Vitor Fontena [1]; Nathan K. Wagner [2]; Cassio Teixeira [3]; João Vitor Lopes [4]; Luciano Moura [5]; Carlos Solon Guimarães [6]

[1] Graduating in Computer Science, São Leopoldo - RS, 93025-000. CEDRA, Brazil; [2] Graduating in Computer Science. Av. Getúlio Vargas, 3239 - Centro, São Leopoldo - RS, 93025-000. CEDRA, Brazil; [3] Graduating in Control and Automation Engineering. Av. Getúlio Vargas, 3239 - Centro, São Leopoldo - RS, 93025-000. CEDRA, Brazil; [4] Graduating in Computer Science. Av. Getúlio Vargas, 3239 - Centro, São Leopoldo - RS, 93025-000. CEDRA, Brazil; [5] Bachelor in Computer Science. Av. Getúlio Vargas, 3239 - Centro, São Leopoldo - RS, 93025-000. CEDRA; [6] PhD in Electrical Engineering. Av. Getúlio Vargas, 3239 - Centro, São Leopoldo - RS, 93025-000. CEDRA, Brazil;

A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

Orchestration of Missions for Coordination between Autonomous Agents in Agriculture.

Abstract.

Due to technological advancement in agriculture, various autonomous agents, such as drones, mobile robots, and intelligent agricultural vehicles, are being used to automate repetitive tasks and increase agricultural production. In addition, these agents, often developed by different manufacturers and endowed with different capabilities, form a highly heterogeneous environment, imposing a central challenge to be solved: the need to manage these agents so that they can act in a coordinated and effective manner. This study presents a software architecture capable of orchestrating autonomous agents in the agricultural environment in an integrated and reliable way, offering mechanisms that support the optimization of routes and the coordination of tasks in the agricultural environment. The architecture is designed in two main services: Management and Orchestration. The Management service is responsible for the graphical interface and user interaction, while the Orchestration service is responsible for the distribution and organization of agents in the field. The Orchestration service receives the missions created by Management and analyzes the requirements needed to execute them. Using these requirements, it evaluates available agents, considering characteristics such as battery, geographic position, and operational capabilities. Based on these parameters, the most suitable agent for each task is selected, ensuring a coherent allocation with the demands of the mission. The Management service is responsible for creating polygonal maps and storing their vertices, the maps are sent to the Orchestration service, which uses geometric processing algorithms to transform these *areas into navigable point paths. If any mission generates an output that has coordinates, these are handled by the orchestrator to generate an optimized path. To validate the architecture, simulated tests were carried out in a computer environment that allowed the evaluation of the architecture's ability to allocate agents efficiently, optimize paths and maintain the consistency of operations in dynamic environments. The proposed architecture provides a solid foundation for multi-agent coordination and facilitates the integration and management of agents in agricultural operations. This advancement can support the development of more autonomous, scalable, and efficient farming systems.*

Keywords.
Multi-Agent Systems, Autonomous Agent Orchestration, Agricultural Robotics, Intelligent Resource Allocation, Route Optimization, Software Architecture, Agricultural Mission Planning

Introduction

Technological advancement in agriculture has driven the use of autonomous agents, such as drones, mobile robots, and smart agricultural vehicles, to automate repetitive tasks and increase productive efficiency. However, these agents are often developed by different manufacturers and possess varying capabilities, resulting in highly heterogeneous operational environments. This scenario poses a central challenge: the need to manage diverse fleets so that they operate in a coordinated and effective manner (MUKHAMEDIEV et al., 2023).

Currently, most available systems are limited to the individual command of agents, without providing cooperation mechanisms. Furthermore, route planning in these systems is typically manual, requiring the user to mark the path to be traveled point by point. This approach not only prevents logistical optimization but also imposes a steep learning curve on the operator, making the adoption of these technologies less accessible and more susceptible to human error (COOMBES; CHEN; LIU, 2017; PHAM; BESTAOUI; MAMMAR, 2017).

