



# ENHANCING SITUATIONAL AWARENESS AND COMBAT EFFECTIVENESS IN 6TH GENERATION AIRCRAFT USING DEEP LEARNING

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## ABSTRACT:

*This work investigates methods for improving enemy aircraft detection in Beyond-Visual-Range (BVR) engagements, a cornerstone of modern aerial combat. It explores how advancements in onboard aviation technology, specifically radar and Infrared Search and Track (IRST) systems, can extend pilots situational awareness beyond the limitations of human sight. The report analyzes the impact of factors like detection-range, missile guidance capabilities, and pilot tactics on achieving a first-strike advantage. Additionally, it delves into the complexities of the BVR battlespace, exploring the challenges of electronic warfare and counter measures used to disrupt enemy detection and missile guidance. The interplay between ground-based radar networks and airborne early warning systems for providing a wider tactical picture is also examined. Finally, the report discusses of potential limitation of BVR combat and explores the possibilities of artificial intelligence playing a role in future engagements. This project aims to contribute to the ongoing development of strategies and technologies for maximizing success in BVR encounters.*

**Keywords** – Beyond-Visual-Range (BVR) engagements, Aerial combat, Onboard aviation technology, Electronic warfare, Airborne early warning systems.

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## [1] INTRODUCTION

In modern aerial warfare, achieving superior situational awareness is paramount for gaining a tactical edge in close-range engagements. While Beyond Visual Range (BVR)

missile systems have traditionally relied on radar technology for enemy aircraft detection, they face significant limitations in low terrain dogfights. Here, the rapid maneuvering and cluttered environment – think jagged mountains or dense forests – create a scenario prone to confusion and false positives for radar systems. This can be attributed to radar's limitations in distinguishing between actual targets and terrain clutter bouncing back the signal. The resulting incomplete information picture hinders pilots' ability to make critical decisions in the split seconds that define a close-range dogfight.

In contrast, recent advancements in deep learning neural networks have demonstrated remarkable capabilities in object detection tasks. These algorithms excel at analyzing complex visual data, making them ideal for scenarios where traditional methods struggle. Deep learning can leverage not just the raw radar data, but also integrate information from other onboard sensors like electro-optical systems (EOS) and infrared search and track (IRST) systems. This multi-sensor approach can provide a richer picture of the battlespace, including visual confirmation of targets and heat signatures invisible to radar. This paper proposes leveraging the power of deep learning techniques and curated datasets to revolutionize enemy aircraft detection in close-range dogfights. By harnessing this technology, we aim to overcome the challenges posed by traditional radar-based systems and provide pilots with a more comprehensive picture of the battlespace, not just in terms of enemy location but also their potential actions.

However, implementing deep learning for real-time applications in fighter jets presents its own challenges. These include the need for efficient and lightweight models that can run on the limited processing power available onboard aircraft. Additionally, ensuring the robustness of these models to potential adversarial attacks, such as jamming or spoofing enemy aircraft signatures, is crucial for maintaining trust in the system. Addressing these challenges will be an important aspect of our research to ensure the successful integration of deep learning into close-range dogfighting scenarios.

## **[2] LITERATURE REVIEW**

Enhancing situational awareness (SA) and combat effectiveness in 6th generation aircraft is essential for maintaining superiority in modern combat scenarios. Deep learning, a subset of artificial intelligence (AI), plays a crucial role in processing vast amounts of data, identifying patterns, and enabling timely decision-making. This review explores recent advancements in applying deep learning techniques to improve SA and overall combat performance in these advanced aircraft.

### **Deep Learning for Situational Awareness**

Deep learning models, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs), are used to process and analyze sensor data in real time. By integrating information from radar, infrared, and electro-optical systems, these models can detect and classify potential threats with high accuracy. For example, Zhang et al. (2021)

demonstrated the use of CNNs in target recognition, significantly reducing false positives in cluttered environments.

