Software Architecture for Agricultural Robots: Systems, Requirements, Challenges, Case Studies, and Future Perspectives

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***Abstract*—Designing software architectures for autonomous robots for agricultural contexts is a demanding and difficult job due to the requirement to monitor numerous sensors and actuators, as well as autonomous decision-making in unpredictable, unexpected scenarios. Depending on the essential requirements of a robotic device for agricultural usage, robot software architecture is created differently. Since no single software architecture exists for all applications, extensive knowledge of the various software architectures for robots is needed when creating your own robotic architecture or selecting one from a number of existing architectures. As a result, this article provides a comprehensive history of software architecture and its application in the agricultural domain along with a chronology of how software design has evolved over time. We provide several case studies to understand the importance of application of software architecture in agriculture and food industry and how to choose the best architecture for agricultural tasks. Finally, this article discusses the open obstacles and difficulties that must be addressed in order to ensure more advancements in the development of robot architecture for agricultural applications.**

***Index Terms*—Agricultural robot, food processing, food packaging, harvesting robot, robot programming, software architecture.**

I. Introduction

EVERY day, robots become more self-sufficient. Applications of robotics are no longer limited to industry; they are increasingly spreading into new areas, such as home care, military operations, and rescue operations ([1]), driverless cars on roads, drones for inspection operations, underwater robots, robots for harvesting vegetables or fruits to space exploration. The agricultural sector, for example, has a huge demand for robots, which is expected to rise from USD 4.6 billion in 2020 to USD 20.3 billion by 2025 ([2]). The agricultural robots market is also growing due to a decline in the number of young farmers entering the agricultural sector and an increase in labor minimum wages [3]. Farmers are eagerly seeking a solution to this issue, with autonomous robots being one of the possibilities.

To construct autonomous robots that can be used in agricultural environments for a variety of tasks, such as harvest management (crops, vegetables, or fruits), field farming, crop management, higher levels of sophistication in perception, complex planning capacity, effective control mechanisms, and increased learning capability, are needed to adapt new environments with daunting challenges for the future. As a result, a thorough understanding of autonomous systems, their behavior, and the overall architecture of the system must be realized, and this remains an important research subject.

One of our research objectives is to devise a methodology for programming that seamlessly integrates complex high-tech tasks and to provide developers with appropriate models to develop their individual software modules which will be part of the large system integration so that the code can be reusable and extendable. It is crystal clear that to design a robot architecture that involves complex functionality is required a great effort to work the whole system smoothly. However, due to the nonavailability of uniform standards in robotics, there is no commonly accepted robot architecture, especially for AI applications ([4]). This has led to researchers being forced to develop their own robotic software architectures. For that purpose, there exists a large variety of robotic architecture. There are still scarce contributions regarding the global state of the art of different robot architectures suitable for agricultural applications. As the agricultural industry increasingly adopts automation and robotics to address its unique challenges, selecting the right software architectural pattern becomes a crucial decision that can significantly impact the success of projects.

This research article dives into the most popular software architectural patterns specifically tailored for agricultural robotics, exploring their benefits, drawbacks, selection criteria, and envisioning future perspectives. By critically analyzing the strengths and weaknesses of each pattern, we aim to guide researchers and practitioners in making informed decisions when selecting the most suitable architectural pattern for their agricultural robotics applications. Through real-world case studies and scenario-based discussions, we highlighted the architectural patterns that align with the unique requirements and challenges encountered in tasks, such as harvesting, food processing, and packaging. We summarize the contribution of this article as follows.

1) It provides a comprehensive exploration of various software architectural patterns and their applicability in the

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