MULTICOPTER DRONE-BASED AERIAL NETWORK FOR AUTONOMOUS OPERATION, DYNAMIC TARGET DETECTION & ANALYSIS

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INTRODUCTION

MOTIVATION

"Alone we can do so little, together we can do so much"

INTRODUCTION

IMPORTANCE OF SWARMING

- Zero Blind-Spots
- Faster Area Coverage
- Built-in Resilience
- Edge Intelligence

*** Swarming turns many small assets into one powerful system**

INTRODUCTION

RESEARCH OBJECTIVE

- Develop a **robust master–slave aerial network** for autonomous UAV coordination using airborne router.
- **Close proximity surveillance** with simultaneous data feed from each drone in the network to achieve an overall awareness of situation.
- Enable **dynamic target detection** via onboard vision-based processing.

BACKGROUND STUDY

BACKGROUND STUDY

CIVIL STUDY

Research Reviewed	Research Results
✓ **Precision agriculture review** Guebsi *et al.* 2024, *Drones* 8(11) : 686	"Multi-UAV teams cut mission time **by ≈ 40 %** and saved **20–30 % chemicals**."
✓ **Wild-fire response** Zhu *et al.* 2025, *Drones* 9(1) : 17	"Collaborative swarms finished suppression **35–48 % faster** than a single large UAV with the same resources."
✓ **Infrastructure inspection** Aljalaud & Alohali 2025, *Energies* 18(1) : 50	"GA-based swarm delivered **≈ 3× faster full coverage** while using **22 % less energy**."

BACKGROUND STUDY

MILITARY STUDY

Article Published	Article preview
✓ **DARPA OFFSET** *DARPA news release, 9 Dec 2021* DARPA USA	Six field experiments culminating in an **urban-canyon raid with 300+ air & ground robots** using a single immersive C2 interface.
✓ **PLA swarm & MUM-T doctrine** CASI monograph, April 2025 Air University China	Reviews PLA writings & prototypes; stresses **EW-resilient, distributed command-and-control** and a shift "from humans-with-drones → drones-with-humans."
✓ **Ukraine battlefield reporting** Modern War Institute, 10 Jan 2025 Modern War Institute -	Real-world proof that low-cost swarms can change operational art today; illustrates rapid "arms-race" feedback cycle and the value of expendable platforms.

BACKGROUND STUDY

GAP IDENTIFIED

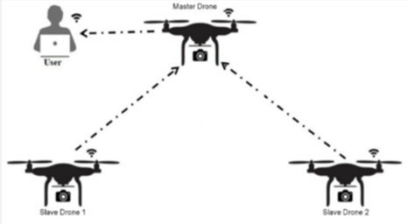
Identified Gap	Source	How our study closes the gap
Real-world **collision-avoidance** on **low-cost** platforms	Guebsi et al. 2024; DARPA OFFSET (2021)	Reliable 3 m separation using only relative positioning and onboard kinematics.
Maintaining formation while executing tasks	Zhu et al. 2025; Aljalaud & Alohali 2025	Square formation preserved during orbiting and return-home maneuvers without re-initialising the swarm.
Heterogeneous fleet architecture	CASI monograph 2025; MWI Ukraine reports 2025	Combines heavy-lift master and off-the-shelf mini-quads; full Python/DroneKit codebase released for replication.
Demonstrated dual-use workflow **(civil & defence)**	Civil MDPI studies vs. military reports	Same swarm maps crop stress, then immediately retasks to perimeter patrol showing a single codebase spans both sectors.

