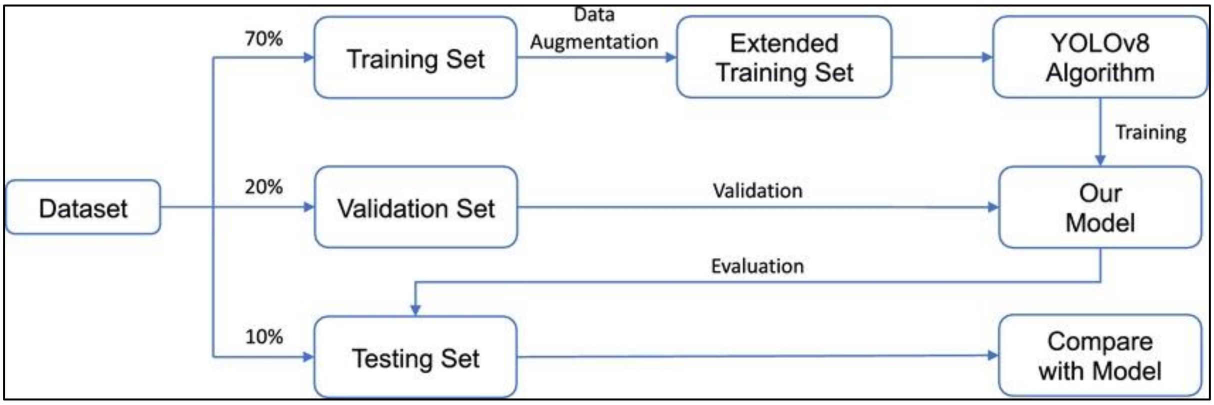


Figure 21: Model Training workflow

1. Dataset

The process begins with a comprehensive dataset that contains labelled images. This dataset is divided into three subsets:

1. Training Set: 70% of the dataset

2. Validation Set: 20% of the dataset
3. Testing Set: 10% of the dataset

This division ensures that the model can be trained on a majority of the data while being validated and tested on separate, unseen data to evaluate its performance and generalizability.

2. Training Set

The training set is the primary subset used to train the model. It comprises 70% of the entire dataset and is used to optimize the model's weights.

Data Augmentation: To increase the variability and diversity of the training dataset, data augmentation techniques are applied. These techniques include transformations such as rotation, scaling, translation, flipping, and color jittering. The augmented data helps the model to learn more robust features and prevents overfitting.

Extended Training Set: After augmentation, the training set is extended with these new variations. This enriched dataset ensures that the model is exposed to a wide range of scenarios during training.

3. YOLOv8 Algorithm

The extended training set is then fed into the YOLOv8 algorithm for training. YOLOv8 is chosen for its balance of speed and accuracy in real-time object detection tasks.

Training Process: The algorithm iteratively processes the training images, adjusting the model's parameters to minimize the loss function. The number of epochs, which indicates the number of complete passes through the training dataset, is set to 50. This iterative training helps the model to learn and generalize the features of the objects effectively.

4. Validation Set

During the training process, the model is periodically evaluated on the validation set, which consists of 20% of the dataset.

Validation Process: This process involves running the trained model on the validation set and calculating metrics such as accuracy, precision, recall, and loss. The validation set provides an unbiased evaluation of the model's performance on unseen data and helps in tuning hyperparameters and preventing overfitting.

5. Model Evaluation

After the training is complete, the final model is evaluated on the testing set, which consists of 10% of the dataset.

Testing Set: The testing set is kept separate and is not used during the training or validation phases. This ensures an unbiased evaluation of the model's performance on entirely unseen data.

Evaluation Metrics: The model's accuracy, which is 92% in this case, is calculated along with other metrics like precision, recall, and F1score to comprehensively assess its performance.

6. Comparison with Baseline Model

To understand the improvements made by the trained model, it is compared with a baseline model. The baseline model could be an earlier version of the YOLO algorithm, or another object detection model used for comparison.

Performance Comparison: Metrics from the trained model are compared against those from the baseline model to evaluate improvements in accuracy, speed, and overall effectiveness.

Accuracy Evolution: Model Optimization Progress

The journey of optimizing an object detection model is a dynamic and iterative process involving various techniques, methods, and models to enhance performance progressively. This section explores how different approaches and strategies were employed to improve the model's accuracy over time, based on the evolution of performance metrics depicted in the provided image.