To mitigate these problems, this study presents a software architecture designed to orchestrate autonomous agents in an integrated and reliable manner. The proposal focuses on two main pillars: multi-agent coordination based on operational requirements and the automation of geometric processing for the generation of optimized paths (PHAM; BESTAOUI; MAMMAR, 2017; MUKHAMEDIEV et al., 2023). In this way, the goal is not only to increase the efficiency of field operations but also to simplify user interaction with the technology, reducing the technical complexity of the operation.

Theoretical Framework

The management of heterogeneous fleets of autonomous agents in precision agriculture has been the subject of recent investigations in international literature due to the complexity of coordinating devices with different autonomy and operational capabilities (MUKHAMEDIEV et al., 2023). While advanced approaches propose the use of meta-heuristics combined with clustering algorithms to optimize the division of complex polygons among multiple agents, these solutions frequently demand high computational costs and robust processing architectures. In contrast, the present research focuses on a scalable software solution that adopts the Boustrophedon cellular decomposition method. This choice is justified by its low computational complexity, which allows for simplified execution on embedded systems and efficient real-time geometric processing of geofences, as demonstrated in the results of this study.

Coverage Path Planning (CPP) utilizing the Boustrophedon decomposition method is widely consolidated in international literature for remote sensing and intervention applications in precision agriculture (COOMBES; CHEN; LIU, 2017; PHAM; BESTAOUI; MAMMAR, 2017). Research indicates that the zigzag scanning pattern considerably simplifies the automation of aerial surveying when applied to regular convex geometries (COOMBES; CHEN; LIU, 2018). However, in practical scenarios, fields often present complex and non-convex polygonal contours. To circumvent this issue, approaches based on exact cellular decomposition and clustering are employed to fragment complex areas into multiple navigable convex sub-polygons (PHAM; ICHALAL; MAMMAR, [2017]). Additionally, the impact of weather variables, such as wind speed and direction on flight autonomy and mission time, has been the subject of rigorous mathematical modeling and practical validation tests in both simulated and real agricultural environments (COOMBES; CHEN; LIU, 2019).

Although approaches such as that of Pham et al. (PHAM; ICHALAL; MAMMAR, [2017]) suggest exact cellular decomposition to fragment complex and non-convex areas, the current stage of this research is delimited to the application of the Boustrophedon method directly onto predominantly regular and convex geometries, with the automation of this geometric fragmentation remaining a future step for this ecosystem.

Proposed Architecture (Methodology)

The macro architecture of the designed system encompasses the Service, Communication, and Physical layers. However, the scope of this article is strictly delimited to the Service Layer and its respective logical organization. The service layer architecture is divided into two blocks: the management service and the orchestration service. Figure 1 illustrates the architecture of the service layer using a C4 model container diagram.

