Project STRIKE: Swarm Tactical Reconnaissance and Intelligence with Kinetic Efficiency

PARTH BHARWAD

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presented in partial fulfilment of the requirement for the degree of MSc Computer Science to the School of Engineering, Arts, Science and Technology

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SITUATION

Modern battlefields demand real-time intelligence, surveillance, and reconnaissance (ISR)

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- Traditional ISR assets (satellites, UAVs) are expensive, Centralized, slow to respond.

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HOW ISR WORKS

Most militaries (including NATO/UK MOD) describe ISR as a **cycle** often called **TCPED**:
Tasking → Commanders set requirements
Collection → Sensors gather raw data
Processing → Raw data is converted into usable form
Exploitation → Analysts interpret the processed data, identifying patterns or threats.
Dissemination → Intelligence is delivered quickly to decisionmakers, effectors (like artillery or aircraft), or other analysts.

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How Project STRIKE Outsmarts Traditional ISR?

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Centralization vs. Decentralization

Traditional ISR: Relies on centralized, high value platforms (satellites, AWACS, manned aircraft)

Weakness: A single point of failure disrupt the comms or disable the platform, and ISR collapses

STRIKE Advantage: A swarm is decentralized even if drones are lost, the mission continues

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Agility vs. Rigidity

Traditional ISR: Tasking, processing, and dissemination cycles can take minutes to hours

Weakness: Slow to adapt in fluid, high threat environments

STRIKE Advantage: Swarm adapts in real time, dynamically reallocating drones to new tasks (patrol, recon, engage)

Survivability vs. Vulnerability

Traditional ISR: Large, expensive assets are high value targets for SAMs, jamming, or cyber attacks

Weakness: Losing one = catastrophic mission failure

STRIKE Advantage : Swarm resilience number of cheap drones are harder to neutralize than 1 large aircraft

Coverage vs. Blindspot

Traditional ISR: Limited by flight paths, orbits, and sensor range

Weakness: Gaps in surveillance, especially in urban area

STRIKE Advantage : Swarm disperses and blankets an area, providing persistent coverage and automatic gap filling

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Intelligence overload vs. Efficiency

Traditional ISR: Produces a flood of data, requires analysts to sift through, Delays decisions

Weakness: Human bottleneck

STRIKE Advantage : Built in AI filtering → drones share processed, prioritized Intelligence instead of raw data. Speeds up decision making.

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Counter ISR Capability

Traditional ISR: Not designed to actively contest or deceive enemy ISR.

STRIKE Advantage:

Swarms can:

Overwhelm sensors by presenting multiple moving targets.

Exploit clutter (urban environments, terrain masking).

Deceive enemy ISR by splitting into decoys and real engagement units.

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Which countries are **already** working on it?

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USA

Replicator Initiative: A program focused on accelerating the acquisition and fielding of thousands of inexpensive, autonomous drones by August 2025 to counter China's numerical Advantage

Perdix System: A foundational program that has developed over 670 micro drones capable of functioning as a swarm without requiring separate human control for each unit.