3.3.5 Accuracy Evolution: Model Optimization Progress

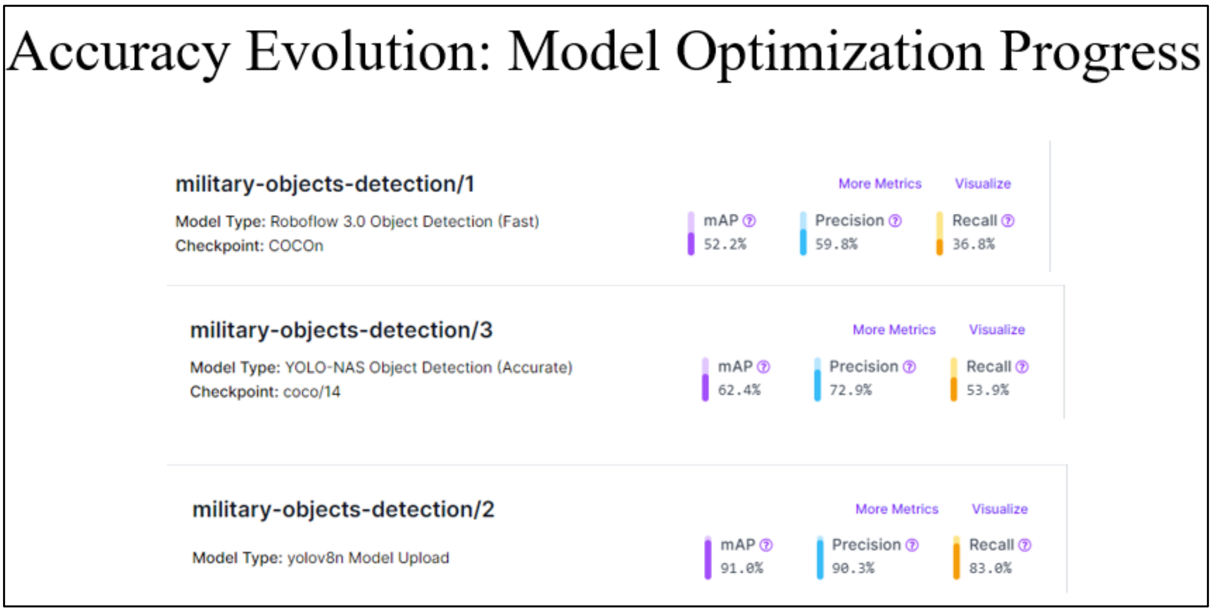


Figure 22: Model optimization Progress: Accuracy Evolution

i. **Initial Model: Roboflow 3.0 Object Detection (Fast)**

mAP: 52.2%

Precision: 59.8%

Recall: 36.8%

Mean Average Precision (mAP): A measure that combines precision and recall to evaluate the accuracy of object detection models.

Precision: The ratio of correctly predicted positive observations to the total predicted positives.

Recall: The ratio of correctly predicted positive observations to all actual positives.

Description:

The initial model utilized was Roboflow 3.0 Object Detection, optimized for speed. It provided a starting point for our object detection tasks but had limitations in terms of accuracy.

Key Insights: The model achieved moderate precision but struggled with recall, indicating it missed many objects.

The lower mean Average Precision (mAP) suggested the need for further optimization to improve overall detection accuracy.

Initial Measures:

1. Baseline Evaluation: We used this model as a baseline to understand its strengths and weaknesses.

2. Dataset Analysis: Conducted a thorough analysis of the training dataset to identify potential areas of improvement, such as class imbalance or insufficient data for certain classes.

ii. Improvement with YOLONAS Object Detection (Accurate)

mAP: 62.4%

Precision: 72.9%

Recall: 53.9%

Description:

To address the limitations of the initial model, we transitioned to the YOLONAS architecture, known for its balance of speed and accuracy. This change aimed to improve both detection accuracy and the number of correctly identified objects.

Techniques and Methods:

1. Enhanced Data Augmentation: Implemented advanced augmentation techniques, such as synthetic data generation and context aware augmentations, to enrich the training dataset.

2. Hyperparameter Tuning: Performed extensive hyperparameter tuning, including learning rate adjustments, batch size optimization, and experimentation with different optimizer algorithms.

