

System Design Document

For

Aerial Swarm Simulator

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SYSTEM DESIGN DOCUMENT

1 INTRODUCTION

1.1 Purpose and Scope

The purpose of this System Design Document is to provide design details of the aerial swarm simulator system. This document encompasses system architecture, the human-machine interface, the software design, the communication design, external interfaces, and system integrity.

1.2 Project Executive Summary

This section provides an overview of the Aerial Swarm Simulation project from a management perspective, this shows the system design framework.

1.2.1 System Overview

This system uses Unreal Engine to simulate the environment and drones make up the simulation. The system takes input from the user on what the drone swarm needs to do in the form of coordinates where an object that needs to be measured is located. The system then simulates the drone swarm flying to and accomplishing the given mission. The user receives data from the simulated drones which appear on the screen in a window that opens on system start. This data can be saved for future use.

Ground control operations such as mission input and saved data will be future work not in this implementation.

A system overview use case diagram is available in Appendix A – Figure 1. This diagram shows the actors and how they interact with the system. The swarm, payload, and ground control are all actors on the swarm system.

Ground control implementation will be future work not in this iteration.

1.2.2 Design Constraints

The design constraints are that the system must be able to run on Unreal Engine. The system must also be able to function autonomously with the only human input being the mission details.

Human input with a ground control station will be future work not in this iteration.

1.2.3 Future Contingencies

Future use of the system could lead to changes in design. If future use of the system were to require autonomous drones led by a human controlled drone the design of the system would have to change. A new human-machine interface would have to be implemented to allow for control and monitoring of the human controlled drone in Unreal Engine. The implementation of the swarm would change as well. The lead drone would be designated as the human controlled drone instead of an unmaned drone. The human machine

interface would also have to be implemented to add controls such as starting the measurement method to account for human control of the simulation as opposed to being an autonomous system.

1.3 Document Organization

This document has notation that indicates current implementation and future implementation for aspects of the system design. The current implementation is not specially notated, the future implementation aspects of system design are clearly notated with **yellow highlight**.

This document is organized by section. These sections break into more detailed pieces. The architecture and detailed design break down into hardware, software, and internal communications. The interface sections break down into inputs and outputs, and architecture and design. The final section covers the system integrity.

1.4 Project References

Links to references listed in this section are in Appendix A Section 7.6.

[1] AirSim program, libraries, and provided tutorials

[2] Unreal Engine platform

[3] Swarming algorithms paper

1.5 Glossary

[1] Unmanned Aerial Vehicle abbreviated as UAV

[2] Unmanned Aircraft abbreviated as UA

[3] Input and Output abbreviated as I/O

[4] Global Positioning System abbreviated as GPS

[5] Valence Shell Electron Pair Repulsion abbreviated as VSEPR

2 SYSTEM ARCHITECTURE

This section provides an overview of the software system architecture for the Aerial Swarm Simulator.

2.1 System Hardware Architecture

No hardware architecture required. This is strictly a software application.

2.2 System Software Architecture

The software modules all exist within the Unreal Engine system. All visual rendering and data gathered is done through the medium of Unreal Engine. The created software is created with Visual Studios 2019 utilizing the python language. The software utilizes the functionality of the AirSim program and library.

The software is split into three modules: the swarm, ground control, and data link. The swarm module communicates internally to a swarm leader drone that connects to the ground station.

The Ground control module will be future work not in this iteration.

The Unreal Engine environment holds the responsibility for creating and maintaining the environment and drone objects within that environment.

The swarm leader drone is responsible for sending messages to the individual drones and the ground station. The individual drones receive the position of the lead drone and make adjustments based on the swarm algorithm. The drones also communicate their sensor data and status which is packaged by the lead drone and sent back to the ground station.

The data package sent by lead drone to ground station will be future work not in this iteration. The data is sent instead to a python environment window as a printout in the current implementation.

The data link module is responsible for the data that is packaged by the lead drone and sent back to the ground station. Data link is also responsible for sending the mission to the lead drone in the drone swarm.

