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REVIEW ON THE APPLICATIONS OF MULTI-AGENT SYSTEMS IN AGRICULTURE

ESTUDIO SOBRE LAS APLICACIONES DE LOS SISTEMAS MULTIAGENTES EN LA AGRICULTURA

María-Eugenia PÉREZ-PONS[1], Javier PARRA-DOMINGUEZ[1], Juan Manuel CORCHADO[1], Jorge MEIRA[2], and Goreti MARREIROS[2]

[1] *BISITE Research Group, University of Salamanca, Edificio Multiusos I+D+i, Calle Espejo, 2, 37007, Salamanca, Spain*

{eugenia.perez, javierparra, corchado}@usal.es

[2] *GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering, Polytechnic of Porto, 4200-072 Porto, Portugal*

{janme, mgt}@isep.ipp.pt

ABSTRACT: Recent technological advances have led to the development of numerous platforms for precision agriculture, which help farmers access detailed information and make the right decisions regarding the management of their farm. Adapting the application of chemicals to crop demands or estimating optimal irrigation duration, are just some possibilities offered by multi-agent systems. Numerous multi-agent systems have been developed for use in precision agriculture. This article reviews state-of-the-art multi-agent systems and their uses in agriculture.

KEYWORDS: multi-agent systems; agriculture; precision agriculture.

RESUMEN: Los recientes avances tecnológicos han propiciado el desarrollo de numerosas plataformas para la agricultura de precisión, que ayudan a los agricultores a acceder a información detallada y a tomar las decisiones correctas sobre la gestión de su explotación. Adaptar la aplicación de productos químicos a las demandas de los cultivos o estimar la duración óptima del riego son algunas de las posibilidades que ofrecen los sistemas multiagente. Se han desarrollado numerosos sistemas multiagente para su uso en la agricultura de precisión. Este artículo repasa los sistemas multiagente más avanzados y sus usos en la agricultura.

PALABRAS CLAVE: sistema multiagente; agricultura; agricultura de precisión.

1 Introduction

Today, there are an increasing number of systems and architectures in the agriculture industry that take advantage of technology to increase the efficiency of farm resources [14, 2, 15]. The advent of decision support systems (DSS) in precision agriculture (PA) has been made possible thanks to the continuous progress of information technology.

Traditionally, field management consists of visually inspecting the development of crops to arrive at a diagnosis with which farmers make decisions and act by giving different treatments to their crops. In places where technology has not yet arrived, this approach is still used. It is based on the farmers' experience in the field and their observations.

Crop management started evolving when the first PA technologies began emerging some thirty years ago, but it has undoubtedly been transformed with the current age of digital information.

1.1 Precision Agriculture

Precision agriculture is a term that has been coined in recent years. It refers to the concept of using new technologies to increase the yield and profitability of crops while reducing the resources needed for cultivation [22, 25]. One of the main goals of PA is to improve agricultural sustainability and to optimize crop growing decisions, taking into account field variability and site-specific parameter values. Raw measurements of key crop parameters need to be processed efficiently so that numbers or images become unambiguously valuable information. Therefore, PA involves the use of geospatial techniques and sensing applications to observe, measure, and respond to interfield and intrafield variability in crops.

Technical and cost-related limitations hamper the deployment of PA infrastructures as decision support systems in smallholder settings. As a result, there has been an upsurge in applications, systems and architectures that aim to reduce costs. One of the fundamental aspects of PA is monitoring sensors' measurements [9] as well as cloud-based systems for data collection, processing and storage. On the basis of this data, predictions may be made. Lately, the implementation of edge architectures has become a popular solution in the field of precision agriculture [21, 2].

Current advances in data management are making PA grow exponentially, as data has become the key element of modern agriculture, helping growers make critical decisions. Figure 1, shows some of the aspects that are usually tracked in PA.