3. Model Architecture Adjustments: Tweaked the YOLONAS architecture to include additional convolutional layers and refined anchor box sizes to better capture various object scales.

Results: The mAP improvement to 62.4% indicated better overall model performance.

Precision increased significantly to 72.9%, showing improved confidence in predictions.

Recall also improved, suggesting the model was now detecting more objects.

Iterative Improvements:

1. Cross-Validation: Applied cross-validation techniques to ensure the model's performance was consistent across different subsets of the data.

2. Error Analysis: Conducted detailed error analysis to understand false positives and false negatives, allowing targeted improvements in the model.

iii. Final Optimization: YOLOv8n Model Upload

mAP: 91.6%

Precision: 90.3%

Recall: 83.0%

Description:

In the final stage, we adopted the YOLOv8n model, representing the latest advancements in the YOLO family. This model focused on achieving high accuracy and recall, leveraging state-of-the-art techniques in neural network design.

Advanced Techniques and Methods:

1. Transfer Learning: Utilized pretrained models on largescale datasets (e.g., COCO) to transfer learned features, significantly boosting performance with limited additional training.

2. Fine-Tuning on Specific Classes: Conducted finetuning specifically for the classes of interest (Tanks, Soldiers, Military Trucks, APCs), ensuring the model was highly specialized.

3. Multi-Scale Training: Employed multiscale training techniques to improve the model's ability to detect objects of varying sizes within the same image.

Results:

Achieved a mAP of 91.6%, demonstrating substantial improvement and high overall accuracy.

Precision reached 90.3%, indicating the model's predictions were highly accurate.

Recall improved to 83.0%, reflecting the model's capability to detect most objects in the dataset.

The evolution of model accuracy and performance through different stages of optimization highlights the importance of iterative experimentation in machine learning.

This detailed process underscores the iterative nature of model development, where continuous experimentation and refinement lead to progressively better results. The journey from the initial Roboflow model to the highly optimized YOLOv8n model demonstrates the effectiveness of systematic optimization strategies in achieving high-performance object detection models.

3.3.6 Model Results

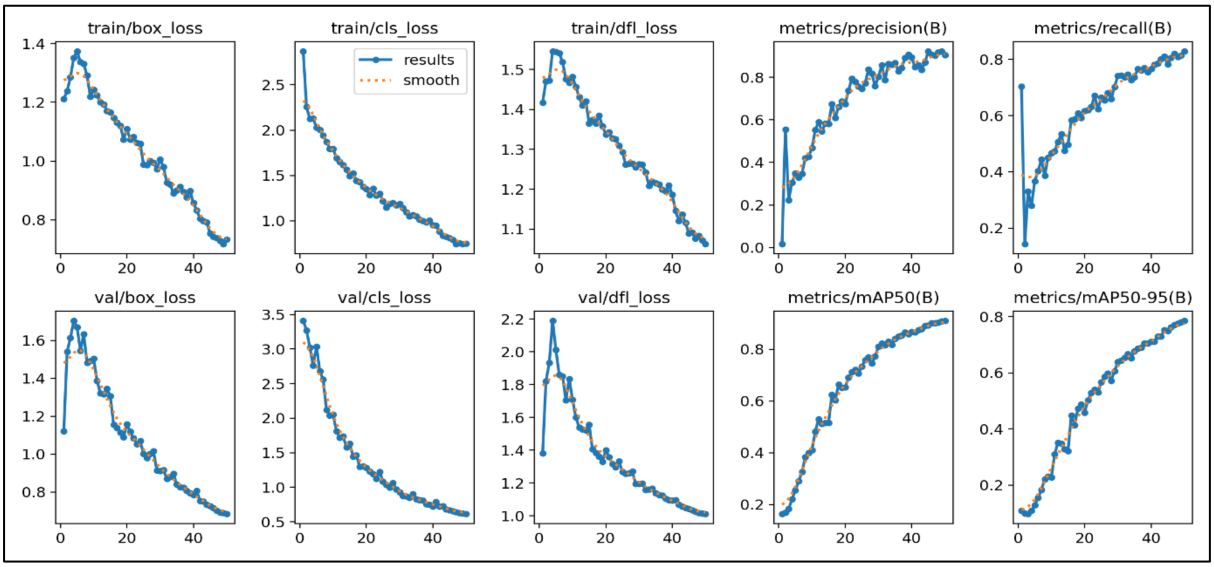


Figure 23: Mean Average Precision Graph showing Model Training journey

The model's training journey is depicted through various graphs. The loss graphs (bounding box, classification, distance focal) all exhibit a gratifying downward trend. This signifies the model's progressive improvement in accurately pinpointing objects (localization) and identifying their types (classification). This learning translates well to unseen data, as evidenced by the similar decline in validation losses.