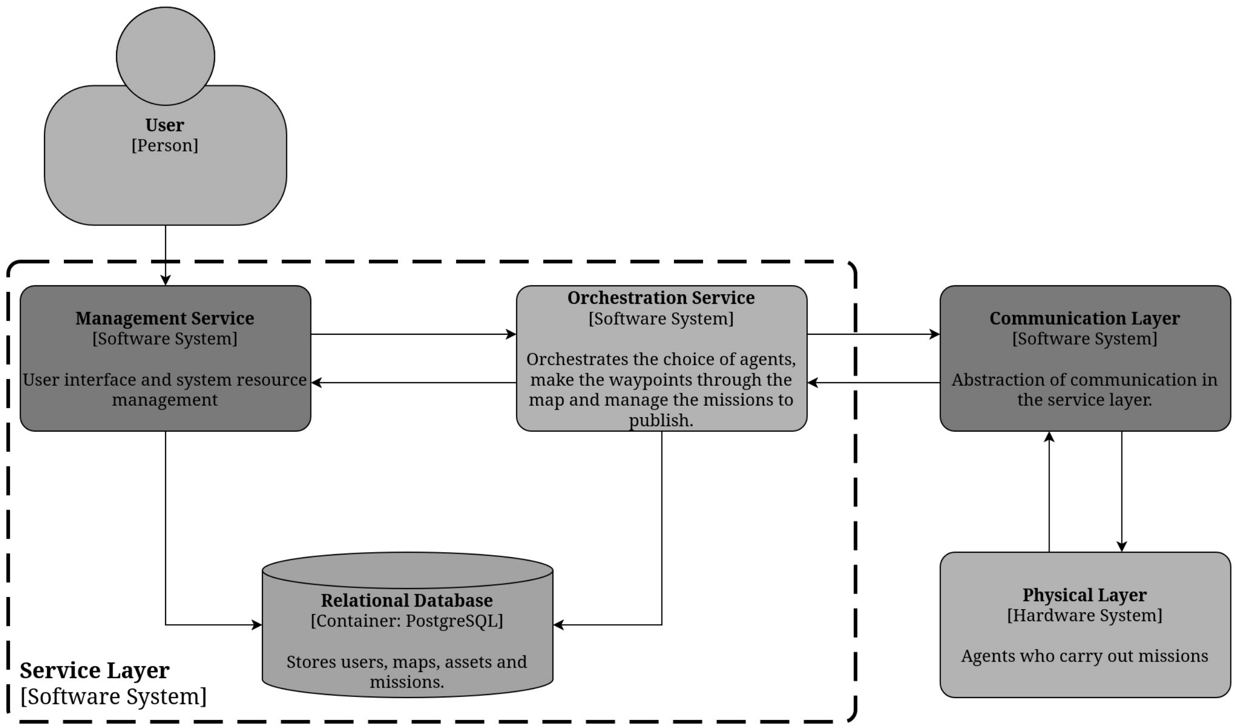

Figure 1: Model C4 diagram of the proposed software architecture and its integration layers.

Management Service

The management service has three major core components:

- **Map Management:** allows the creation of maps and geofences (virtual fences) that will delimit where the drones and robots will operate. Subsequently, these fences are converted into a path of waypoints to be traveled by the agents.
- **Agent Management:** allows the registration of agents in the system. In addition to their connection, it also enables the visualization of telemetry data, such as position, battery, and speed.
- **Mission Management:** allows the creation of missions in which the agents will operate. Missions are divided into sequences of activities and isolated activities. Activities are the tasks sent for the agents to execute (e.g., weed monitoring activity).

Tasks within the same sequence are performed in parallel, while activities allocated to different sequences are executed sequentially. As can be observed in Figure 2, there are three sequences of activities. In the first sequence, there are two monitoring activities and one mapping activity; these tasks will be executed in parallel, as they are contained within the same sequence. In the second sequence, there is a weeding activity and another mapping activity, which will also be executed in parallel, but only after the completion of the first sequence. Furthermore, the weeding activity of the second sequence will receive as input data the result (output) generated by the first sequence. Finally, in the third sequence, there is a mapping activity, which will only be executed after the completion of the two previous sequences.