DRONE SYSTEM DESIGN AND SPECIFICATIONS

DRONE SYSTEM DESIGN AND SPECIFICATIONS

FABRICATION OVERVIEW

- **Octacopter** as **Master –** High payload, stable, long flight time
- **Quadcopters** as **Slaves –** Lightweight, low-cost, easy to deploy and repair

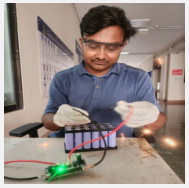


DRONE DESIGN AND SPECIFICATIONS

MASTER DRONE (OCTACOPTER)

- **Carbon fiber octagonal frame** with CNC precision.
- Payload-focused structure: **MTOW 7.2 kg** with1kg margin.
- **Power system:** 6S custom Li-ion (24 Ah), hover time ~22 mins.
- On-board **Dual 5 dBi antenna Router** for Local Area Network






DRONE DESIGN AND SPECIFICATIONS

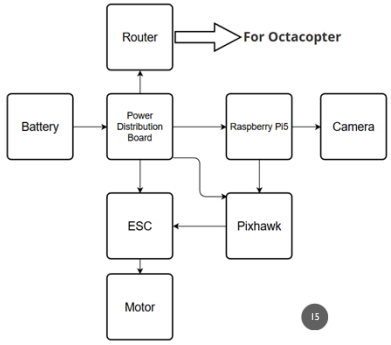
SLAVE DRONE (QUADCOPTER)

- Frame: **S500**, lightweight and agile
- Payload capacity, **MTOW**= 1.8 kg (approx.)
- **RPi Camera V3 NOIR** (for target detection)
- **Power** 4S LiPo (5200 mAh), hover 8-10 mins
- Optimized for cost-effective deployment & autonomous imaging.


DRONE DESIGN AND SPECIFICATIONS

AVIONICS AND NETWORK

- **Flight controller:** Pixhawk 4
- **Companion computer:** Raspberry Pi 5
- **Router:** D-Link DIR-615 enabling star-topology "SwarmLAN"
- Supports command broadcasting, real-time telemetry & vision processing.



DRONE DESIGN AND SPECIFICATIONS

ASSEMBLY, TESTING & OUTCOME

- **Build Process:** Arm/frame assembly, avionics wiring, pre-flight checks
- **Calibration:** Motors, ESCs, GPS, IMU
- **Tested for:** Power endurance, formation reliability, and communication
- **Outcome:** Stable platform enabling tight formation, autonomy, and vision-based missions

AUTONOMOUS DRONE SWARM ARCHITECTURE

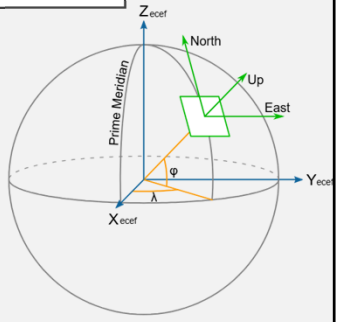
SYSTEM OVERVIEW

- A **centralized master–slave swarm architecture** enables coordinated multi-UAV missions.
- Utilizes **LAN-based star topology** for network communication.

Star Topology

ENU LOCALIZATION FRAMEWORK

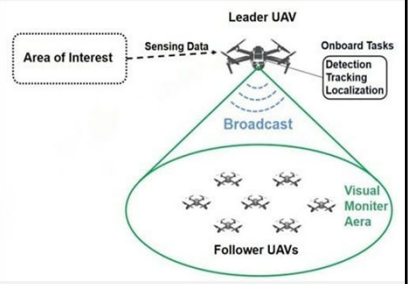
- Each drone computes position relative to master using the **ENU coordinate system.**
- It enables accurate **formation control** and spatial awareness.



DRONE SWARM ARCHITECTURE

- **Master Drone handle:**
  - Mission launch & decision-making
  - Command and network control
  - Data collection & formation updates
- **Slave Drones handle:**
  - Follow commands & hold formation
  - Obstacle detection & avoidance
  - Imaging and data transmission

Designed for fully **autonomous missions** launched via a single **SSH command.**