The ground control module is responsible for the user interface. This includes the visual portion of the simulation, visualizing drone status, and visualizing the received data from the drones.

Ground control and mission sending will be future work not in this iteration.

Figures 2 and 3 in Appendix A detail the data flows through the simulation system. Figures 4 and 5 are the class models that detail the system and subsystem structures of the Aerial Swarm Simulation. Shown in the class models are the breakdown of the composition of the subsystems and how the system connects as a whole.

Ground control data source and sink in figures 2 and 3 will be future work not in this iteration. Ground control class and its aggregating classes will be future work not in this iteration.

2.3 Internal Communications Architecture

There is no internal communications architecture as there is no hardware connected in this system.

3 HUMAN-MACHINE INTERFACE

The human-machine interface for the basic user involves a user interface that allows the user to visualize the simulation, drone statuses, and the sensor data from the drone payloads. The interface has another important function, sending the mission to the drone swarm. A second type of human-machine interface is one for a developer who can extend the current work of the team. This interface involves the visualization of the simulation, more detailed drone statuses, and the sensor data from the drone payloads. The developer interface shares many outputs with the basic user interface. The developer interface will have more detailed output information to allow for analysis on system performance to improve the system. This section details the inputs and outputs of this interface.

The interface allowing the basic user to send missions to the drone swarm will be future work not in this iteration.

3.1 Inputs

The input for the basic user interface is the mission data to send to the drone swarm. This data is the (x,y,z) coordinates for the object to be measured by the swarm as taken from the Unreal Engine rendered environment.

More input data relevant to the drone swarm mission data will be future work not in this iteration.

3.2 Outputs

The outputs for the basic user interface are the visual representation for the drone swarm, the sensor data, and the drone statuses. The visual representation of the drone swarm is accomplished with visual renderings in the Unreal Engine platform. Sensor data is displayed in a python environment window that opens on system start. This sensor data is formatted and printed to this window. The drone statuses are defined as operational or not operational. This status is printed in the python environment window that opens on system start.

4 DETAILED DESIGN

This section contains the detailed software design for the Aerial Swarm Simulator.

4.1 Hardware Detailed Design

No hardware is utilized.

4.2 Software Detailed Design

The software, as mentioned in section 2.2, has three modules: the swarm, the data link, and ground control. Using figures 1, 2, and 3 in Appendix A, one can see the use cases and data flow for the system.

In Figure 1 the use case diagram shows the actors being the three software modules. These modules communicate through the system to form the swarm, assign the mission, monitor drone status, and transmit the payload data. This diagram shows the interconnectivity of the modules and the relationships between them in accomplishing these use cases.

4.2.1 The Swarm Module

In figure 2, the diagram shows the base level of data flow in the system. The swarm transmits position, mission status, and individual drone statuses through the system. In return, the swarm receives mission assignments and position updates. Figure 3 provides a more in-depth diagram of the inner workings of how the data is transferred through the system. The swarm algorithm process takes in the drone positions and provides the adjustments needed for those drone positions. It also transmits the mission to the drone swarm. Figures 4 and 5 show the breakdown of the system and different subsystems in a class model. The swarm module is made up of the UAV subsystem. The UAV subsystem is made up of three more subsystems, Aircraft, Payload, and Internal I/O. The Aircraft subsystem is composed of Airframe, Propulsion, and Avionics classes. The Payload subsystem is made up of Chemical Sensor, Camera, Radar, and Temperature Sensor

classes. These all inherit characteristics from the Payload Class. The Internal I/O subsystem is made up of Altimeter, Antennae, Camera, GPS, and Inertial Measurement Unit classes. These subsystems compose the UAV subsystem.

4.2.2 The Data Link Module

In figure 2, the diagram shows the base level of data flow in the system. The data link sends the measured data into the system as well. Figure 3 provides a more in-depth diagram of the inner workings of how the data is transferred through the system. The payload data store stores the payload data that is transmitted into the system. Figures 4 and 5 show the breakdown of the system and different subsystems in a class model. The data link subsystem is made up of Command and control, Payload, and External classes in a parent child relationship.