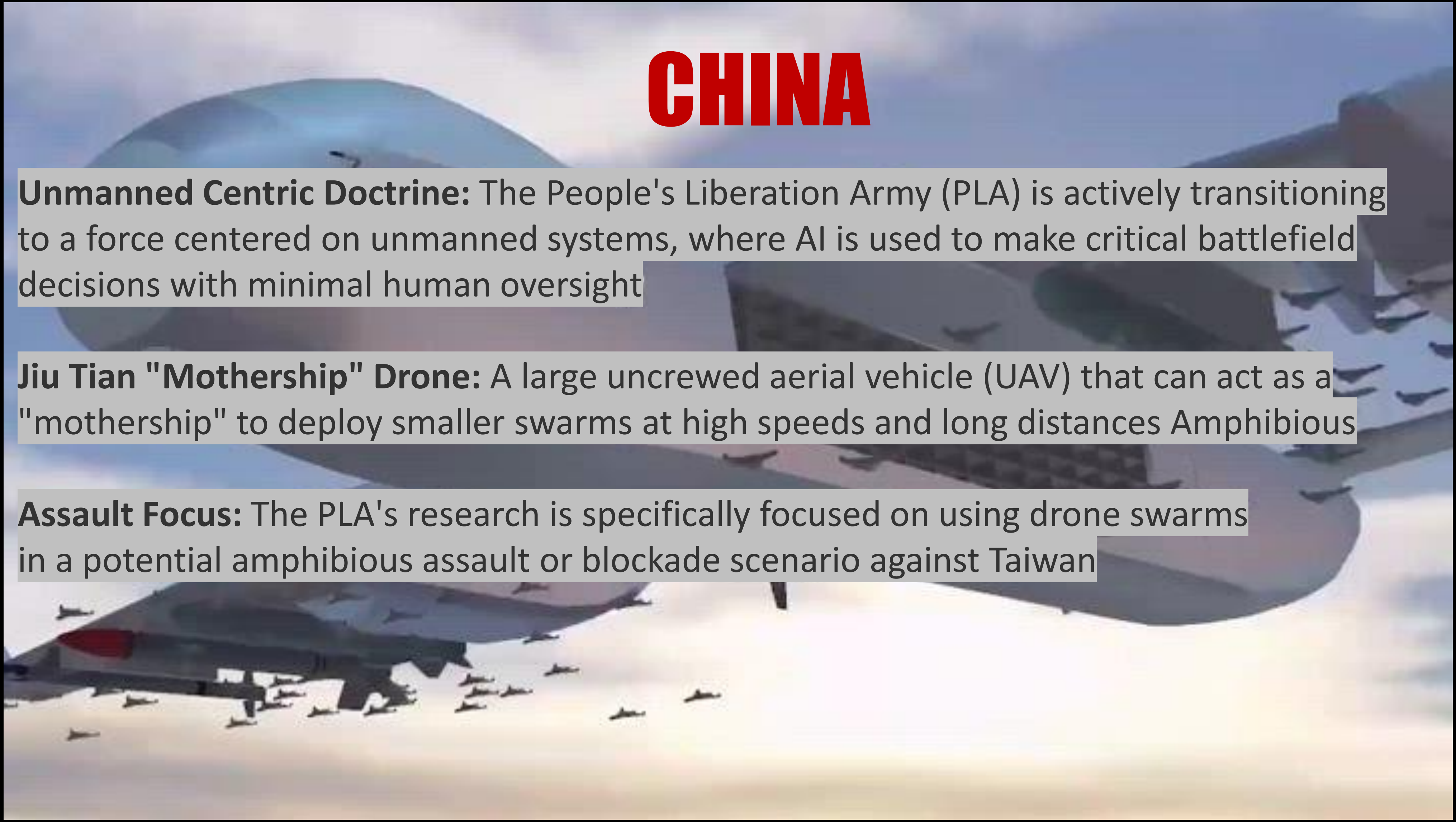
DARPA OFFSET: A program that envisions small infantry units using swarms of up to 250 drones and ground systems to conduct missions in urban environments.

UK

Mixed Multi Domain Swarms (MMDS): The UK Defence Science and Technology Laboratory (Dstl) is developing a secure architecture that enables autonomous collaboration between air, land, and maritime robotic systems. The UK is also working on swarm attack technology.

France

France: The **ASSYDUS project** is designed to make a drone swarm appear as a single entity on radar. France also integrates drones into its national defense efforts.



CHINA

Unmanned Centric Doctrine: The People's Liberation Army (PLA) is actively transitioning to a force centered on unmanned systems, where AI is used to make critical battlefield decisions with minimal human oversight

Jiu Tian "Mothership" Drone: A large uncrewed aerial vehicle (UAV) that can act as a "mothership" to deploy smaller swarms at high speeds and long distances Amphibious

Assault Focus: The PLA's research is specifically focused on using drone swarms in a potential amphibious assault or blockade scenario against Taiwan

TURKEY

Kargu2 Drone: A portable, rotary wing attack drone that can operate in swarms of up to 30 units and features autonomous navigation and target recognition based on machine learning.