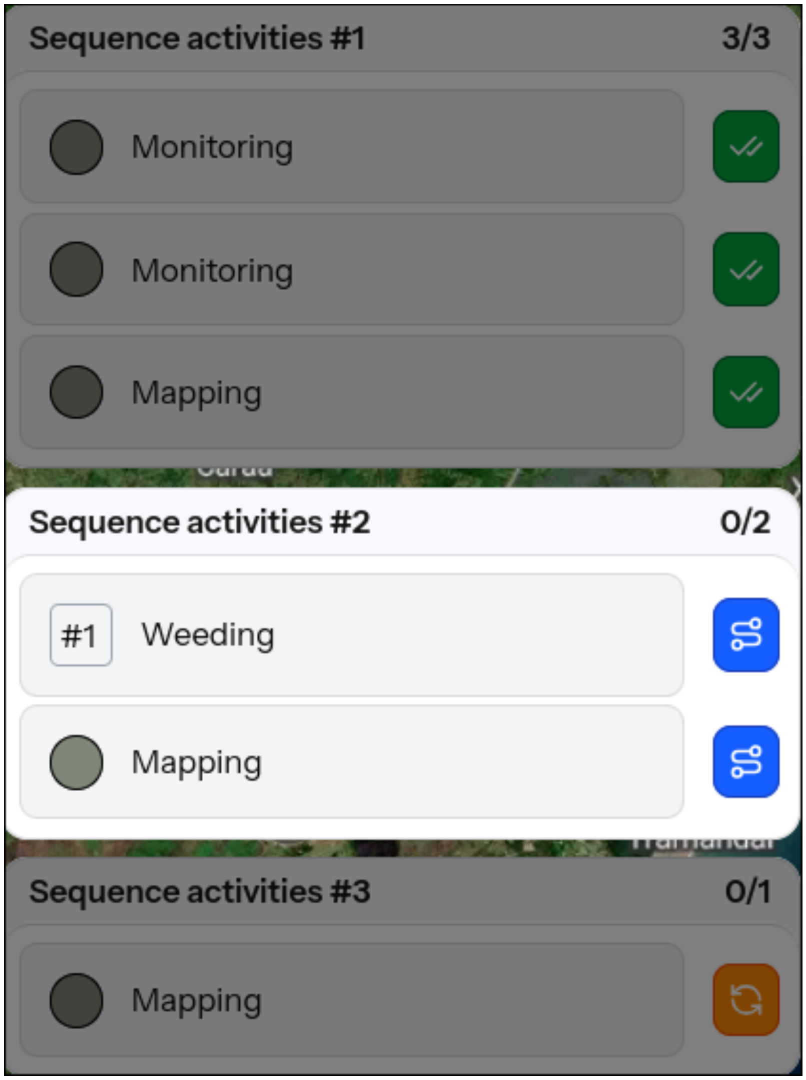

Figure 2: Mission in the Graphical Interface

Orchestration Service

The orchestration service constitutes the logical and decision-making core of the application. This module is responsible for converting geofences into trajectories composed of waypoint paths, as well as selecting the ideal agent for each allocation based on criteria such as positioning, battery level, and availability. Additionally, it manages the missions to be dispatched, publishing the activities in chronological order, respecting the chaining of pre-defined sequences.

Converting Maps into Waypoint Paths

To generate the trajectories, CPP utilizes the Boustrophedon decomposition method. This algorithm generates a zigzag path that enables full coverage of the area of interest. Furthermore, in scenarios where the area must be operated by two agents concurrently, the algorithm performs an equitable segmentation of the polygon so that both agents execute the sweep in a balanced manner.

It receives the polygon vertices sent by the management service. In this version of the architecture, the processing assumes convex scenarios, mapping the operational limitations with complex geometries that are discussed later in this work.

The algorithm also eliminates intermediate waypoints contained within the same straight-line segment, reducing the total volume of coordinates and optimizing the data size of the activities. As input parameters, the algorithm receives the vertices of the polygon, the number of required subdivisions, and the sweep width (or operating area) of the agents. Figure 3 illustrates the operation of the proposed algorithm:

