Mälardalen University
M.Sc.Eng. Dependable Aerospace Systems
Västerås, Sweden

Project Course in Dependable Systems
22.5 credits

Pre-Study

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Contents

Glossary

ACO
: Ant Colony Optimisation. 6

ad-hoc
: Created or done for a specific purpose or situation without prior planning or structure. 5, 6

agent
: A single UAV that is a member of a UAV swarm. 4, 8

CE
: Chief Engineer. 11

CM
: Configuration Manager. 12

CMP
: Configuration Management Plan. 10

FANET
: Flying Ad-hoc Network. 5, 6

FMU
: Fault Management Unit. 4

IRDS
: Intelligent Replanning Drone Swarm. 4, 5, 8

QCM
: Quality & Configuration Manager. 11

QM
: Quality Manager. 12

QMP
: Quality Management Plan. 10

RM
: Requirements Manager. 11

RMP
: Requirements Management Plan. 10, 12

SAR
: Search and Rescue. 4, 8

SM
: Safety Manager. 11

SMP
: Safety Management Plan. 10, 12

UAV
: Unmanned Aerial Vehicle. 4–6, 8

V&V
: Validation & Verification. 10

VVM
: Validation & Verification Manager. 11

VVMP
: Validation & Verification Management Plan. 10, 12

1 Introduction

- **Project title:** Intelligent Replanning Drone Swarm (IRDS).
  Orignal title: Intelligent Replanning Protocol for a Fail-Operational Drone Swarm.
- **Project owner:** Luiz Giacomossi

1.1 Background

The Intelligent Replanning Drone Swarm (IRDS) project will address the challenge of maintaining mission continuity in Search and Rescue (SAR) operations when individual Unmanned Aerial Vehicles (UAVs) suffer degraded health or fail entirely. Previous work by [1] established a high-level blueprint for a safety-driven conceptual architecture for a fail-operational UAV swarm intended for SAR missions. The architecture contained a Fault Management Unit (FMU) to detect hardware component failures and broadcast a degraded health message across the swarm. The next step is to transform this information into a protocol for collective replanning.

In dynamic and uncertain environments, conventional single-UAV fault tolerance is insufficient. Instead, swarms must demonstrate fail-operational behaviour by continuing their mission despite the loss or degradation of one or more agents. This requires distributed consensus, adaptive task allocation, and resilient communication. The project shall build on current research on swarm resilience, distributed consensus, and communication architectures while focusing on dependable design and validation.

The IRDS project builds on this foundation by transforming that degraded health message into swarm-level replanning logic to enable the swarm to continue its SAR effectively even when one or more UAVs are degraded.

To achieve this, the following challenges must be addressed:

1) Distributed Consensus
2) Dynamic Task Allocation
3) Protocol Design
4) Validation

The contribution of the project team will be to create a decentralised replanning protocol that allows a degraded UAV to hand over its tasks, assume a secondary role, and allow the swarm to reach consensus on what to do – all validated in simulation with fault injection.

1.2 Purpose

The purpose of this pre-study is to establish the foundations for a decentralised replanning protocol that ensures SAR missions can continue with maximum effectiveness despite UAV degradation. This includes:

- Review prior work on consensus, task allocation, and communication in UAV swarms.
- Define the conceptual system description and dependability objectives.
- Identify relevant standards and regulations to guide the project.
- Outline planned activities, roles, and deliverables for the project.

1.3 Scope

The scope of this project is limited to the design, simulation (using gym-pybullets-drone [2]), and validation and verification of the replanning protocol. The project will establish what the UAV swarm will do, not how to do it. Hardware implementation and certification are excluded. The replanning protocol will be validated using a modified version of the simulation software, using fault injection, to test the performance of the replanning protocol. The outcome will be a validated protocol design, documented processes, and assurance artefacts in accordance with the FLA402 course requirements and course guide [3].

