TABLE IV
CONCEPTUAL-LEVEL ROBOT SOFTWARE ARCHITECTURES THAT ARE STILL UNDER DEVELOPMENT OR IN THE EARLY STAGES OF IMPLEMENTATION

Paradigm	Description	Features	Application in agriculture
Ethical ([22])	It aims to incorporate ethical decision-making capabilities into robots, allowing them to make morally sound choices and interact responsibly with humans and the environment.	Prioritizes well-being of plants and animals.	Harvesting, crop spraying, animal welfare.
Explainable ([23])	It focuses on designing robots that can provide explanations for their actions and decisions, allowing humans to understand and trust the reasoning behind their behavior.	Enables transparency and understanding.	Task auditing, compliance, trust-building.
Cognitive ([24])	It aims to develop robots with advanced cognitive capabilities, such as perception, learning, reasoning, and decision-making, enabling them to exhibit more human-like intelligence and adaptability.	Analyzes sensor data, intelligent decision-making.	Crop monitoring, disease detection, irrigation optimization.
Socially aware ([25])	It focuses on designing robots that can understand and respond to social cues, norms, and context, allowing them to interact with humans in a socially acceptable and appropriate manner and recognizes human gestures, interacts gently with animals.	Recognizes human gestures, interacts gently with animals.	Collaborative work with farm workers, livestock interaction.
Self-adaptive ([26])	It aims to develop robots that can autonomously adapt and reconfigure their software and hardware components based on changes in their environment or task requirements, improving their flexibility and performance.	Adjusts behavior, task allocation, physical configuration.	Handling dynamic environments, different crops or terrains.
Human-in-loop ([27])	It refers to a type of software architecture where a human operator plays an active role in the control and decision-making process alongside robots. It is designed to enable effective collaboration and synergy between humans and robots, leveraging the unique capabilities of both.	Combines the strengths of both humans and robots, leveraging skill augmentation, precision, and endurance.	Precision agriculture, target pesticide application.

While the field of robotic software architecture is continually evolving, there are several conceptual-level architectures that are still under development or in the early stages of implementation. Here are a few examples of architectural paradigm listed in Table IV.

These architectures are still in the conceptual stage, and their practical implementation and widespread adoption may vary. Socially aware paradigm enables robots to recognize and respond appropriately to human gestures, expressions, or vocal commands. They can work collaboratively with human workers, navigate crowded farm environments safely, and interact gently with animals, promoting efficient and harmonious interactions. The robots with self-adaptive paradigm can adapt their behavior, task allocation, or physical configuration to handle changing conditions or new farming requirements. This allows them to optimize their performance, adjust to different crops or terrains, and improve overall productivity and efficiency. Human-in-loop robot architectures allows for efficient collaboration between humans and robots, enabling them to work together effectively and achieve common goals.

V. SOFTWARE ARCHITECTURE PATTERNS APPLIED FOR AGRICULTURAL ROBOTS

In the literature, several studies have investigated various software architectures that have been employed for agricultural robots, and these architectural choices often depend on the specific mission or purpose of the robot ([28], [29]). The Table V summarize software architectures employed in various agricultural robot applications, including arable farming, horticulture, animal husbandry, food processing, and food packaging.

1) *Arable farming:* multiple software architectures are used, including subsumption architecture that was used by Blackmore ([30]) to decompose human-controlled agricultural operations into an autonomous tractor. Hybrid architecture was introduced by Vougioukas ([28]) for mobile robots that combined deterministic and reactive behaviors. Distributed and hierarchical architecture, sense–plan–act architectures are applied to tasks, such as ploughing, seeding, navigation, and weed management. Notably, for wheat and maize weed management, the Future Internet WARE (FIWARE) and Apache Kafka-based architecture is employed. Agrobot, built by Durmuş et al. [33], proposed cloud-based architecture for robot that connects to farmers through a cloud service to mobile devices. However, they had not yet completed their implementation of this concept.
2) *Horticulture:* various architectures are used for tasks, such as greenhouse harvesting, image data collection, navigation in vineyards, and weed management. Kashiwazaki et al. [29] suggested a greenhouse mobile robot device that would work with humans to harvest and manage pests. They design architecture to allow the robot to navigate the greenhouse on its own, while the human partner operates the control panel to complete the necessary tasks. However, the architecture is only appropriate for use in a greenhouse and is not suitable for use in an open area. Adamides et al. [38] proposed a robot architecture for a semiautonomous agricultural teleoperated sprayer robot that focuses on human–robot interaction evaluation. The architecture, on the other hand, is not scalable to vast vineyards. Another VineRobot created by [39] is an agriculture mobile robot designed to roam the wine field autonomously and collect data to estimate vegetative production, water status, and grape composition, among other things. Emmi et al. [40] build a system architecture for both individual robots and fleets of robots that improves reliability, reduces complexity and costs, and allows applications from various developers to be integrated. Despite the fact that they recognized the need for agriculture robots to be smaller, more complex, and less expensive. Their architecture is anything but small, plain, or inexpensive.
Recently, a few fully integrated autonomous robots have been registered, including cherry tomato harvesting