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MISSION

- Provide **fast, resilient, and scalable battlefield awareness**.
- **Survive and adapt** under contested communication environments.
- Demonstrate cost effectiveness compared to legacy ISR assets.

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Execution

Simulation Environment

- Python based simulation **(NumPy, Matplotlib)**.
- **200m x 200m grid** with obstacles and **1** high value target.
- **50 UAVs** operating in swarm.

Swarm Behaviour

- Bio inspired rules: **Cohesion, Alignment, Separation**.
- Finite State Machine: **PATROL → RECON → ENGAGE**.

Optimization

- **Genetic Algorithm (GA)** tuned swarm parameters.
- Ran across multiple generations with crossover & mutation.

Evaluation Metrics

- **Survivability** of drones.
- **Target neutralization success**.
- **Steps taken to neutralize target**.
- **Distance traveled**.

CODE Execution

```python
# -------------------- Main Execution Block --------------------
def main():
    """Main function to run the full Project STRIKE pipeline."""
    # --- Step 1: Initialize Environment and Entities ---
    static_obstacles = [Obstacle((50, 50), 10), Obstacle((150, 150), 15)]
    dynamic_obstacles = [DynamicObstacle((100, 100), 5, (0.5, 0.5)), DynamicObstacle((10, 190), 8, (-0.2, 0.3))]
    no_fly_zones = [NoFlyZone((70, 90), (120, 140))]
    threat_zones = [ThreatZone((20, 50), (170, 190), energy_drain_rate=0.5)]

    # --- Step 2: Genetic Algorithm Optimization ---
    print("--- Starting Genetic Algorithm to Find Optimal Weights ---")
    hvt_initial_pos = np.random.uniform(50, 150, 2)
    ga = GeneticAlgorithm(GA_POPULATION_SIZE, GA_GENERATIONS, GA_MUTATION_RATE, GA_CROSSOVER_RATE,
                          hvt_initial_pos, static_obstacles, dynamic_obstacles, no_fly_zones, threat_zones)
    best_weights = ga.evolve()

    # --- Step 3: Multi-Trial Statistical Analysis ---
    print(f"\n--- Starting {NUM_STATISTICAL_TRIALS} Statistical Trials ---")
    trial_metrics = []
    if os.path.exists(OUTPUT_DIR):
        for file in os.listdir(OUTPUT_DIR):
            if file.endswith("_metrics.csv") or file.endswith("_log.csv"):
                os.remove(os.path.join(OUTPUT_DIR, file))

    for i in range(NUM_STATISTICAL_TRIALS):
        hvt = HighValueTarget(np.random.uniform(50, 150, 2))
        sim = Simulation(NUM_UAVS, AREA_SIZE, hvt, static_obstacles, dynamic_obstacles, no_fly_zones, threat_zones, best_weights)
        metrics = sim.run_trial(trial_id=i, log_to_csv=True)
        trial_metrics.append(metrics)

        # Save metrics for statistical plotting later
        metrics_df = pd.DataFrame([metrics])
        metrics_df.to_csv(os.path.join(OUTPUT_DIR, f'trial_{i}_metrics.csv'), index=False)

    avg_metrics = pd.DataFrame(trial_metrics).mean(numeric_only=True)

    print("\n--- Statistical Analysis Complete ---")
    print("Average Performance Metrics over all trials:")
    print(f"  Average Survivability Rate: {avg_metrics['survivability_rate']:.2f}")
```