2 Related Work

Year	Title	Main Focus	Relevance to IRDS
2025	Design of a Fail-Operational Swarm of Drones for Search and Rescue Missions [1]	High-level blueprint for a conceptual architecture for a fail-operational UAV swarm.	Degraded health message.
2023	Cooperative Search and Rescue with Drone Swarm [4]	Distributed coordination and search resilience in UAV SAR missions.	Defines the application domain and justifies decentralised swarm cooperation for dependability.
2021	Autonomous and Collective Intelligence for UAV Swarm in Target Search Scenario [5]	Conceptual architecture for autonomous & collective intelligence in target search.	Serves as a theoretical base.
2025	Development of Adaptive Drone Swarm Networks [6]	Adaptive network layer (AeroSyn)	Suggests implementation model for health-state messaging
2025	Dynamic reconnaissance operations with UAV swarms: adapting to environmental changes [7]	Dynamic replanning under failure	Provides comparative benchmark and validation model
2025	Energy Efficient Scheduling for Position Reconfiguration of Swarm Drones [8]	Energy-efficient reconfiguration	Supports energy-aware task redistribution
2023	A Novel Distributed Situation Awareness Consensus Approach for UAV Swarm Systems [9]	Distributed consensus	Algorithmic basis for swarm agreement
2022	A Review of Consensus-based Multi-agent UAV Implementations [10]	Consensus-based UAV control	Practical implementation insights
2021	Review of Dynamic Task Allocation Methods for UAV Swarms Oriented to Ground Targets [11]	Dynamic task allocation	Framework for reallocation strategy
2019	UAV swarm communication and control architectures: a review [12]	Swarm communication architectures	Justifies decentralised, FANET-based design

Table 1: Caption

2.1 Cooperative Search and Rescue with Drone Swarm

This paper presents a cooperative search-and-rescue (SAR) strategy using UAV swarms. It explores collective intelligence, distributed coordination, and fault-tolerant cooperation among UAVs in dynamic SAR missions. The swarm shares situational data to maintain coverage and efficiency while adapting to UAV losses or degraded conditions.

2.2 Autonomous and Collective Intelligence for UAV Swarm in Target Search Scenario

This paper investigates collective intelligence architectures for UAV swarms performing target-search missions. It introduces autonomous decision layers combining individual UAV autonomy (sensing, navigation) with collective coordination for search coverage.

2.3 Development of Adaptive Drone Swarm Networks

This paper introduces AeroSyn, a hybrid network architecture that combines cellular and ad-hoc links. It enables UAVss to switch between connected and leader-follower communication modes to maintain stable swarm coordination.

2.4 Dynamic reconnaissance operations with UAV swarms: adapting to environmental changes

This paper develops a dynamic mission-replanning framework for UAV swarm reconnaissance using Ant Colony Optimisation (ACO). The model handles two events that force the system to adapt:

1) Swarm composition changes (e.g., UAV failures/additions).
2) Mission or environment changes (e.g., new area of responsibility).

2.5 Energy Efficient Scheduling for Position Reconfiguration of Swarm Drones

This study proposes an energy-balancing reconfiguration scheme for UAV swarms operating in urban wind fields. The model determines when and how UAVs should exchange positions to equalise energy use and extend swarm flight time.

2.6 A Novel Distributed Situation Awareness Consensus Approach for UAV Swarm Systems

This paper proposes a distributed situation awareness consensus framework that allows UAVs to share perception and align decision-making without a central controller. It introduces a dual-loop feedback mechanism to maintain robust cognitive agreement.

2.7 A Review of Consensus-based Multi-agent UAV Implementations

This review analyses consensus-based distributed control for UAV swarms. The review highlights practical issues in formation flight and target tracking, focusing on how communication delay and sensing accuracy affect practical use.

2.8 Review of Dynamic Task Allocation Methods for UAV Swarms Oriented to Ground Targets

This review surveys dynamic task allocation methods for UAV swarms facing changing ground-target situations. The review classifies dynamic task allocation models into global and local approaches and analyses algorithms including market-based, intelligent optimisation, and clustering strategies. Each method's advantages and practical performance trade-offs are discussed. The review identifies ongoing challenges such as communication limits and heterogeneous UAV swarms, and suggests future integration of AI and distributed optimisation for adaptive task allocation.