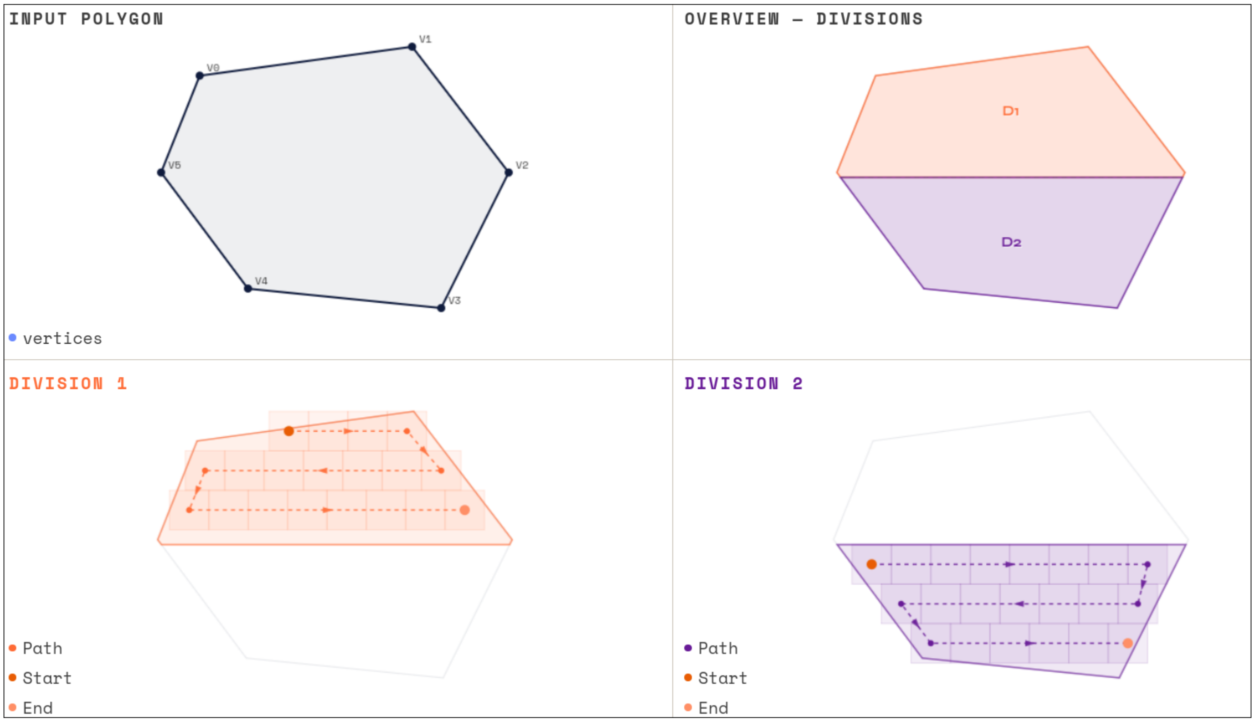

Figure 3: CPP algorithm

As observed in Figure 3, the input polygon is initially decomposed into two subareas (Division 1 and Division 2). Sequentially, the algorithm calculates the zigzag pattern adapted to the geometry of each subdivision, clearly demarcating the start and end points of the sweep, while simultaneously optimizing the vertices along the straight alignments.

Mission Management

Regarding mission management, the orchestration service queries the relevant record in the database, structuring the mission based on its respective sequences of activities and associated tasks. Subsequently, the activities linked to the first sequence are published.

For each activity, the system verifies the existence of a previously allocated agent for its execution; in its absence, an allocation procedure is initiated. If the process fails, the activity is directed to a retry queue for later processing.

Upon completion of an activity, the agent transmits the corresponding return data to the orchestration service for storage purposes. Once it is confirmed that no other activities are in progress within the current sequence, the system advances to the subsequent stage, triggering the tasks scheduled there. The mission is considered completed when all planned sequences have been fully finalized.

Agent Allocation

In the agent allocation process, it is initially verified whether the activity already has a device previously designated by the user through the management service. If no agent has been defined, a scenario in which the user opted for the automatic mode in the interface, the allocation is performed autonomously based on efficiency criteria.

First, the total displacement of the agent is analyzed based on the trajectory generated by the coverage algorithm. Next, the autonomy capacity in minutes required to fulfill the task is evaluated, assuming a constant speed. The required flight time Treq, in minutes, is calculated by the total trajectory distance d, in meters, divided by the agent's speed converted to the same unit of time, as expressed in Equation 1:

$$T_{req} = \frac{d}{60 \cdot 3} \quad (1)$$

Where T_{req} = required flight time, d = total trajectory distance, 60 = seconds in a minute, 3 = locked nominal speed of the agents in meters per second.

After obtaining the result for T_{req}, a query is performed in the database to identify and select the available agents that present a flight autonomy equal to or greater than the estimated time.

Results

To validate the proposed architecture, tests were conducted in a simulated computational environment using specific scripts to emulate the behavior and responses of the Communication layer.

Regarding interaction with the system, it was observed that the developed interface provided high operational abstraction. This factor allows users without in-depth technical knowledge of aerial robotics to structure complex missions and coordinate multiple drones in a simplified manner, eliminating the need for manual point-by-point trajectory input or direct control of takeoff procedures.

The geometric processing algorithm demonstrated high efficiency in trajectory optimization through the elimination of redundant intermediate nodes (collinear reduction). Taking the polygon presented in Figure 3 as a test scenario, configured with an operating area of 10x10 meters for the agents, the sweep method initially generated a mesh containing 684 coordinate points. After applying the collinear filtering, the data volume was reduced to only 52 fundamental points, which represents a 92.4% reduction in the size of the activity to be transmitted to the agent. This reduction minimizes memory consumption in embedded systems and mitigates data traffic in the communication network.