Performance metrics paint an even rosier picture. Precision, indicating the model's ability to identify real objects without false alarms, steadily increases. Recall, reflecting the model's success in detecting a higher proportion of actual objects, also shows a positive trend. Finally, the mAP metrics (mean Average Precision) showcase the model's overall object detection proficiency with a clear upward trajectory.

In essence, the model is effectively learning its task, as evidenced by decreasing losses and increasing performance metrics. This translates to robust object detection accuracy.

i. Our Model's Winning Formula

The graphs unveil a successful training process, culminating in robust object detection of tanks, soldiers, military trucks, and APCs. This achievement can be attributed to several key strategies:

- **Data on Steroids:** By employing data augmentation techniques, we exposed the model to diverse scenarios, enhancing its ability to handle real-world variations.
- **Fine-Tuning the Learning Machine:** Through hyperparameter tuning, we optimized the model's learning process, finding the ideal settings for training.
- **Transfer Learning: A Head Start:** Utilizing a pre-trained model gave our model a strong foundation to build upon, accelerating its learning of general object features. This knowledge was then specifically tailored to identify our target military objects.
- **YOLOv8: Powerhouse Architecture:** Leveraging the state-of-the-art YOLOv8 architecture provided a powerful framework for achieving high accuracy and resilience in object detection.
- **Validation: Keeping an Eye on Overfitting:** Continuous monitoring of the validation set ensured the model wasn't overfitting to the training data and maintained its ability to generalize to unseen data.
- **Learning from Mistakes:** The model underwent iterative training cycles, with each iteration involving evaluation, refinement, and targeted improvements based on error analysis. This process minimized false positives and negatives, boosting the model's overall performance.

By meticulously applying these strategies and continuously refining the model, we achieved significant improvements in detection accuracy and object classification, as evidenced by the decreasing losses and rising precision, recall, and mAP values. This systematic approach is vital for developing high-performance object detection models and significantly contributes to the project's success.