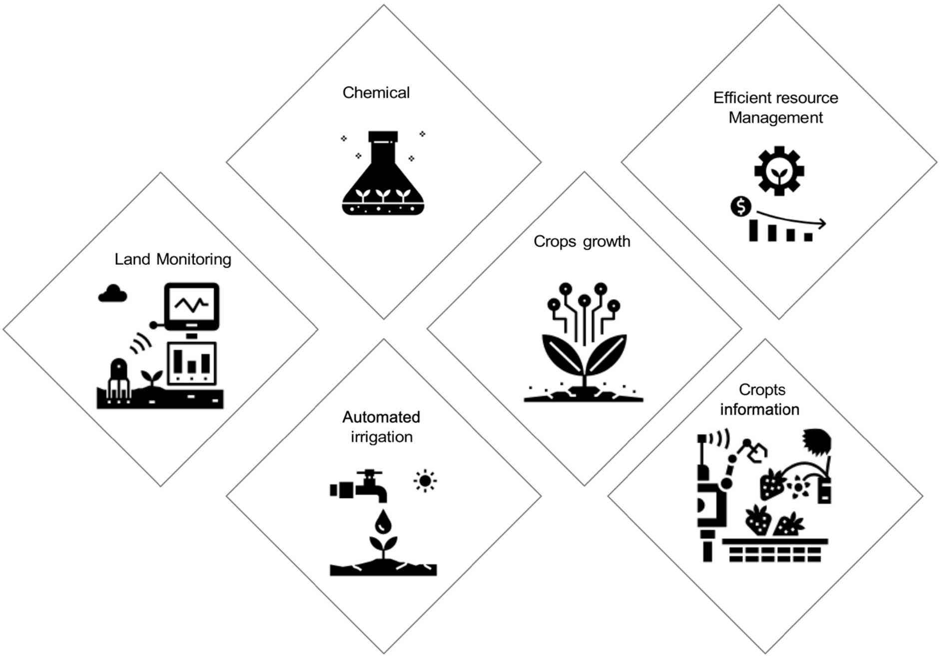

Fig. 1. Precision Agriculture Diagram.

Although many technologies have been developed for precision farming, in this case we have focused on multi-agent systems that have been developed for monitoring agriculture.

This article is organized as follows: Section 2 describes the state of the art of multi-agent systems in agriculture as well as different use cases, section 3 includes the discussion and draws the conclusions.

2 Multi-Agent Systems in Agriculture

Throughout the years, different authors have provided different definitions of multi-agent systems. Nevertheless, [24] gathered the main definitions and what was common to all of them is that multiple agents act autonomously to overcome complex problems that a single agent would not be able to solve. Figure 2 represents a general MAS architecture, in which agents are interconnected in a changing environment.

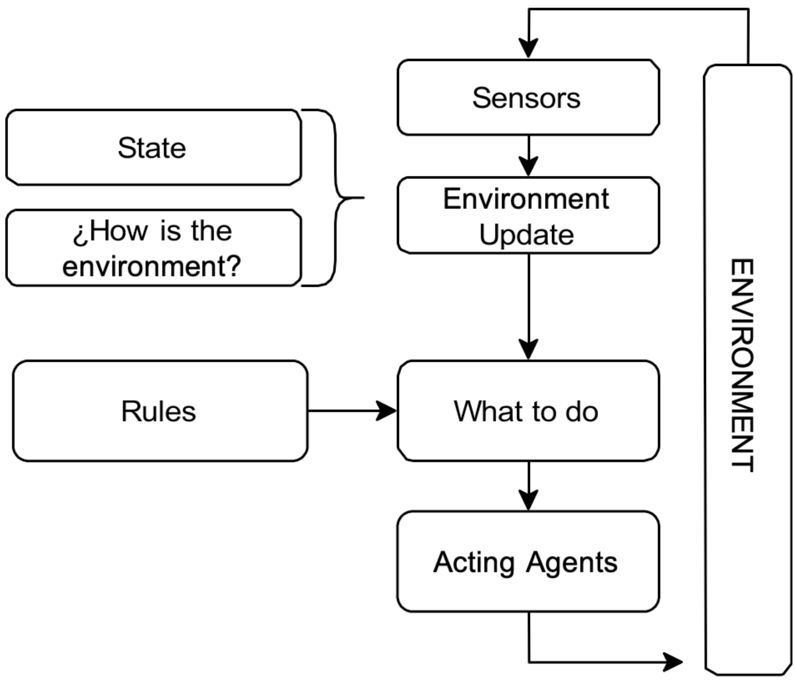

Fig. 2. Multi-agent Architecture.

