A Precise Survey on Multi-agent in Medical Domains

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***Abstract*—Agent technology has provided many opportunities to improve the human standard of life in recent decades, starting from social life and moving on to business intelligence and tackling complicated communication, integration, and analysis challenges. These agents play an important role in human health from diagnosis to treatment. Every day, sophisticated agents and expert systems are being developed for human beings. These agents have made it easier to deal with common diseases and provide high accuracy with less processing time. However, they also have some challenges in their domain, especially when dealing with complex issues. To handle these challenges, the domain has become characterized by distinctive and creative methodologies and architectures. This survey provides a review of medical multi-agent systems, including the typical intelligent agents, their main characteristics and applications, multi-agent systems, and challenges. A classification of multi-agent system applications and challenges is presented, along with references for additional studies. For researchers and practitioners in the field, we intend this paper to be an informative and complete resource on the medical multi-agent system.**

Keywords*—*Artificial intelligence; agent systems; multi-agent systems

I. INTRODUCTION

Agent-based systems are one of the most exciting and essential fields of research that appeared in information technology in the 1990s [1]. Multi-agent systems (MAS) are significant and active research areas in artificial intelligence (AI). They combine several agents that collaborate, cooperate, negotiate, and communicate in a shared environment to pursue specific high-level objectives.

MAS research contains a broad scope of technical issues, including how to develop MAS to help encourage actions in agents, design algorithms that enable agents to accomplish a set of objectives, knowledge exchange and communications between agents. Their various approaches can be used to handle a multitude of applications, including industrial applications, commercial applications, entertainment, and medical applications [2][3].

In recent years, the world population has grown significantly, increasing the requirements of people and organizations in many sectors. One of the most critical sectors is healthcare, which plays a vital role in our society. However, medical centers, such as hospitals and medical laboratories, need help with dealing with this expansion and organizing the tasks between their departments. Collaborative and integrated systems such as MAS can be considered flexible solutions to these kinds of issues. Different health areas have used these systems for many purposes, such as home health care, eHealth services, patient monitoring, disease diagnosis, and other issues that can be managed using multiple agents.

Our motivation in this paper is to provide an overview of multi, single, and sophisticated intelligent agent technologies in the medical domain, allowing the reader to fully grasp this large field. To do so, we first provide a comprehensive view of the agent's systems by defining the agents and outlining some of their main features and applications. Second, we discuss AI and MAS for the medical sector and review various recent studies in this area. The main contributions of this paper are:

- A detailed survey was conducted on agent-based technology.
- The MAS applications in the healthcare field were covered in five different domains. These are management and organization, decision-making support, data management, remote care, and disease diagnoses.
- The most recent studies (published from 2015 to 2022) were reviewed and presented.

Overall, the MAS background, achievements, and research challenges have been discussed in detail in each corresponding section. The rest of this paper is organized as follows. The second section introduces artificial agents and their various applications. Sections III and IV provide a general discussion of MAS and their key characteristics and of AI in healthcare. Section V is a comprehensive discussion of recent studies in medical MAS in different subfields. Moreover, the reviewed papers have been summarized and are presented in tabular form. Section VI discusses the challenges of using MAS in this field, and finally, Section VII concludes the review.

II. ARTIFICIAL AGENTS

The agents, their main characteristics, the diversity of environments, and the variety of agent types will be discussed in this section.

A. Intelligent Agents

Multiple definitions of agents have been proposed in the literature, arising from various application-specific aspects of their use. The agent can be defined as "anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators," as illustrated in Fig. 1 [4].

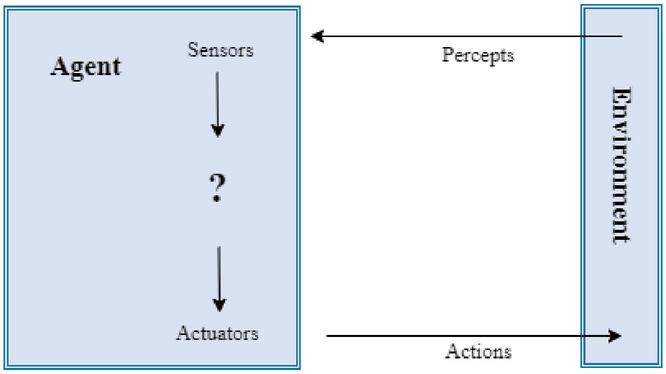

Fig. 1. Agents interact with environments through sensors and actuators.

Furthermore, a generalized definition of the agent was presented in [5]: The authors defined an agent as "an entity which is placed in an environment and senses different parameters that are used to make a decision based on the entity's goal. Based on this decision, the entity performs the necessary action on the environment." The preceding definition has four keywords that can be further expanded upon.

- Entity: This represents the type of agent. The agent can be software, hardware, or a combination of software and hardware.
- Environment: The agent's surroundings are referred to as the environment.
- Parameters: Parameters relate to the various types of data that an agent can get from its environment.
- Action: Each agent has the ability to take action that causes changes in its environment.

Table I presents some examples of agent types discussed in [4], as well as descriptions of their environments, actuators and sensors.

TABLE I. EXAMPLES OF AGENT TYPES

Agent Type	Environment	Actuators	Sensors
Taxi driver	Roads, other traffic, pedestrians, customers	Steering, accelerator, brake, signal, horn, display	Cameras, sonar, speedometer, GPS, odometer, accelerometer, engine sensors
Medical diagnosis system	Patient, hospital, staff	Display of questions, tests, diagnoses, treatments, referrals	Keyboard entry of symptoms, findings, patient's answers
Satellite image analysis system	Downlink from orbiting satellite	Display of scene categorization	Color pixel arrays
Interactive English tutor	Set of students, testing agency	Display of exercises, suggestions, corrections	Keyboard entry

The agent's environment can be physical, such as the control system, or computing systems, such as data sources and computing sources [6]. Moreover, Russell and Norvig (1995) recommended a categorization of environmental properties, as presented in Fig. 2.