2.9 UAV swarm communication and control architectures: a review

This paper reviews UAV swarm communication and control architectures by comparing centralised (ground-based) and ad-hoc (FANET) models. The paper discusses autonomy levels, swarm coordination algorithms, and the potential of 5G networks to improve UAV-to-UAV communication. The paper highlights the need for hybrid architectures that combine distributed decision-making with reliable infrastructure support to overcome range, latency, and scalability issues.

3 System Description (Baseline)

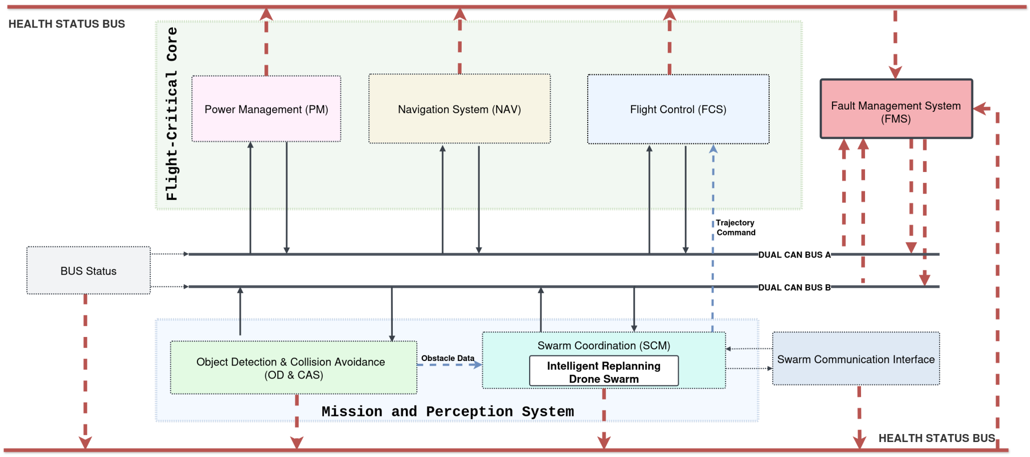

Figure 1: Baseline system architecture.

A larger version of figure 1 can be found in the Appendix (figure 2).

4 Dependability Perspective

The IRDS project is focused on dependability, and the project's success depends on the swarm's ability to complete SAR missions in uncertain and dynamic environments, even when individual UAVs degrade. The following dependability properties are central to the project:

- Reliability
- Availability
- Safety

Those attributes shall ensure that the replanning protocol design does not focus only on functionality, but also incorporates dependability as an objective. Each of the dependability properties mentioned are achieved by the project's management plans (Safety, Quality, Requirements, V&V, and Configuration) to guarantee consistency and traceability during the development process.

4.1 Reliability

The UAV swarm must continue to perform its SAR mission despite the loss or degradation of one or more UAVs. Reliability will be achieved by implementing distributed consensus and task reallocation mechanisms that prevent mission failure when agents are compromised. The replanning protocol must tolerate both single-UAV faults and swarm-level faults. This includes graceful performance degradation when a UAV is partially functional and collective resilience when UAVs are lost. Fault injection in simulation will be used to validate the system's robustness against such conditions.

4.2 Availability

The UAV swarm should remain operational as long as possible, ensuring that SAR coverage is maintained unless the number of failed drones reaches a critical threshold. The ability to retask degraded UAVs as communication relays or in less demanding roles supports availability by ensuring continued contribution of partially functioning agents.

4.3 Safety

Replanning must not introduce unsafe behaviours, such as mid-air collisions or conflicting tasks. Safety shall be considered by following established standards (ARP4754A, ARP4761A, and SORA), and by defining safety requirements that prevent hazardous states.

5 Standards & Regulations

The selection of standards (table 2) for the project ensures that the project is consistent with recognised international standards and guidelines.