4.2.3 The Ground Control Module

In figure 2, the diagram shows the base level of data flow in the system. Ground control receives the drone and mission statuses as well as the payload data from the system. Ground control transmits the mission data into the system as well. Figure 3 provides a more in-depth diagram of the inner workings of how the data is transferred through the system. The ground control draws the data out of this data store to display to the user. The process status process takes in the drone and mission statuses from the drone swarm and processes and relays that information to be displayed to the user in ground control. Figures 4 and 5 show the breakdown of the system and different subsystems in a class model. The Ground subsystem is an aggregate of Ground Terminal Data, Ground Control Station, Flight Planning, UA Pilot, Launch Recovery Station, and Mission Monitoring classes.

4.2.4 The Swarm Algorithms

The swarming algorithms used by the Swarm module to position the drones are provided by the paper, *APAWSAN: Actor Positioning for Aerial Wireless Sensor and Actor Networks* written by Dr. Akbas and Damla Turgut in 2011. This paper describes algorithms based on the VSEPR theory to create geometries for drones in a swarm. The algorithms are provided in Appendix A Section 7.7.

These algorithms are used to create geometries that the drones can form in order to swarm in Unreal Engine. These geometries are dependent on how many drones are forming the swarm around the “sink”, in this case the lead drone. The system is designed to check how many active drones are in the swarm and change geometries if the number of drones in the swarm changes. The minimum number of drones in a swarm excluding the lead drone is 2 and the maximum is currently 8.

Using these modules, figures, and algorithms one can get an in depth idea of the system design, its modules, the use cases, and the data flow through the system.

4.2.5 Volume Measurement

The volume measurement, handled by the swarm module, is best described with a statechart. The statechart in figure 6 describes the behavior of the system as the volume measurement happens. The system starts when the swarm arrives at the object to measure. The swarm then splits into drone pairs and moves to either side of the object making sure the front of the drones are clear. The drones then move forward taking slice measurements of the object and storing these distances in an array. Once they reach the end of the object, (the system checks the array to detect the end of the object) the drone pair moves vertically up and saves the sum of the array and clears the array. This process repeats until the entire array is detected as having 0 values. This signifies that the drone pair has moved above the object and finished the measuring. The volume is then calculated and printed to the user. The drones then return to swarming.

4.3 Internal Communications Detailed Design

We do not have internal communications.

5 EXTERNAL INTERFACES

We are not currently using external interfaces.

5.1 Interface Architecture

We are not currently using external interfaces.