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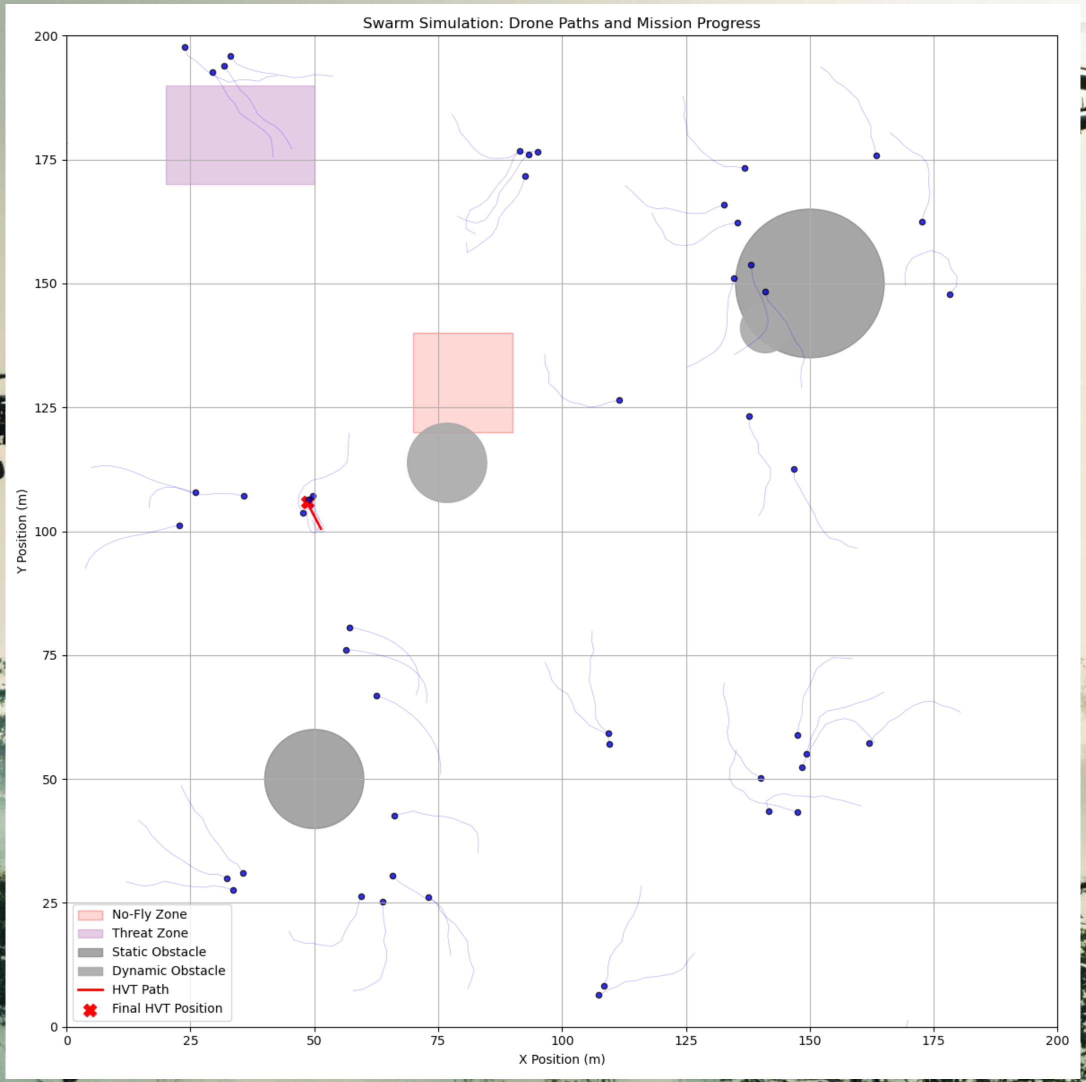
RESULTS