Document ID	**Document Title**
IEEE Std 1012-2024	IEEE Standard for System, Software, and Hardware Verification and Validation [13]
ISO/IEC/IEEE Std 29119-1:2022	Software and systems engineering - Software testing - Part 1: General Concepts [14]
ISO/IEC/IEEE Std 29119-4:2021	Software and systems engineering - Software testing - Part 4: Test techniques [15]
ISO/IEC/IEEE Std 15288:2023	Systems and software engineering - System life cycle processes [16]
ISO/IEC/IEEE 29148:2018	Systems and software engineering - Life cycle processes - Requirements engineering [17]
ISO 10007:2017	Quality management - Guidelines for configuration management [18]
ISO 9001:2015	Quality management systems — Requirements [19]
ISO/IEC 25002:2024	Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Quality model overview and usage [20]
IEEE 730-2014	IEEE Standard for Software Quality Assurance Processes [21]
JAR-DEL-SRM-SORA-MB-2.5	Specific Operations Risk Assessment (SORA) [22]
ARP4754A	Guidelines for Development of Civil Aircraft and Systems [23]
ARP4761A	Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment [24]

Table 2: Standards and guidelines.

6 Planning of Activities

6.1 Pre-study & Planning Phase

- Date: 2025-09-01 - 2025-10-05
- Literature review of related work
- Baseline system description
- Define the perspective of dependability
- Define relevant standards and guidelines
- Create Project Plan
- Create Management Plans
    - Configuration Management Plan (CMP)
    - Quality Management Plan (QMP)
    - Requirements Management Plan (RMP)
    - Safety Management Plan (SMP)
    - Validation & Verification Management Plan (VVMP)

6.2 SEM1

- Date: 2025-10-09
- Oral examination of the Pre-study & Planning Phase

6.3 Execution & Validation Phase

- Date: 2025-10-06 - 2025-11-16
- Requirements elicitation
- Safety requirements elicitation
- Validation & Verification
- Configuration Management
- Quality Management
- Design replanning protocol by developing distributed consensus and task allocation logic
- Modify simulation software (gym-pybullet-drone [2]) for fault injection and protocol tests.

6.4 SEM2

- Date: 2025-11-20
- Oral examination of Execution & Validation Phase

6.5 Reporting Phase

- Date: 2025-11-17 - 2025-12-07
- Final report

6.6 SEM3

- Date: 2025-12-11
- Presentation of the project

7 Roles & Responsibilities

The IRDS project is organised according to a role-based structure:

- Chief Engineer (CE)
  - Provides overall technical leadership and ensures that all work aligns with the system concept and project objectives
  - Approves design choices and oversees integration of results from other roles
  - Acts as the main point of contact with the project owner and examiners
- Requirements Manager (RM)
  - Responsible for eliciting, documenting, and maintaining requirements
  - Ensures traceability between stakeholder needs, system functions, and dependability objectives
  - Works closely with the VVM to guarantee that all requirements are verifiable, and works with the SM to ensure safety-critical requirements are properly captured.
- Safety Manager (SM)
  - Identifies hazards and defines safety goals
  - Ensures that safety considerations are incorporated into the design of the replanning protocol
  - Works closely with the CE and RM to embed safety into requirements and system architecture
- Quality & Configuration Manager (QCM)
  - Maintains consistency and traceability across all project artefacts
  - Manages version control, document reviews, and configuration baselines
  - Supports all team members in adhering to quality processes and ensures that deliverables meet expected standards
- Validation & Verification Manager (VVM)
  - Defines the V&V strategy, including test cases and fault injection scenarios
  - Ensures compliance with relevant standards
  - Works with the CE to validate that the protocol meets stakeholder needs and with the RM to ensure requirements are testable.