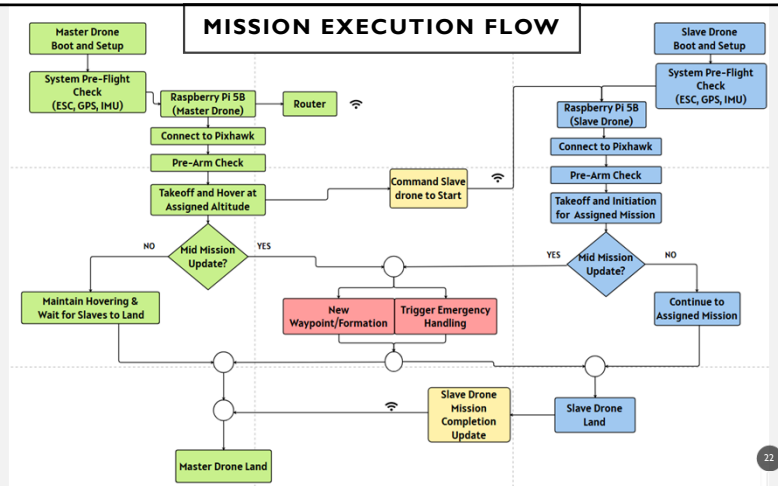


AUTONOMOUS DRONE SWARM ARCHITECTURE

SYNCHRONIZATION & COMMUNICATION

- Master sends heartbeat messages every 1 second.
- Slaves reply with:
  - Position coordinates
  - Battery status
  - Collision flags
  - Timeout (5s) triggers **auto-hover** or **RTL** for safety.
- Enables real-time swarm awareness and fail-safe behaviors.

MISSION EXECUTION FLOW



FORMATION FLYING

- Our plan was to enable drones to:
  - Fly in different tight formations
  - Detect & avoid mid-air conflicts
  - Perform **vision-guided tasks**

FORMATION FLYING

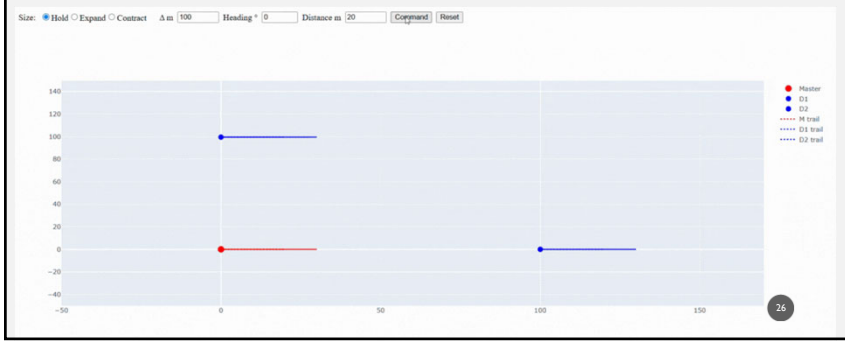
CIRCULAR ORBIT

- Slave Drones fly in a circle around the master at fixed radius.
- Ideal for surveillance and symmetric area coverage.

WINGMAN FORMATION

- Each slave maintains a fixed heading & offset from the master's body frame.
- Used for visual coverage and **tight maneuvering**

WINGMAN AND ECHELON FORMATION (HEADING HOLD)



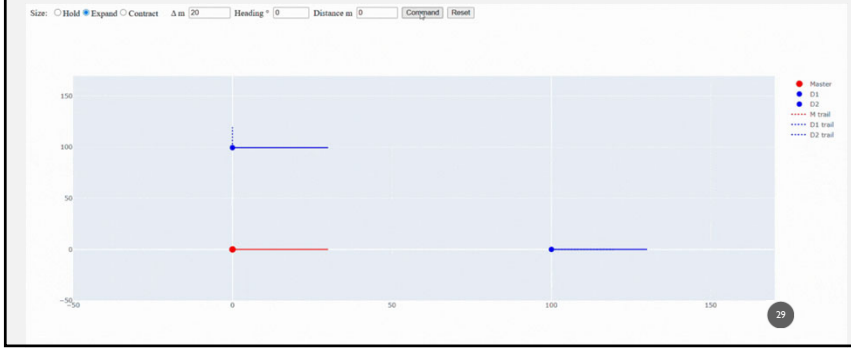
WINGMAN AND ECHELON FORMATION (HEADING CHANGE)