5.2 Interface Detailed Design

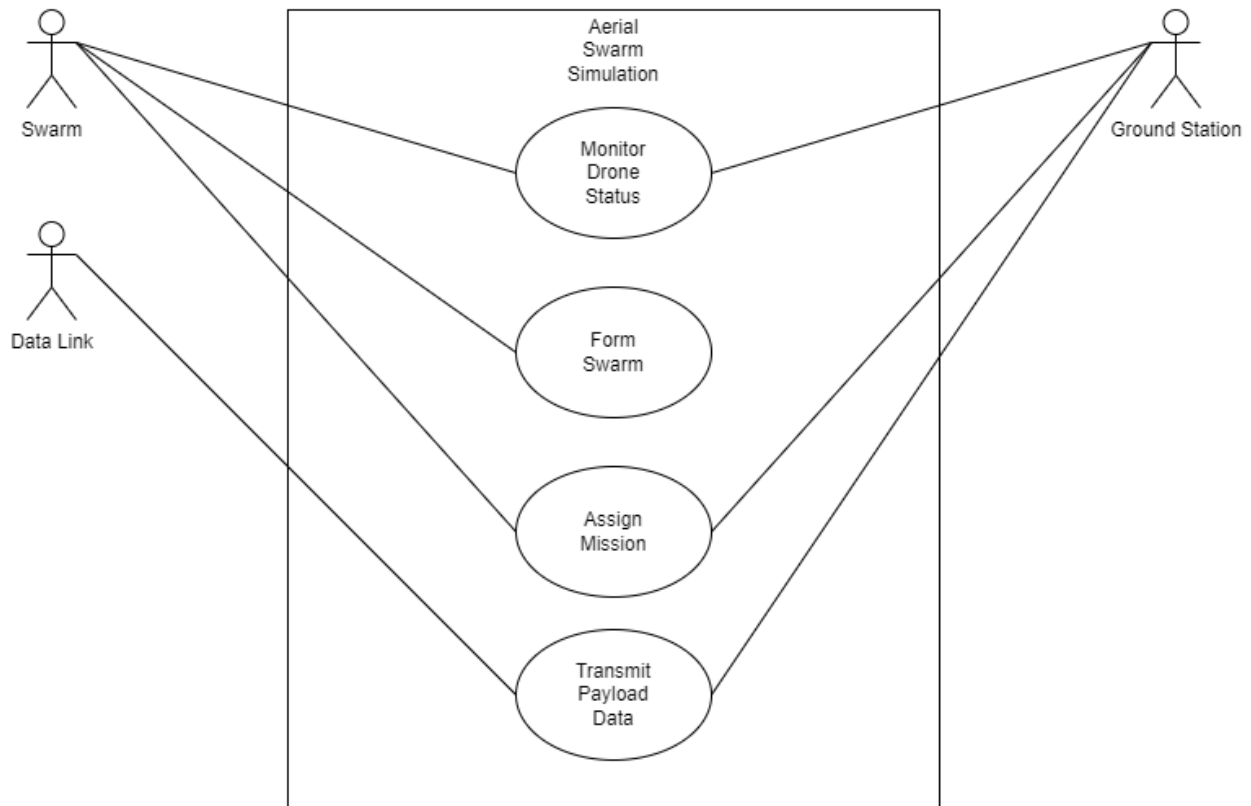
We are not currently using external interfaces.

6 SYSTEM INTEGRITY CONTROLS

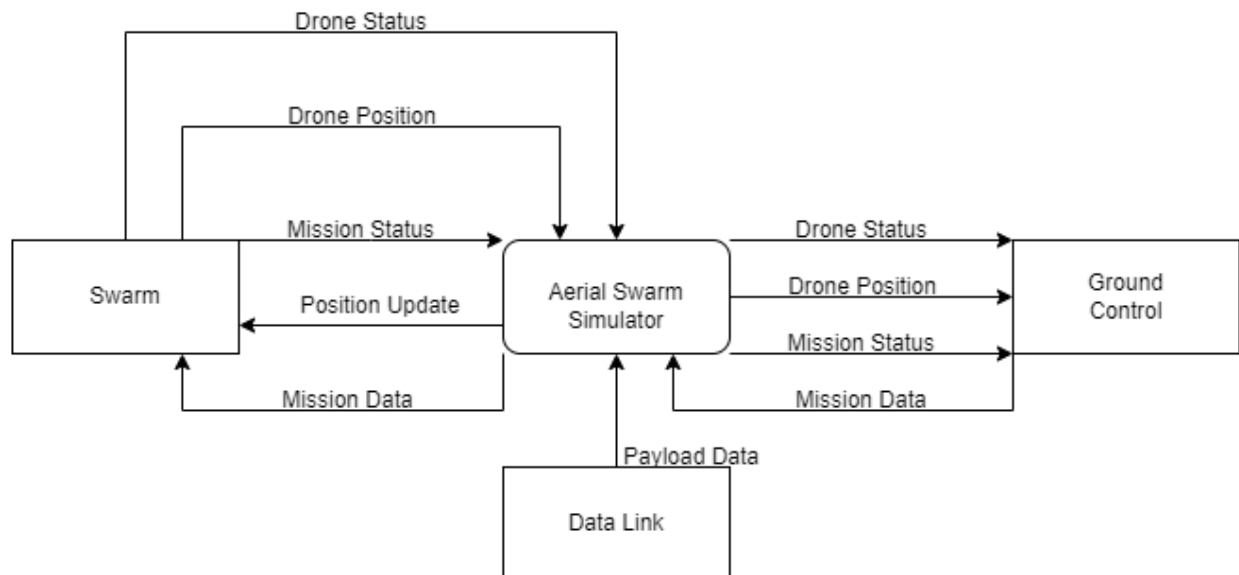
There is no sensitive data that needs extra security, tracking, or audit in this system.