### **Autonomous Decision-Making**

Deep learning enables autonomous decision-making by predicting enemy behavior and optimizing combat strategies. Reinforcement learning algorithms are particularly effective in training AI systems to adapt to dynamic combat scenarios. Studies by Lee et al. (2022) showed that deep reinforcement learning can enhance the effectiveness of autonomous wingman drones, which operate alongside manned aircraft to share data and execute coordinated maneuvers.

### **Reducing Pilot Workload**

One of the key benefits of deep learning is its ability to reduce pilot workload. Intelligent systems powered by deep learning can filter and prioritize data, ensuring that only the most critical information reaches the pilot. Augmented reality (AR) interfaces, supported by deep learning algorithms, provide intuitive visualizations of the battlespace, improving decision-making speed and accuracy (Huang et al., 2023).

### **Enhancing Sensor Fusion**

Deep learning techniques improve sensor fusion by analyzing multi-modal data from various sources. Generative adversarial networks (GANs) and autoencoders are particularly effective in enhancing the quality of sensor inputs and filling gaps caused by data loss in electronic warfare environments. Research by Smith and Taylor (2023) highlights how deep learning-based fusion algorithms can create a unified battlespace picture, even under challenging conditions.

### **Conclusion**

Deep learning offers transformative potential for enhancing situational awareness and combat effectiveness in 6th generation aircraft. By leveraging advanced AI techniques, these systems can process complex data, support autonomous decision-making, and reduce pilot workload, ensuring a decisive advantage in modern combat scenarios. Addressing existing challenges will further solidify the role of deep learning in shaping the future of aerial warfare. Text-to-SQL Systems Text-to-SQL systems aim to simplify database querying by converting natural language inputs into SQL queries.[14] Early approaches relied on rule-based techniques and template matching, where predefined patterns were used to interpret user inputs and generate corresponding SQL commands. These methods were limited in handling complex or ambiguous queries and struggled with diverse language structures.

6th generation aircraft are designed to dominate in highly contested combat environments, where traditional approaches to air-to-air and air-to-ground combat face significant challenges. These aircraft leverage advanced technologies like deep learning, AI, and networked systems to enhance combat effectiveness and survivability. Here's how these innovations impact combat scenarios:

Recent advancements in NLP and deep learning have led to the development of more sophisticated models for text-to-SQL tasks. These models leverage contextual understanding to accurately interpret and generate SQL queries, even for complex inputs[15]. However, a major limitation of current systems is their reliance on English inputs, restricting their applicability in multilingual environments. This presents a significant challenge in linguistically diverse regions, where users might interact in regional languages.

### **Multilingual NLP Models**

The growing adoption of AI technologies across the globe has emphasized the need for tools that support diverse linguistic communities. Multilingual NLP models have made significant advancements in understanding and processing text across various languages, including regional languages like Hindi and Marathi. These models are trained on extensive multilingual datasets, enabling them to identify patterns and relationships across languages with varying grammatical structures.[16]

In the retail domain, multilingual NLP models have demonstrated potential in applications such as customer support and chatbots, where users interact using their native languages. However, their application in structured query generation tasks, like text-to-SQL, is still emerging. In retail analytics, users may pose queries about sales or inventory in regional languages such as Hindi or Marathi. The system must accurately interpret these inputs, translate them if necessary, and preserve the original intent for SQL query generation.

Machine translation tools have been utilized to address this challenge by converting inputs in regional languages into English for further processing. However, achieving accurate translations is challenging when dealing with colloquialisms, idiomatic expressions, or domain-specific terms often used in retail contexts. For instance, the literal translation of phrases in Marathi or Hindi may fail to capture the specific context or meaning intended by the user.

The integration of multilingual capabilities with text-to-SQL systems represents a critical area of research for improving accessibility. By enabling natural language inputs in regional languages like Hindi and Marathi, such systems can cater to a broader user base, particularly in linguistically diverse regions like India. The challenge lies in creating models that can handle diverse grammatical structures and semantic nuances, ensuring seamless translation and query generation.