ii. Precision-Recall Curve Analysis

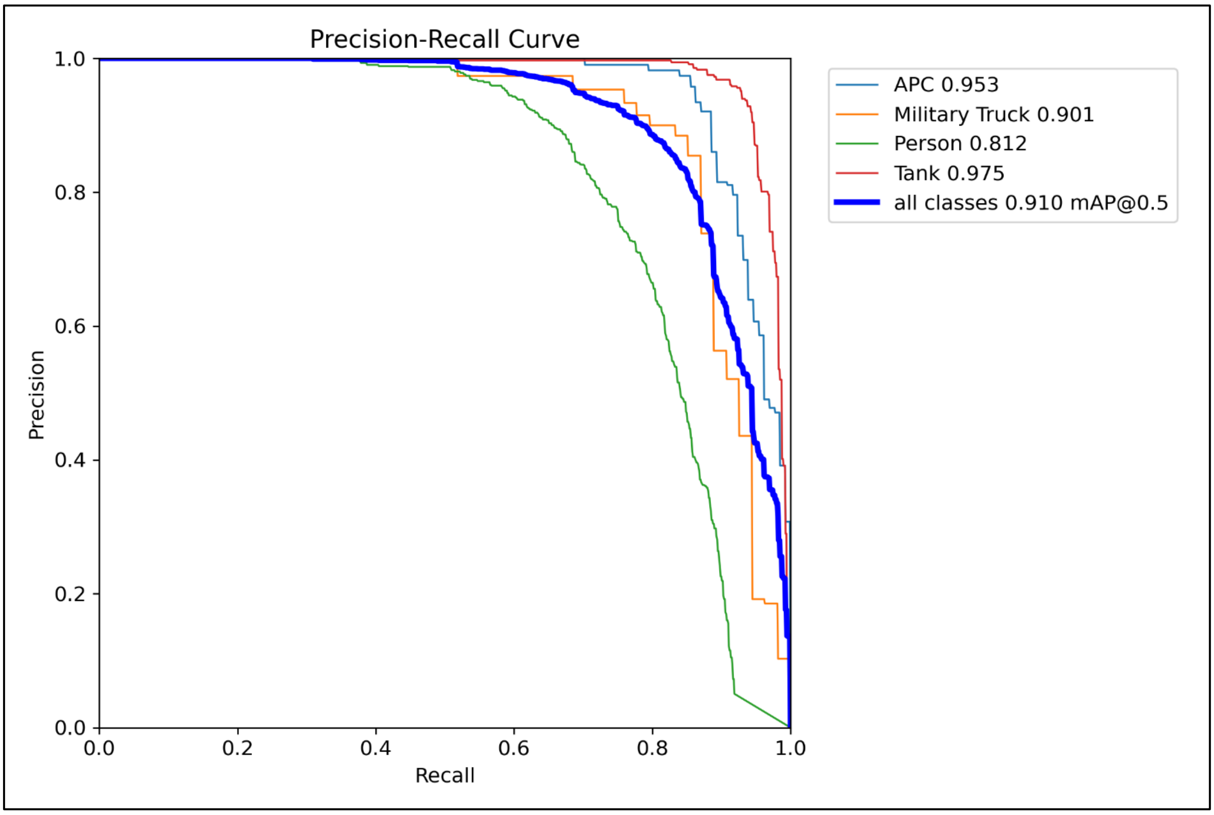


Figure 24: Precision Recall Curve Analysis used for Object detection Model

The Precision-Recall (PR) curve is a crucial tool for evaluating the performance of our object detection model, particularly in imbalanced datasets. It provides a comprehensive view of the trade-off between precision (the accuracy of positive predictions) and recall (the ability to find all positive instances) across different thresholds. The PR curve for our model, as shown in the provided image, includes performance metrics for different classes: APC, Military Truck, Person, and Tank, as well as the overall performance across all classes.

Understanding the PR Curve

1. Precision:

Definition: Precision is the ratio of true positive detections to the total number of positive detections (true positives + false positives).

Importance: High precision indicates a low number of false positives, meaning the model's predictions are reliable.

2. Recall:

Definition: Recall is the ratio of true positive detections to the total number of actual positives (true positives + false negatives).

Importance: High recall indicates the model's ability to detect most of the actual objects in the dataset, minimizing false negatives.

3. PR Curve:

Description: The PR curve plots precision against recall for different threshold values. Each point on the curve represents a specific threshold.

Importance: The area under the PR curve (AUCPR) is a single metric summarizing the model's performance, where a larger area indicates better performance.

Analysis of the PR Curve

The PR curve for our model shows distinct curves for different classes:

1. APC:

Precision: 0.953

Analysis: The APC class shows a high precision, indicating that most of the APC detections are accurate.

2. Military Truck:

Precision: 0.901

Analysis: The military truck class also demonstrates high precision, albeit slightly lower than APC, indicating reliable detection.

3. Person:

Precision: 0.812

Analysis: The person class has the lowest precision among the classes, reflecting more false positives.

4. Tank:

Precision: 0.975

Analysis: The tank class exhibits the highest precision, indicating exceptionally accurate detection.

5. All Classes:

Overall mAP 91%.

Analysis: The overall performance across all classes is strong, with an mAP@0.5 of 91%, indicating high accuracy and recall.

iii. Achieving These Results

To achieve these impressive precision-recall results, we implemented several strategies and techniques throughout the model development process:

1. Data Augmentation:

Action: Applied extensive data augmentation techniques to enhance the diversity of the training dataset.

Impact: This increased the model's ability to generalize and improved its performance across different object classes.

2. Class-Specific Tuning:

Action: Fine-tuned the model specifically for each class (APC, Military Truck, Person, Tank).

Impact: This helped in optimizing the detection accuracy for individual classes, leading to higher precision and recall for critical classes like tanks and APCs.

3. Advanced Model Architecture:

Action: Utilized the YOLOv8 architecture, which offers superior feature extraction and object detection capabilities.

Impact: The advanced architecture contributed to the model's high precision and recall by efficiently capturing and processing image features.

5. Transfer Learning:

Action: Leveraged pretrained models and finetuned them on our specific dataset.