7 APPENDIX A

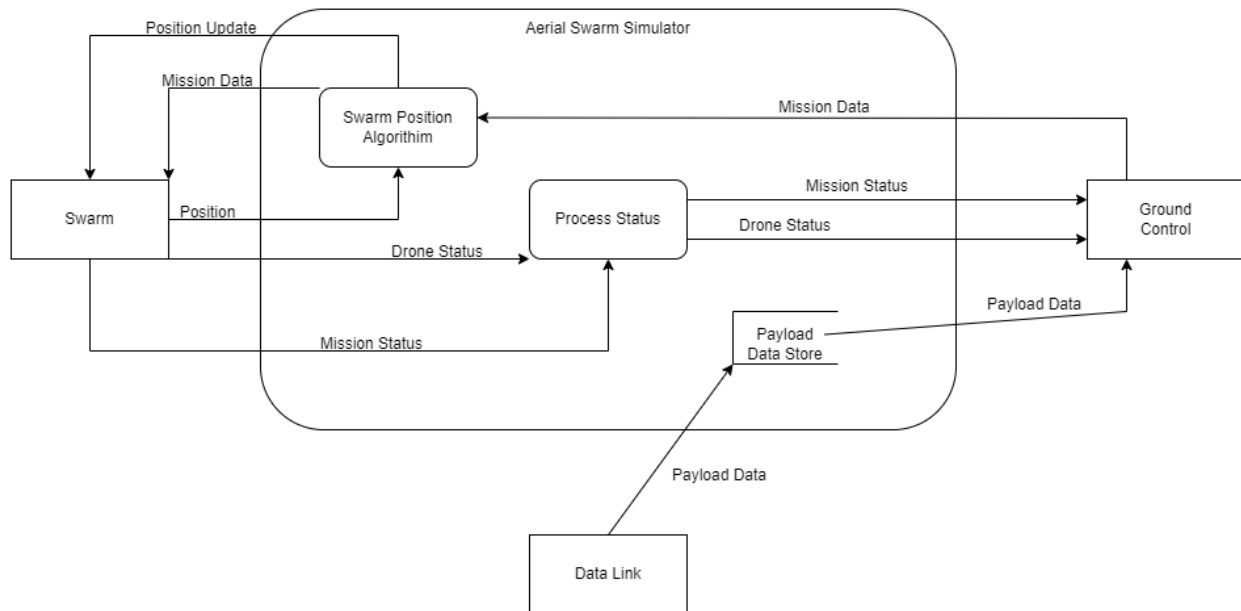
7.1 Use Case – Figure 1



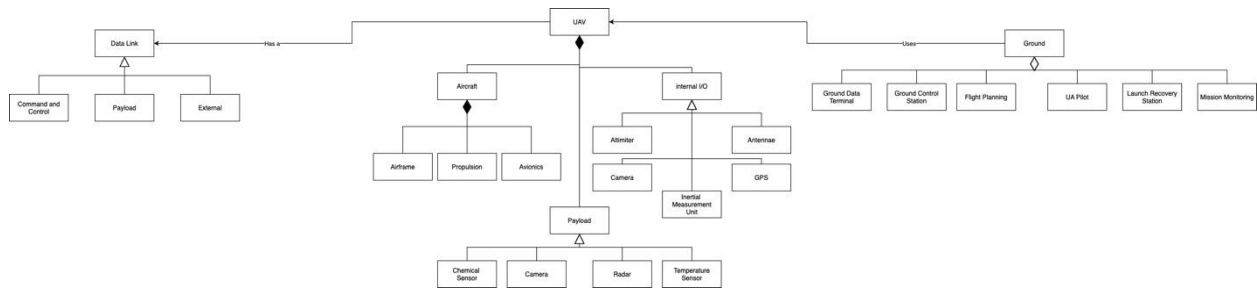
7.2 Data Flow Diagram Level 0 – Figure 2