EXPANSION CONTRACTION

- Master sends a radius adjustment command, and slaves reposition to maintain symmetrical formation around it.
- Useful for **navigating tight spaces** or covering large areas

FORMATION FLYING

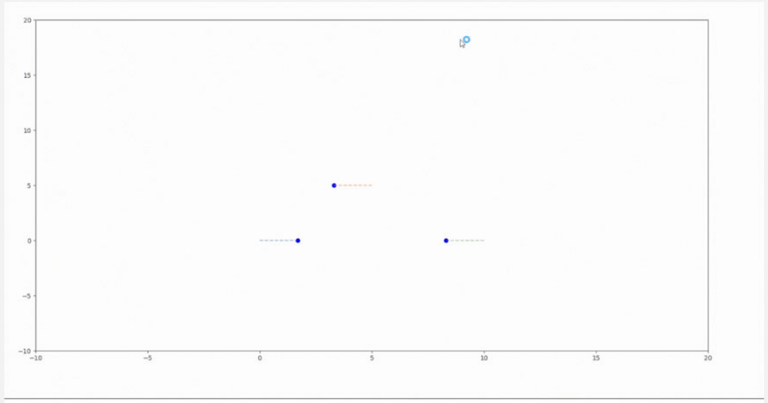
EXPANSION-CONTRACTION DYNAMICS



COLLISION AVOIDANCE

- Drones exchange **ENU positions** at 1 Hz.
- Each drone calculates distance to others in real time.
- If distance between two drones < 3 meters, it **Yaws ±15°** and **reduces speed** to avoid collision.
- If spacing is safe, drone maintains heading and speed.
- All logic runs **fully onboard**, enabling decentralized safety.

COLLISION AVOIDANCE



EMERGENCY HANDLING

- **No heartbeat for 3s** → drone hovers at 3m
- **Low battery (<20%)** → auto-RTL with broadcast alert
- **Sensor fault** → auto-climb at 3m + hover
- **ESC anomaly** → immediate landing at safe spot
- Ensures swarm safety under **unpredictable conditions**

ONBOARD VISION

- **YOLOv8n** model runs on **Raspberry Pi 5 & NoIR Camera**
- Slave drones **detect humans** in real time
- Detection confidence and counting of human sent to master drone
- Enables **vision-based mission reconfiguration**