Impact: This approach allowed the model to start with a robust baseline of learned features, significantly enhancing its performance.

6. Regular Validation and Testing:

Action: Implemented continuous validation and testing with a separate validation set to monitor performance.

Impact: This helped in early detection of overfitting and ensured the model's robustness and generalizability to new data.

7. Error Analysis and Iterative Improvement:

Action: Conducted thorough error analysis to identify and address false positives and false negatives.

Impact: Iterative improvements based on error analysis led to refined model predictions and better overall performance.

The Precision-Recall curve is a vital metric for evaluating the performance of our object detection model, especially in applications where the cost of false positives and false negatives is high. The high precision and recall values for critical classes such as tanks and APCs underscore the effectiveness of our training and optimization strategies. By employing advanced data augmentation, class specific tuning, hyperparameter optimization, and leveraging state-of-the-art model architectures, we achieved a robust and reliable object detection model suitable for real-world applications.

3.3.7 Testing of the Model

The trained model weights were hosted on Roboflow, a platform designed for hosting trained deep learning models. Using Roboflow's web-based dashboard, we can perform inference on images with our trained model.

Additionally, we have integrated this model into our React-based application. This integration allows users to upload images and perform object detection. Once the objects are detected, we display a graph that shows the count of individual objects and the total count. Furthermore, we visualize the detected objects on a web-based map powered by the Mapbox mapping library.

Our trained model is also capable of processing videos efficiently. Videos are first converted into images based on the frame rate (frames per second), allowing the model to detect objects within the video frames accurately.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

In conclusion, this research marks a significant advancement in military technology through the development of a sophisticated Military Common Operating Picture (MCOP) that harnesses the power of Geographic Information Systems (GIS). By integrating advanced sensor technology, AI-based algorithms, and dynamic visualization capabilities with GIS, the MCOP offers a comprehensive and intuitive platform for battlefield management.

The utilization of sensors such as the ADXL345 accelerometer and GPS modules, coupled with the YOLOv8 algorithm for enemy detection, provides real-time data on own and team locations, movement patterns, and enemy positions. This wealth of information is seamlessly integrated with GIS, enabling spatial analysis and visualization that enhances situational awareness and decision-making on the battlefield.

Furthermore, the development of a dynamic dashboard, built using modern web technologies like React.js and Grafana, facilitates the visualization and interpretation of this spatial data. By overlaying sensor data and AI-driven analysis onto GIS maps, commanders gain actionable insights into the operational landscape, allowing for more informed and effective responses to dynamic threats and changing conditions.

In summary, the integration of sensor data, AI algorithms, visualization tools, and GIS in the MCOP represents a significant advancement in military technology. By providing commanders with a comprehensive understanding of the battlefield environment and enabling real-time decision-making, the MCOP enhances mission effectiveness and contributes to the safety and success of military operations.

4.2 Recommendations

Continued Development and Integration of Sensor Technologies: The project should focus on further enhancing the capabilities of sensor technologies such as GPS and ADXL345 accelerometers. This includes exploring advanced sensor fusion techniques to improve the accuracy and reliability of location tracking and movement detection in diverse operational environments.

Optimization of YOLOv8 Algorithm: Continuous refinement and optimization of the YOLOv8 algorithm are essential to enhance enemy detection and classification capabilities. This may involve fine-tuning the model parameters, expanding the training dataset, and integrating real-world feedback to improve detection accuracy and reduce false positives.

Integration with Existing Military Systems: The project should prioritize seamless integration with existing military command and control systems to ensure interoperability and compatibility. This may involve developing standardized data exchange protocols and interfaces to facilitate data sharing and collaboration across different military units and command echelons.

Enhanced Training and User Adoption: Training programs should be developed to familiarize military personnel with the new MGIS capabilities and workflows. User feedback should be actively solicited and incorporated into system refinements to ensure usability and effectiveness in real-world operational scenarios.

Cybersecurity and Data Protection Measures: Robust cybersecurity measures must be implemented to safeguard sensitive military data and prevent unauthorized access or tampering. This includes encryption of data transmission channels, secure authentication mechanisms, and regular security audits to identify and mitigate potential vulnerabilities.

Research and Development for Future Enhancements: Continuous research and development efforts should be directed towards exploring emerging technologies and methodologies that can further enhance the capabilities of the MGIS. This may include advancements in AI, machine learning, and geospatial analysis techniques to address evolving operational challenges and requirements.