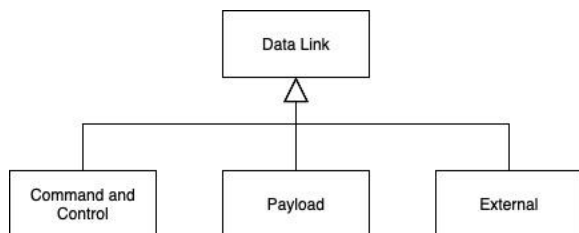
7.3 Data Flow Diagram Level 1 – Figure 3

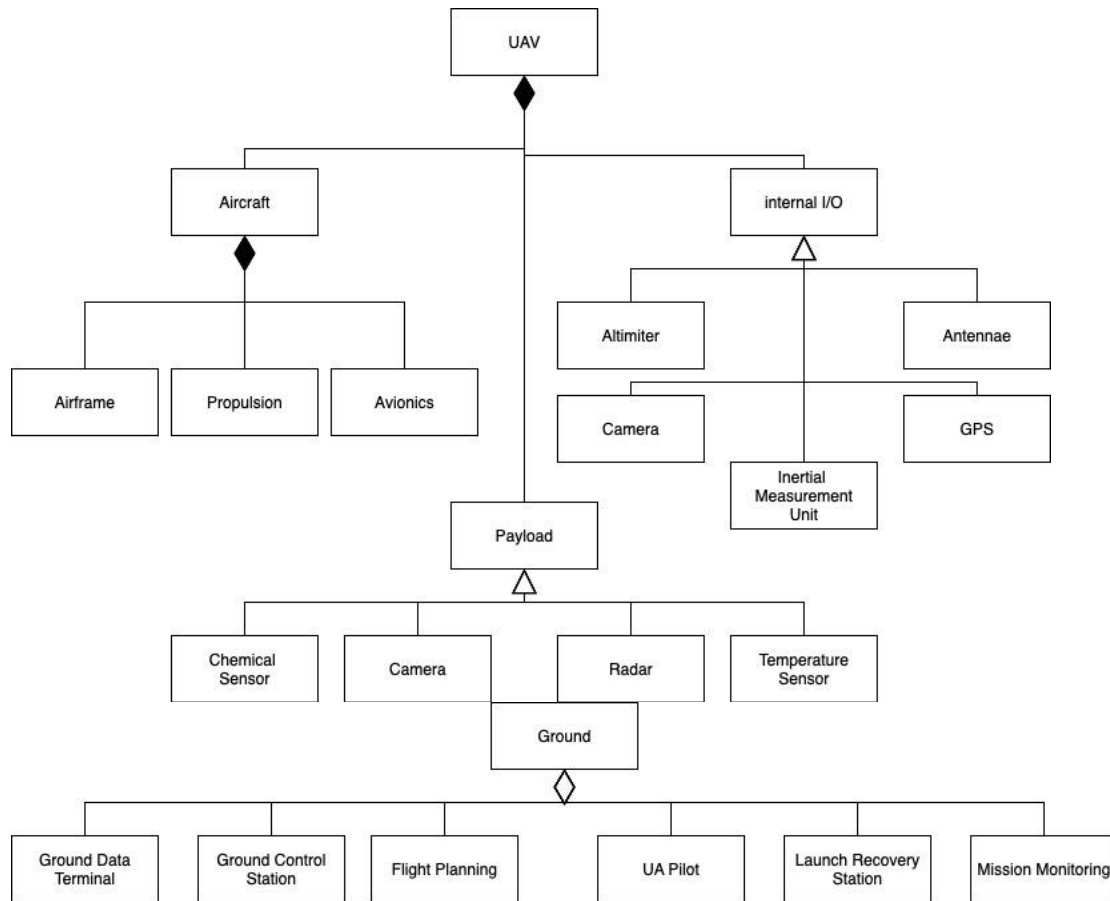


7.4 System Class Model – Figure 4



7.5 Subsystem Class Models – Figure 5





7.6 Project Reference Links

[1] <https://microsoft.github.io/AirSim/>

[2] <https://www.unrealengine.com/en-US/>

[3] M. İ. Akbaş and D. Turgut, "APAWSAN: Actor positioning for aerial wireless sensor and actor networks," *2011 IEEE 36th Conference on Local Computer Networks*, 2011, pp. 563-570, doi: 10.1109/LCN.2011.6115518. <https://ieeexplore-ieee-org.ezproxy.libproxy.db.erau.edu/document/6115518>

7.7 Swarming Algorithms

As taken from the paper of resource [3]

7.7.1 Swarming Algorithms – 2 actors

$$pa1(x, y, z) = (r, 0, 0)$$

$$pa2(x, y, z) = (-r, 0, 0)$$

7.7.2 Swarming Algorithms – 3 actors

$$pa1(x, y, z) = (r, 0, 0)$$

$$pa2(x, y, z) = (-r \cdot \sin(30^\circ), r \cdot \sin(60^\circ), 0)$$

$$pa3(x, y, z) = (-r \cdot \sin(30^\circ), -r \cdot \sin(60^\circ), 0)$$

7.7.3 Swarming Algorithms – 4 actors

pa1 (x, y, z) = (0, 0, r)
pa2 (x, y, z) = (-r.a, -r.b, r.cos(109.5))
pa3 (x, y, z) = (-r.sin(109.5°), 0, r.cos(109.5))