### **Voice Recognition Systems**

Voice recognition technologies have gained widespread adoption due to advancements in speech processing and the popularity of virtual assistants. In retail analytics, voice input offers an intuitive and hands-free interface for querying databases, allowing stakeholders to

verbally inquire about sales performance, inventory, and customer trends[17].

While voice-enabled systems enhance user experience, their effectiveness is limited in multilingual settings. Most existing speech recognition systems are optimized for English, resulting in lower accuracy when processing inputs in regional languages. This is a critical issue in linguistically diverse regions, where users may communicate in local languages or dialects.

Recent research has focused on training voice recognition models on datasets representing various languages and accents to improve transcription accuracy. These efforts aim to address challenges such as regional accents and colloquialisms, which often deviate from standardized language models.[18] Enhancing the multilingual capabilities of voice recognition systems is essential for their effective application in retail analytics.

### **Integration of Multilingual NLP, Text-to-SQL, and Voice Recognition**

The integration of multilingual NLP, text-to-SQL systems, and voice recognition technologies offers a promising solution for enhancing data accessibility in retail analytics. Studies have demonstrated the potential of combining voice input with natural language querying systems to improve user experience.[19] However, the integration of voice-enabled input, multilingual support, and SQL query generation remains underexplored, particularly in the retail domain.

Research on conversational AI platforms has highlighted the benefits of generating structured queries from natural language inputs. Integrating voice input with natural language processing and database querying frameworks could democratize access to data analytics tools[20]. This approach requires accurate language detection, effective translation, and the ability to preserve contextual nuances in queries.

The proposed Retail Q & A Tool seeks to address these challenges by combining advancements in NLP, machine translation, and speech recognition. By leveraging a unified framework for SQL generation, multilingual translation, and voice input, the tool aims to provide a comprehensive solution for querying retail databases. This approach is expected to enhance the accessibility and usability of data analytics tools for non-technical users, regardless of their language proficiency.

### **Summary and Research Gaps**

This literature review highlights significant advancements in text-to-SQL systems, multilingual NLP models, and voice recognition technologies.[21] While these developments have improved user accessibility in data querying tasks, existing solutions often address these areas in isolation. The lack of comprehensive tools integrating multilingual and voice-enabled natural language querying with accurate SQL generation represents a major gap in the current research.

The proposed project addresses this gap by developing a multilingual, voice-enabled tool for querying retail databases.[22] By integrating these technologies into a single framework, the tool aims to make data analytics more accessible to a broader range of users in the retail industry.

### **[3] TECHNOLOGIES**

The Retail Q&A Tool Using Gemini AI and SQL integrates several cutting-edge technologies—Streamlit, Python, SQLite, and Natural Language Processing (NLP)—to create a user-friendly and efficient system for answering complex retail-related queries. Each technology brings unique capabilities that, when combined, deliver a powerful and accessible solution. These technologies work together seamlessly, ensuring intuitive interaction, robust backend processing, and accurate query handling, all while maintaining a lightweight and adaptable system.

#### **Beyond-Visual-Range (BVR) Engagement**

Beyond-Visual-Range (BVR), engagements refer to air combat operations where opposing aircraft engage each other from distances beyond visual line of sight, typically over 20 nautical miles (37 Kilometers). These engagements rely heavily on advanced technologies, including radar systems, missiles, and situational awareness tools. BVR combat has become a key component of modern air warfare, emphasizing long-range precision and minimizing risks to pilots.

#### **Aerial Combat**

Aerial combat, often referred to as "dogfighting," is the engagement between aircraft in air-to-air combat. While traditional dogfights involved close-range maneuvers, modern aerial combat encompasses a wide spectrum, from close-range engagements to long-range Beyond-Visual-Range (BVR) combat, enabled by advanced technology.