4.3 Applications

The project has the capability to be implemented quite easily in domains other than the military

These domains can include but are not limited to:

i. Law Enforcement
ii. Fire Fighting
iii. Disaster Management

iv. Telecommunication Companies
v. Mineral Resource Companies
vi. Mining
vii. Health
viii. Education
ix. Election Information and Management
x. Agriculture
xi. Businesses
xii. Transportation
xiii. Fleet Management
xiv. Electricity

5. REFRENCES

1. Al-Qaheri, S., & Alias, A. Y. (2014). A Review of Battlefield Management Systems (BMS). International Journal of Advanced Science and Technology, 76(1), 147-158. https://en.wikipedia.org/wiki/Battlefield_management_system
2. Bode, M., & Hallenbeck, S. (2010). The impact of situational awareness on team performance in command and control. Cognition, Technology & Work, 12(3), 183-196. https://link.springer.com/book/10.1007/978-1-4614-6230-9
3. Grzonka, S., Wróbel, P., & Kasprzyk, J. (2018). A Review of Literature on Situational Awareness Technologies for Military Applications. International Journal of Occupational Safety and Ergonomics, 24(3), 527-542. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5868480/
4. Department of Defense (DoD) Instruction 4650.01 (2018). Managing Software Acquisition. https://dodcio.defense.gov/Portals/0/Documents/Library/SWAPathwayIntegration-RMF.pdf (This reference highlights the growing acceptance of open-source technologies within the DoD)
5. Garfinkel, S. (2010). Open source software for science. Computers & Geosciences, 36(9), 1220-1226. https://www.researchgate.net/publication/354742265_Relevant_Aspects_for_Sustainable_Open_Source_Pandemic_Apps_and_Platform_Deployment_with_Focus_on_Community_Building (This reference showcases the potential of open-source solutions in scientific and technical fields)
6. MacInnis, R., & Pearce, J. (2018). Open source software in the military: A review of the literature. Journal of Open Innovation: Technology, Market, and Complexity, 4(2), 9. https://www.mdpi.com/432844
7. Amodei, D., & Clark, J. (2016). AI Moves: Deep Learning and the Future of Warfare. Foreign Policy, 214. https://foreignpolicy.com/2023/06/19/ai-artificial-intelligence-national-security-foreign-policy-threats-prediction/ (This is a high-level overview of AI in warfare)
8. Department of Defense (DoD) Artificial Intelligence Strategy (2018). https://www.defense.gov/News/News-Stories/Article/Article/3578219/dod-releases-ai-adoption-strategy/ (This official document outlines the DoD's approach to AI development)
9. Scharre, P. (2016). Autonomous Weapons Systems: An Introduction to the Issues. Carnegie Endowment for International Peace. https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-12_Issue-1/Leys.pdf (This reference delves into the ethical considerations of AI in warfare)
10. Esri. (2024). ArcGIS for Defense [Website]. https://www.esri.com/en-us/industries/defense/overview
11. Goodchild, M. F., Wilson, M. F., & Clinton, B. D. (2013). Military Applications of Geographic Information Systems (GIS). Progress in Human Geography, 37(4), 445-472. https://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch63.pdf
12. MIL-STD-2525C (2008). Department of Defense Military Standard: Graphic Symbols for Use on Defense Maps and Charts. https://worldwind.arc.nasa.gov/java/tutorials/tactical-symbols/
13. United Nations. (2015). Sustainable Development Goals. https://sdgs.un.org/goals