RESULT

RESULT

OCTOCOPTER FLIGHT TEST

RESULT

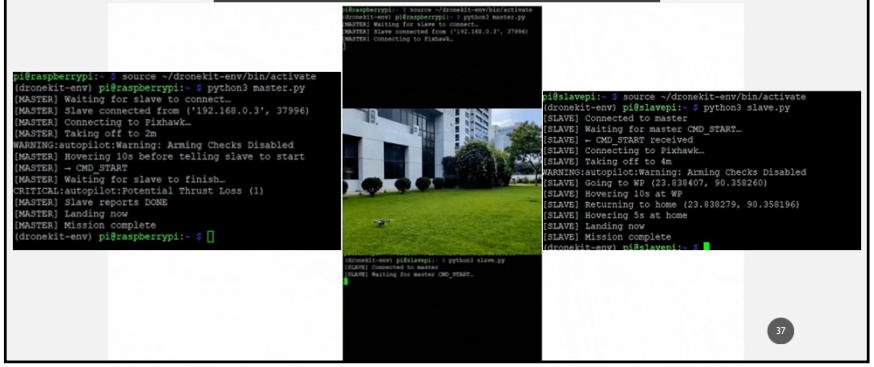
OCTOCOPTER FLIGHT LOG

```
Current location: (23.838339, 90.3582319, 5.26)
Current location: (23.8383564, 90.3582292, 5.22)
Current location: (23.8383745, 90.3582277, 5.14)
Current location: (23.8383931, 90.3582264, 5.08)
Current location: (23.8384116, 90.3582252, 4.96)
Current location: (23.8384292, 90.3582232, 4.92)
Current location: (23.8384465, 90.3582215, 4.88)
Current location: (23.838464, 90.3582204, 4.93)
Current location: (23.8384816, 90.3582192, 4.95)
Current location: (23.8384996, 90.358218, 4.98)
Current location: (23.8385139, 90.3582161, 4.96)
Current location: (23.8385239, 90.358215, 4.91)
Target location reached!
Hovering for 10 seconds
Returning to takeoff location...
Navigating to: Latitude=23.8382908, Longitude=90.3582371, Altitude=5
Current location: (23.838526, 90.3582141, 5.01)
Current location: (23.8385241, 90.3582144, 5.01)
Current location: (23.8385154, 90.3582157, 5.05)
Current location: (23.8385002, 90.3582178, 5.09)
Current location: (23.8384813, 90.3582196, 5.17)
Current location: (23.8384644, 90.3582226, 5.22)
```

```
Current location: (23.8384444, 90.3582226, 5.22)
Current location: (23.8384443, 90.3582254, 5.18)
Current location: (23.8384246, 90.3582267, 5.12)
Current location: (23.8384064, 90.3582289, 4.98)
Current location: (23.8383892, 90.3582303, 4.84)
Current location: (23.8383708, 90.358232, 4.90)
Current location: (23.8383526, 90.3582341, 5.00)
Current location: (23.8383352, 90.3582361, 5.01)
Current location: (23.838318, 90.3582377, 5.07)
Current location: (23.8383041, 90.3582392, 5.08)
Current location: (23.8382944, 90.3582403, 4.90)
Target location reached!
Hovering for 5 seconds
Landing...
Altitude: 4.98 meters
Altitude: 4.84 meters
Altitude: 4.22 meters
Altitude: 3.74 meters
Altitude: 3.31 meters
Altitude: 2.91 meters
Altitude: 2.62 meters
Altitude: 1.53 meters
Altitude: 1.26 meters
Altitude: 0.82 meters
Altitude: 0.27 meters
Closing vehicle connection...
Mission complete.
```

RESULT

NETWORK WITH TWO DRONES

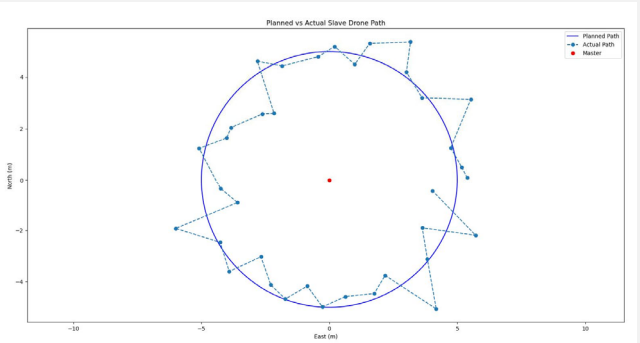


RESULT

SLAVE ORBITING MASTER

RESULT

SLAVE ORBITING MASTER



RESULT

SLAVE ORBITING MASTER

Metric	Value
Mean radial error	0.600 m
RMSE radial error	0.768 m
Max radial error	1.612 m
Mean heading error	2.234°
Std dev heading error	1.162°
Path-length error	+8.867 m (14.11 %)
Fitted-circle radius Δ	0.040 m
Residual scatter	0.440 m

RESULT

SQUARE FORMATION

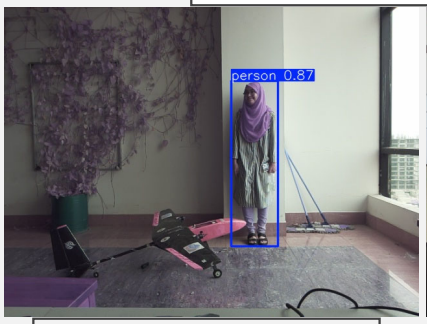
RESULT

SQUARE FORMATION

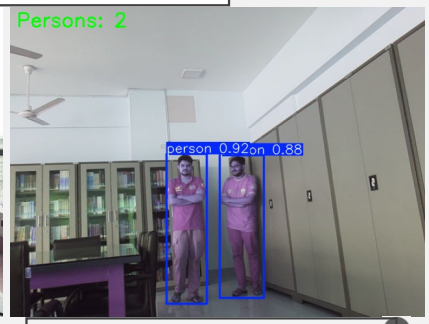
- 2-3meter GPS drift in open field resulted distorted square
- While moving with speed, the slave drone decreases its altitude slightly
- Less effect on field of view due to wide angle camera