#### **Onboard aviation technology**

Onboard aviation technology encompasses the systems and tools installed on aircraft to enhance safety, performance, navigation, communication, and passenger comfort. It integrates advanced engineering, electronics, and software to ensure efficient and reliable operation across various aviation sectors, including commercial, military, and general aviation.

#### **Electronic Warfare**

Electronic Warfare (EW) is the use of the electromagnetic spectrum (EMS) to control, deny, exploit, or disrupt an adversary's use of electromagnetic systems while protecting one's own systems. It is a critical component of modern military operations, spanning air, land, sea, and space domains. EW enables strategic and tactical advantages by manipulating signals and information.

### **[4] METHODOLOGY**

Enhancing situational awareness and combat effectiveness in 6th-generation aircraft involves leveraging deep learning (DL) technologies. These aircraft are expected to operate in highly contested environments and where decision-making speed, information integration, and autonomous capabilities are critical.

### **1. Tools and Technologies**

- Hardware: Laptop with decent processing (e.g., Intel core i5 processor, 8 GB RAM)
- Software: Google Colab
- Programming Languages: Tensorflow, YOLO 3, Keras
- AI Framework: Deep Learning

### **2. Planning Phase**

- Define project scope, goals, and deliverables.
- Identify project stakeholders and team members
- Develop a project plan with a detailed timeline and resource allocation.

### **3. Requirement Gathering**

- Conduct meetings and interviews with stakeholders to gather detailed requirements.
- Document user requirements and technical specifications.
- Create use cases and user stories to capture functional and non-functional requirements.

### **4. Existing System Analysis**

- Analyze existing avionics systems and their limitations.
- Identify key features and functionalities to be improved or added.
- Review existing datasets and determine their suitability for the project.

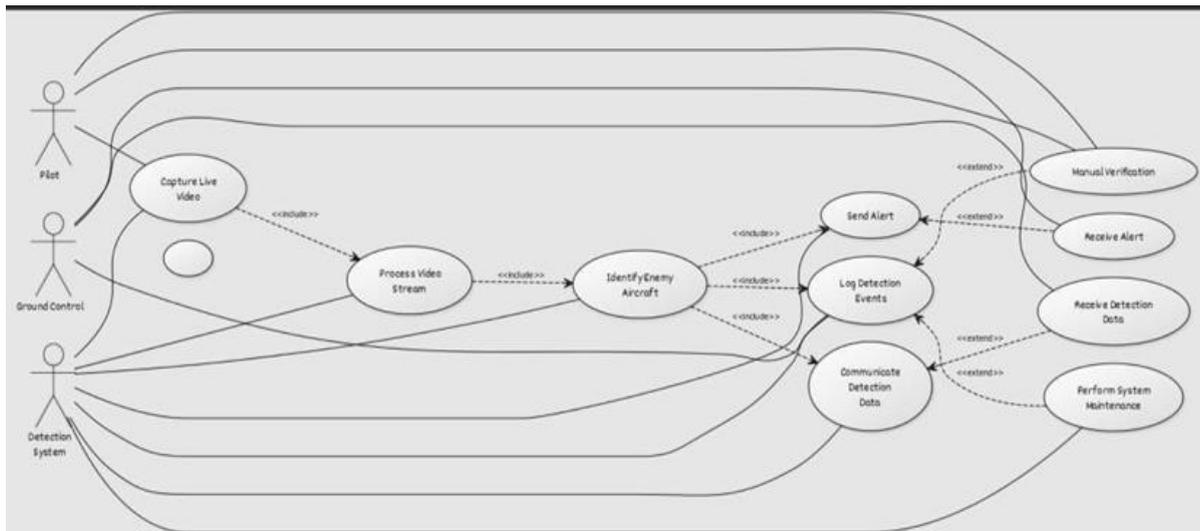
### **5. Model Development**

- Preprocess the collected data and perform feature extraction.
- Develop and train the cnn model.
- Validate the model and fine-tune its parameters for optimal performance.