8 Expected Outcomes

The deliverables expected from each phase are:

8.1 Pre-study & Planning Phase

- Baseline system description
- Project Plan
- Requirements Management Plan
- Safety Management Plan
- Validation & Verification Management Plan
- Configuration Manager
- Quality Manager
- Review protocols

8.2 Execution & Validation Phase

- System Architecture
- Design Specification
- Configuration Logs
- Review Protocols
- Requirements Specification
- Safety Goals & Requirements
- Preliminary Safety Assurance Case
- Risk Analysis
- Validation Protocols
- Verification Protocols
- Test Specification

8.3 Reporting Phase

- Final Report

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Appendix

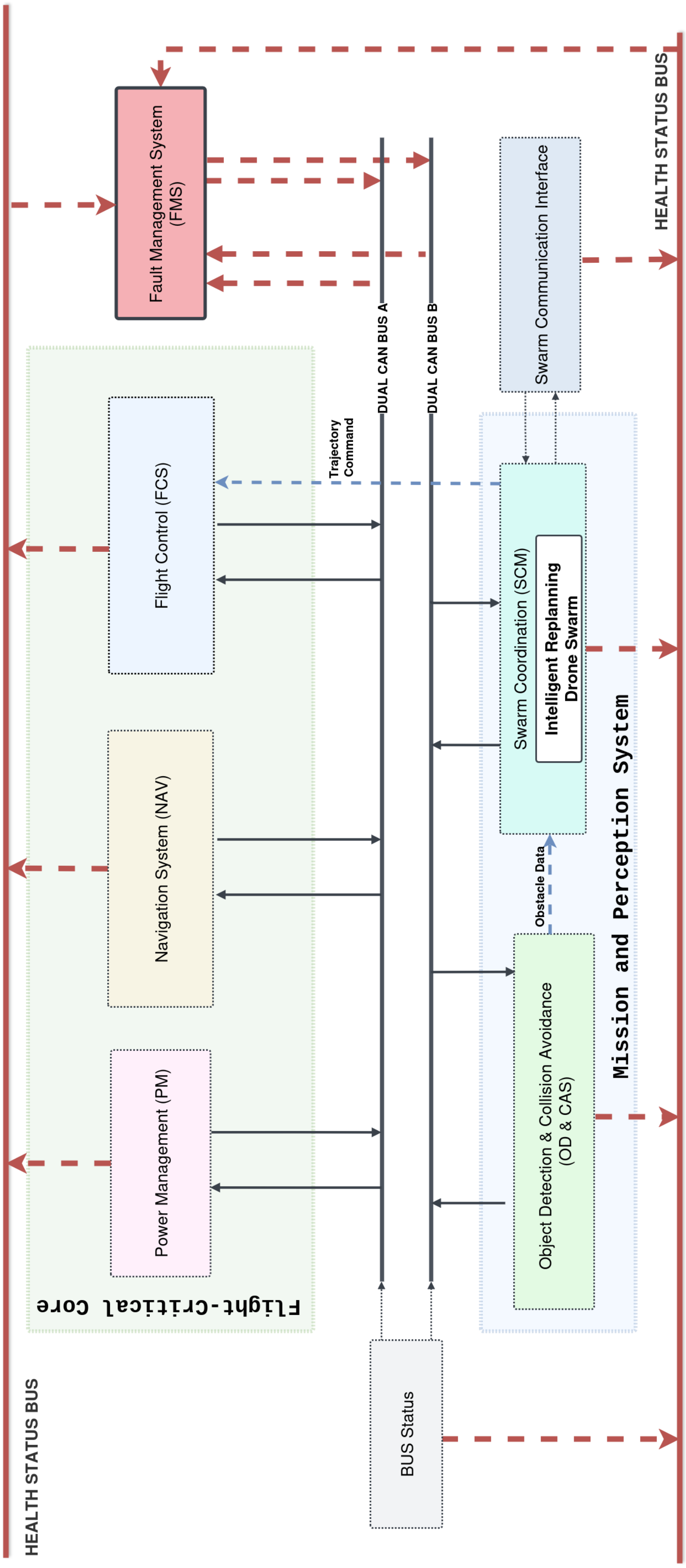

Figure 2: system architecture.