RESULT

DYNAMIC TARGET DETECTION



INDOOR (MULTIPLE OBJECT)



INDOOR LIGHTING

RESULT

DYNAMIC TARGET DETECTION

OUTDOOR (WITH MOTION)

RESULT

DYNAMIC TARGET DETECTION

Scenario	Precision (%)	Recall (%)	F1-Score (%)	Avg. Confidence (%)
Indoor - Daylight	77	85	81	88
Indoor - Multiple Object	64	70	67	74
Outdoor – with Motion	72	78	75	80

*** Average of around 100 samples**

RESULT

ACHIEVEMENT CHECKLIST

✓ Field-tested **drone swarm networking** with **on-board router**

✓ ±3 m multi- swarm formation

✓ Inter-drone Collision Avoidance Algorithm

✓ Real-time AI on low-cost SBCs

CONCLUSION

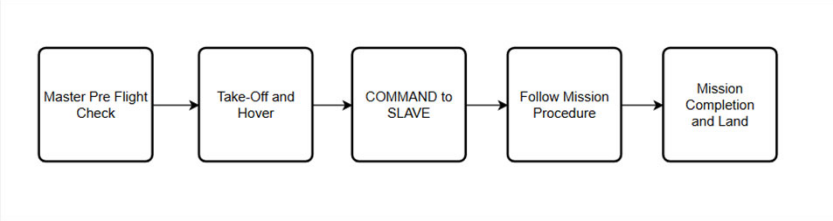
CONCLUSION

SYSTEM SUMMARY

- Designed and validated a **master–slave UAV swarm** combining one octacopter and two quadcopters.
- Developed a **swarm architecture** with ENU-based localization and real-time communication.
- Implemented autonomous planning for **surveillance** and **target detection**.
- Field-tested under real conditions, achieving **reliable formation accuracy** and coordination.

CONCLUSION

SYSTEM SUMMERY



CONCLUSION

CURRENT LIMITATIONS

- Limited to **three UAVs**; large-scale swarm behavior not tested.
- No avoidance of **static or dynamic obstacles** in the environment.
- Field trials lacked testing in **complex terrain** or **high-interference zones**.
- **Onboard AI** was limited by Raspberry Pi's computational capacity.

CONCLUSION

SCOPE FOR IMPROVEMENT

- Expand to **multi-layer hierarchical swarms** for scalable operations.
- Add **LIDAR or stereo-vision sensors** for full environmental awareness.
- Integrate **hardware AI** for real-time vision-based decisions.
- Improve energy management with **battery-aware mission** planning.

CONCLUSION

IMPACT

Precision AG (Civil Use)	**Precision ISR** (Military Use)
○ **Precision Agriculture :** Faster Survey Cycle	○ **Intrusion-alert latency** : Faster than lone UAV
○ **Battery per hectare :** 40% saving	○ **Blind-spot gaps :** 0 → Full fence visual
○ **Row-coverage gaps :** 0 → 100% coverage	○ **Attritable Mass & Decoy** : low-cost slaves can absorb hostile fire or jam radars

CONCLUSION

CONCLUDING REMARKS

- Portable, fast, and **easily deployable** network for data collection in remote outdoor areas.
- Proves that **low-cost, modular UAV swarms** can operate autonomously.
- Suitable for real-world tasks like **reconnaissance** and **disaster response.**

ACKNOWLEDGEMENT

THANK YOU

QUESTION-ANSWER SESSION