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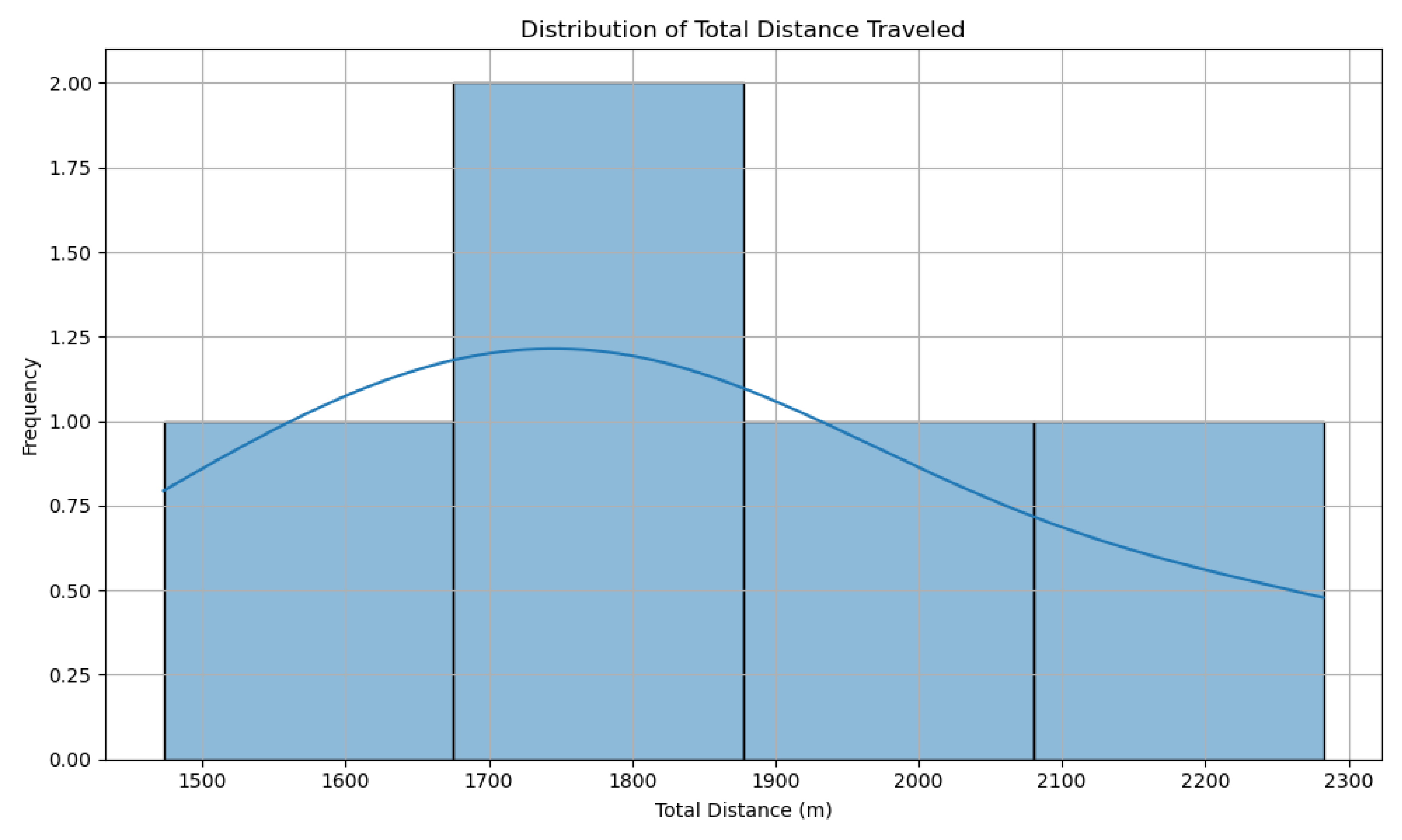

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RESULTS

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RESULTS & FINDINGS

1. Swarm Effectiveness

- Achieved **100% survivability** across trials
- Outperformed centralized ISR in adaptability and resilience

2. Algorithm Strengths

- **PSO** → rapid target engagement
- **ABC** → strong reconnaissance/exploration
- **ACO** → efficient navigation in cluttered terrain

3. Optimization Impact

- Genetic Algorithm significantly improved efficiency
- Reduced wasted movement and time to neutralization

4. Broader Implications

- Demonstrates swarms as **cost effective, scalable ISR assets**
- Raises **ethical/legal concerns** (autonomy, accountability, escalation)

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CONCLUSION

Key Takeaways

- Project STRIKE proved **swarms are resilient, efficient, and scalable ISR assets**.
- Outperformed centralized ISR in **survivability, adaptability, and speed**.
- Different algorithms fit different tasks (**PSO, ABC, ACO**).
- **Genetic Algorithm optimization** improved mission success and efficiency.

Challenges Ahead

- Ethical & legal debates (LAWS, accountability, escalation).
- Technical hurdles: secure comms, real-world deployment.

Final Thought

- Swarm intelligence offers a **new paradigm for military ISR**
- Fast, resilient, and autonomous but must be developed **responsibly**.

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THE END