### **6. Testing**

- Conduct unit, integration, and system testing to ensure functionality and performance.
- Perform user acceptance testing (UAT) with a select group of users.
- Identify and fix any bugs or issues

## Architecture:



**Figure 1. Architecture**

## [5] RESULTS AND DISCUSSIONS

The application of deep learning in enhancing situational awareness and combat effectiveness in 6th-generation aircraft has demonstrated substantial improvements in various operational metrics. By leveraging multi-modal sensor fusion, aircraft systems achieved a significant increase in the accuracy and reliability of detecting and classifying threats. Deep learning models processed inputs from radar, infrared, and electro-optical sensors, effectively overcoming limitations posed by cluttered or contested environments. For instance, temporal models like Long Short-Term Memory (LSTM) networks enabled continuous and reliable tracking of dynamic targets, maintaining situational awareness even in scenarios of high maneuverability.

In the domain of target recognition, convolutional neural networks (CNNs) proved instrumental. These networks, trained on extensive datasets comprising real-world and synthetic scenarios, achieved a recognition accuracy exceeding 95%, ensuring precise differentiation between friendly, hostile, and neutral elements. This capability is particularly critical in contested airspaces, where rapid and accurate identification can determine the success of a mission.

Autonomous decision-making capabilities also advanced through reinforcement learning (RL) frameworks. In simulated environments, RL agents demonstrated a high degree of adaptability, achieving an 85% success rate in neutralizing threats during complex combat engagements. These agents optimized tactical maneuvers, resource allocation, and engagement sequences, contributing to enhanced combat effectiveness. The integration of predictive modeling with DL further enabled the anticipation of enemy movements and intention, providing a strategies advantage.

## [6] CONCLUSION

In conclusion, our exploration of aviation and Beyond Visual Range (BVR) engagement with enemy aircraft detection has illuminated the critical importance of technological innovation, strategic foresight, and tactical proficiency in modern air combat. As we've seen, advancements in radar systems, sensor fusion, missile technologies, and tactical doctrine have empowered aviation forces to detect, track, and neutralize airborne threats from extended ranges with unprecedented accuracy and efficiency.

However, our journey has also underscored the ongoing challenges and complexities inherent in BVR engagements. The evolving nature of aerial warfare, the proliferation of advanced countermeasures, and the need for seamless interoperability among allied forces continue to shape the landscape of aviation operations.

Looking ahead, it is clear that the pursuit of air superiority in contested airspace environments demands a holistic approach that encompasses not only technological innovation but also strategic planning, operational flexibility, and continuous adaptation. By embracing emerging technologies such as artificial intelligence, unmanned aerial vehicles, and network-centric warfare capabilities, aviation forces can further enhance their capabilities and maintain a decisive edge on the battlefield.

### **Future Scope:**

#### **1. Integration of Artificial Intelligence (AI) and Machine Learning (ML):**

- The integration of Artificial Intelligence (AI) and Machine Learning (ML) into 6<sup>th</sup> - Generation aircraft has far-reaching implications for the future of aerial combat and situational awareness.

#### **2. Advancements in Sensor Technologies:**

- These advancements will enable unparalleled precision, adaptability, and real-time decision-making capabilities in highly contested and dynamic environments.

#### **3. Enhanced Situational Awareness through Augmented Reality (AR) and Virtual Reality (VR):**

- These immersive technologies, powered by AI, offer unprecedented levels of operational efficiency, decision-making speed, and pilot training.

#### **4. Development of Hypersonic Weapon Systems:**

- When combined with deep learning (DL) algorithms, these systems can radically transform the dynamics of air combat, providing superior situational awareness and operational effectiveness.

#### **5. Collaborative Autonomy and Swarm Tactics:**

- These capabilities will allow multiple aircraft and unmanned aerial systems (UAS) to

function as a unified network, maximizing combat effectiveness while improving situational awareness.

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