Different studies have been carried out to implement multi-agent systems in different sectors. For instance, in the supply chain sector, in which there are many interconnected variables, numerous MAS applications have been proposed [11]. Regarding the applications of MAS in PA, the information provided by crops only becomes beneficial when managed efficiently. The multi-agent systems that improve the decision-making of the field management nodes, save resources at the farm level while increasing the income. They achieve this through optimal water and fertilizer use and through respecting the environment and the consumer. Some authors have presented complete systems regarding the management of resources in agriculture, however, others focus on each of the phases of precision agriculture. Although it is true that there are some multi-agent systems that cover a wide spectrum of possibilities, such as the case of [20], where a review has been conducted of the data processing methods in crop management. The platforms developed in recent years allow farmers to access knowledge that can help them make the right decisions when implementing PA management actions [3]. Some examples of different applications are described below.

2.1 Landscape

Nowadays, different systems have been developed for the study of land and crop location through models of multiagent land use change and land cover systems [10] did a review of the application of multi-agent models in agriculture and land use modelling. Agricultural landscape modelling can make a key contribution to design, but it still has to overcome several difficulties to offer reliable tools to decision makers [16, 13] presented a model which offered a promising new tool of land cover phenomena that focus on human-environment interactions.

2.2 Irrigation

Water is an essential natural resource for social, economic and environmental development [12]. Among the multiple sectors using water, agriculture is the largest consumer of this resource, accounting for approximately 70 % of total freshwater consumption [1]. That is why different authors have proposed multiagent systems, specially oriented to this end [3] developed a platform based on MAS that integrates the use of a soft computing technique based on expert knowledge. It was designed for when limited data precludes the ability to develop accurate empirical models. Moreover, [6, 5] presented other use cases in which multi-agent systems were developed to reduce water consumption and to determine the relationship between water and the type of soil.

In the case of [6], the author proposed an architecture that was tested in an agricultural environment to optimize the irrigation of a corn crop. Thanks to the wireless sensor network (WSN) it was possible to obtain information on the crop's terrain and its climatic conditions, extracting information on the needs of the cultivated corn and making efficient irrigation decisions based on these needs, reducing water consumption by 17.16 % compared to traditional automatic irrigation.

2.3 Energy Consumption

The use of wireless sensor networks is essential for the implementation of information and control technologies in application areas such as precision agriculture [19] designed a system with the objective of achieving energy efficiency during the awakening synchronization, exchanging the energy consumed in the receiver for that of the transmitter [7] presented the results obtained from the simulation of a system that allowed to reuse the energy of a power plant. They showed how the agents that make up the system communicate with sensors and actuators and how data analysis algorithms are applied to allow for the use of this energy in greenhouses, providing a reduction in the energy they need without the system [18] conducted a review of the state-of-the-art applications in the energy sector, as in the case of the electricity grid, in which a multi-agent system became the best option.

2.4 Pesticides

It is important to reduce the consumption of pesticides [8] or instead prevent fungi [4], since fungal diseases have been underestimated worldwide, but constitute a substantial threat to various plant and animal species, and to public health. In the case of [8] they built a new model based on Mathematical Programming-based Multi-Agent System (MPMAS). It is a multi-agent system that allows an ex-ante evaluation of the impact of alternative strategies to reduce the use of pesticides, including a series of taxes on pesticides, the introduction of integrated pest management, a price premium for safe agricultural products and grants for biopesticides.

3 Discussion and Conclusions

An advantage of multi-agent systems is that they allow solving problems or situations in which a single agent would not be able to perform the task by itself. As evidenced by this article, multi-agent systems have been used over the last few years to facilitate different agricultural processes. Thanks to multiple agents, a large amount of information can be obtained and parallel processes, in which the agents exchange information, can be executed. Moreover, they perform prediction tasks and incorporate artificial intelligence techniques.

Nevertheless, other disruptive technologies may be applied in the field of agriculture in conjunction with multi-agent systems. For example, blockchain to keep a record of territories or track manufactured products, as [23] poposed, which is a system that uses smart contracts and blockchain technology to eliminate intermediaries and streamline logistics activities. As in the case of the solution proposed in [17], which was implemented on a mixed farm.

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