pa4 (x, y, z) = (-r.a, r.b, r.cos(109.5))

7.7.4 Swarming Algorithms – 5 actors

pa1 (x, y, z) = (r, 0, 0)
pa2 (x, y, z) = (-r.sin(30°), r.sin(60°), 0)
pa3 (x, y, z) = (-r.sin(30°), -r.sin(60°), 0)
pa4 (x, y, z) = (0, 0, r)
pa5 (x, y, z) = (0, 0, -r)

7.7.5 Swarming Algorithms – 6 actors

pa1 (x, y, z) = (r, 0, 0)
pa2 (x, y, z) = (0, r, 0)
pa3 (x, y, z) = (-r, 0, 0)
pa4 (x, y, z) = (0, -r, 0)
pa5 (x, y, z) = (0, 0, r)
pa6 (x, y, z) = (0, 0, -r)

7.7.6 Swarming Algorithms – 7 actors

pa1 (x, y, z) = (r, 0, 0)
pa2 (x, y, z) = (r.cos72°, r.sin72°, 0)
pa3 (x, y, z) = (-r.cos36°, r.sin36°, 0)
pa4 (x, y, z) = (0, 0, r)
pa5 (x, y, z) = (r.cos72°, -r.sin72°, 0)
pa6 (x, y, z) = (-r.cos36°, -r.sin36°, 0)
pa7 (x, y, z) = (0, 0, -r)

7.7.7 Swarming Algorithms – 8 actors

pa1 (x, y, z) = (r.a $\sqrt{2}/2$, 0, r.h/2)
pa2 (x, y, z) = (0, r.a $\sqrt{2}/2$, r.h/2)
pa3 (x, y, z) = (-r.a $\sqrt{2}/2$, 0, r.h/2)
pa4 (x, y, z) = (0, -r.a $\sqrt{2}/2$, r.h/2)
pa5 (x, y, z) = (r.a, r.a, -r.h/2)
pa6 (x, y, z) = (-r.a, r.a, -r.h/2)
pa7 (x, y, z) = (-r.a, -r.a, -r.h/2)
pa8 (x, y, z) = (r.a, -r.a, -r.h/2)

7.8 Figure 6 – Volume Measurement Statechart