14. Van der Meulen, F. R. (2003). The role of defense R&D in sustainable development. Technological Forecasting and Social Change, 70(6), 653-673. https://www.sciencedirect.com/science/article/pii/S0160791X22000549
15. I. Pham and M. Polasek, "Algorithm for military object detection using image data," 2014 IEEE/AIAA 33rd Digital Avionics Systems Conference (DASC), Colorado Springs, CO, USA, 2014, pp. 3D3-1-3D3-15, doi: 10.1109/DASC.2014.6979457. keywords: {Object detection;Cameras;Image color analysis;Algorithm design and analysis;Prediction algorithms;Temperature distribution},
16. S. Astapov, J. -S. Preden, J. Ehala and A. Riid, "Object detection for military surveillance using distributed multimodal smart sensors," 2014 19th International Conference on Digital Signal Processing, Hong Kong, China, 2014, pp. 366-371, doi: 10.1109/ICDSP.2014.6900688. keywords: {Acoustics;Direction-of-arrival estimation;Intelligent sensors;Vectors;Digital signal processing;Magnetoacoustic effects;Wireless sensor networks;Multimodal information;acoustic source localization;object detection;distributed computing;smart sensors},
17. Hua, Xia, Xinqing Wang, Dong Wang, Jie Huang, and Xiaodong Hu. 2018. "Military Object Real-Time Detection Technology Combined with Visual Salience and Psychology" *Electronics* 7, no. 10: 216. https://doi.org/10.3390/electronics7100216
18. Liu, Huanhua, Yonghao Yu, Shengzong Liu, and Wei Wang. 2022. "A Military Object Detection Model of UAV Reconnaissance Image and Feature Visualization" *Applied Sciences* 12, no. 23: 12236. https://doi.org/10.3390/app122312236
19. C. Ke, "Military object detection using multiple information extracted from hyperspectral imagery," 2017 International Conference on Progress in Informatics and Computing (PIC), Nanjing, China, 2017, pp. 124-128, doi: 10.1109/PIC.2017.8359527. keywords: {Object detection;Hyperspectral imaging;Shape;Airplanes;Principal component analysis;Anomaly detection;object detection;hyperspectral imagery;superpixel;self-similarity;shape matching},
20. M. Safaldin, N. Zaghden and M. Mejdoub, "An Improved YOLOv8 to Detect Moving Objects," in IEEE Access, vol. 12, pp. 59782-59806, 2024, doi: 10.1109/ACCESS.2024.3393835.
21. keywords: {YOLO;Feature extraction;Real-time systems;Detectors;Computer architecture;Object recognition;Task analysis;Deep learning;Deep learning;localization;object detection;segmentation;YOLO},
22. W. Wu and J. Lai, "Multi Camera Localization Handover Based on YOLO Object Detection Algorithm in Complex Environments," in IEEE Access, vol. 12, pp. 15236-15250, 2024, doi: 10.1109/ACCESS.2024.3357519.
23. keywords: {Cameras;YOLO;Feature extraction;Target recognition;Target tracking;Monitoring;Image color analysis;Object detection;multiple cameras;location tracking;YOLO algorithm;homomorphic transformation},
24. S. Yan, Y. Fu, W. Zhang, W. Yang, R. Yu and F. Zhang, "Multi-Target Instance Segmentation and Tracking Using YOLOV8 and BoT-SORT for Video SAR," 2023 5th International Conference on Electronic Engineering and Informatics (EEI), Wuhan, China, 2023, pp. 506-510, doi: 10.1109/EEI59236.2023.10212903. keywords: {Analytical models;Target tracking;Object detection;Detectors;Switches;Streaming media;Reconnaissance;Video SAR;moving targets detection and tracking;YOLOv8;BoT-SORT},
25. D. Deshpande, M. Jain, A. Jajoo, D. Kadam, H. Kadam and A. Kashyap, "Next-Gen Security: YOLOv8 for Real-Time Weapon Detection," 2023 7th International

Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), Kirtipur, Nepal, 2023, pp. 1055-1060, doi: 10.1109/I-SMAC58438.2023.10290401. keywords: {Training;Adaptation models;Weapons;Streaming media;Rendering (computer graphics);Real-time systems;Security;Object Recognition;Deep Learning;Convolutional Neural Network;Computer Vision;Single Shot Detection;You Only Look Once version 8-Small (YOLO v8s)},

26. Gabriele Oligeri, Savio Sciancalepore and Alireza Sadighian. "David and Goliath: Asymmetric Advantage in MIoT." *2023 6th International Conference on Advanced Communication Technologies and Networking (CommNet)* (2023): 1-8. https://doi.org/10.1109/CommNet60167.2023.10365313.
27. Simon Dahdal, Filippo Poltronieri, M. Tortonesi, C. Stefanelli and Niranjan Suri. "A Data Mesh Approach for Enabling Data-Centric Applications at the Tactical Edge." *2023 International Conference on Military Communications and Information Systems (ICMCIS)* (2023): 1-9. https://doi.org/10.1109/ICMCIS59922.2023.10253568.