Finally, the mission management module demonstrated robustness in coordinating multiple agents operating simultaneously and sequentially. In trials with activities arranged in distinct sequences, the orchestration service successfully captured the output data from one stage and redirected it as input data for the subsequent phase.

In scenarios of greater complexity and task density, the system performed the equitable subdivision of geofences, generating individualized and balanced routes for each agent in the field. Additionally, the ecosystem guaranteed the integrity and persistence of telemetry histories and return data, ensuring the homogeneous transfer of information to the devices allocated in subsequent operations.

Conclusion

This work presented a software architecture for the coordination of multi-agent systems in the agricultural context. Based on the trials conducted, the success of the proposed solution was validated, demonstrating efficiency in the integrated operation of the management and orchestration services. The CPP algorithm based on the Boustrophedon method met the requirements for logistical automation, enabling a significant collinear reduction of 92.4% in the volume of coordinate points. This result simplifies field operations and optimizes resource consumption in embedded systems.

However, operational constraints were identified in the current stage of development. The algorithm presented difficulties when processing non-convex polygons, generating trajectories that exceeded the area delimited by the geofence. Additionally, the automatic allocation model adopts a static nominal speed of 3 m/s, discounting dynamic field variables such as the impact of wind on battery autonomy and topographical terrain variations.

As future work, it is proposed to improve the geometric algorithm to support complex and non-convex polygonal meshes, as well as to integrate stochastic models for the predictive calculation of the drones' energy consumption. Furthermore, plans include conducting tests in real operational environments to validate inter-agent cooperation and expanding the orchestration service to support dynamic real-time route reconfiguration in the face of critical device failures.

Acknowledgments

The Gemini LLM was used for translating the original text into English and for text revision, followed by a final review by the authors.

This work has been fully funded by the project Agrobot supported by the **Center for Embedded Devices and Research in Digital Agriculture (CEDRA) of SENAI-RS**, with financial resources from the PPI IoT/Manufatura 4.0 / PPI HardwareBR of the MCTI, grant number 056/2023, signed with EMBRAPII.

References

T. H. Pham, D. Ichalal and S. Mammar, "Complete coverage path planning for pests-ridden in precision agriculture using UAV," 2020 IEEE International Conference on Networking, Sensing and Control (ICNSC), Nanjing, China, 2020, pp. 1-6, doi: 10.1109/ICNSC48988.2020.9238122.

T. H. Pham, Y. Bestaoui and S. Mammar, "Aerial robot coverage path planning approach with concave obstacles in precision agriculture," *2017 Workshop on Research, Education and Development of Unmanned Aerial Systems (RED-UAS)*, Linköping, Sweden, 2017, pp. 43-48, doi: 10.1109/RED-UAS.2017.8101641.

M. Coombes, W. -H. Chen and C. Liu, "Flight Testing Boustrophedon Coverage Path Planning for Fixed Wing UAVs in Wind," *2019 International Conference on Robotics and Automation (ICRA)*, Montreal, QC, Canada, 2019, pp. 711-717, doi: 10.1109/ICRA.2019.8793943.

M. Coombes, W. -H. Chen and C. Liu, "Boustrophedon coverage path planning for UAV aerial surveys in wind," *2017 International Conference on Unmanned Aircraft Systems (ICUAS)*, Miami, FL, USA, 2017, pp. 1563-1571, doi: 10.1109/ICUAS.2017.7991469.

M. Coombes, W. -H. Chen and C. Liu, "Fixed Wing UAV Survey Coverage Path Planning in Wind for Improving Existing Ground Control Station Software," *2018 37th Chinese Control Conference (CCC)*, Wuhan, China, 2018, pp. 9820-9825, doi: 10.23919/ChiCC.2018.8482722.

R. I. Mukhamediev *et al*., "Coverage Path Planning Optimization of Heterogeneous UAVs Group for Precision Agriculture," in *IEEE Access*, vol. 11, pp. 5789-5803, 2023, doi: 10.1109/ACCESS.2023.3235207.