- Accessible versus inaccessible: Accessibility refers to the ability of an agent to obtain comprehensive, precise, and up-to-date information from its environment. In this sense, the majority of real-world environments (such as the common physical world and the Internet) are inaccessible.
- Deterministic versus non-deterministic: A deterministic environment is one in which each action has a specific predetermined impact, and there is no ambiguity about the state that will emerge from that action.
- Static versus dynamic: Static environments are those in which changes can only happen due to the agent's actions. On the other hand, a dynamic environment is affected by other processes and changes in directions that are outside the agent's control.
- Discrete versus continuous: If an environment has a definite, limited number of activities and percepts, it is discrete. In contrast, a continuous environment, such as a moving agent in a physical environment, impacts the agent's state by a continuous function.

The agent can be considered an intelligent agent when it meets its design objectives with flexible and autonomous action [7]. Flexibility has been summarized by [8] into three concepts. First, reactivity occurs when the agent can perceive and respond to its environment. Second, the agent shows a goal-oriented attitude, which is known as pro-activeness. Finally, there is social ability, allowing the agent to interact with other agents.

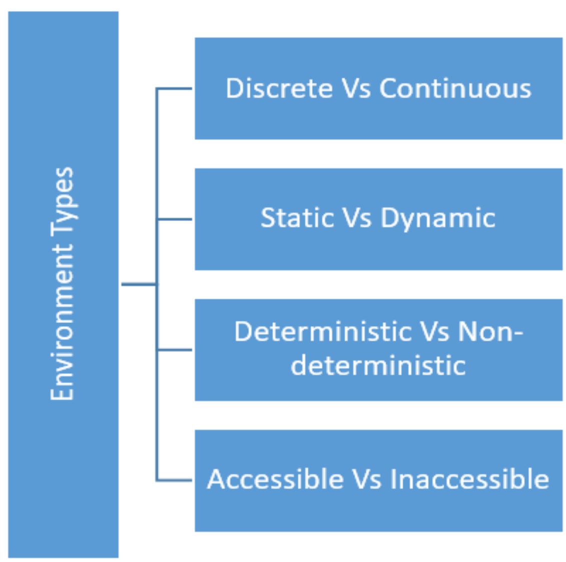

Fig. 2. Agent's environment types.

B. Applications of Agents

Agent applications can be variously categorized by the type of agent, the technology used to implement the agent, or the application domain. The applications, based on the domain type, have been classified by [2] as Industrial Applications, Commercial Applications, Medical Applications, and Entertainment. Fig. 3 shows some examples of these applications for each domain.

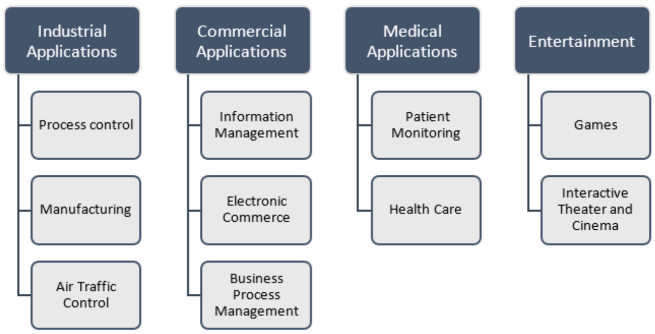

Fig. 3. Examples of some agent applications.

III. Multi-Agent Systems

Generally, an agent can operate alone due to autonomy; however, the actual worth of agents can be increased when they collaborate with other agents. This has led to the creation of the MAS concept, in which two or more agents collaborate to solve a complex problem. Multi-agent systems can be defined as abstractions that can encapsulate the core of several software systems in varying degrees of detail [9]. The agents in these systems are autonomous entities that respond to input from humans and robots in a variety of possible contexts. Additionally, these systems accept information from various sources, including human and autonomous ones, and then respond with a computational strategy based on cross-referencing all the available data [10]. The MAS mainly consists of a collection of agents (Ag1, Ag2, etc.) and a set of potential environmental states in the form of a pair (A and Env) [11]. Fig. 4 presents the main characteristics of the MAS environment.

The MAS is an effective way to fix complicated activities because of its key characteristics, such as efficiency, relatively low cost, adaptability, and dependability [5]. Moreover, its effectiveness originates from the underlying distribution of resources, which divides a complicated task into several subtasks, each allocated to a different agent [12]. Additionally, the MAS can be classified based on features such as [5]:

- Leadership: The MAS can be categorized as leader-follow or leaderless based on the presence or absence of the leader agent (an agent that establishes objectives and tasks for other agents based on one primary goal).
- Mobility: An agent can be either mobile or static, based on its dynamicity. A mobile agent can move throughout the environment. Moreover, it can be hosted by other agents. On the other hand, a static agent remains in one place.
- Delay Consideration: Agents may face many delay sources while performing tasks. Based on this feature, the agents that take the delay sources into account have been classified as delay agents, while those that suggest that there are no sources of delay are known as without delay agents.
- Heterogeneity: MAS can be either homogeneous or heterogeneous. The heterogeneous MAS includes agents with a variety of properties, whereas a homogeneous MAS contains agents with the same features and functionalities.
- Topology: Based on the agents' locations and relations, the MAS can have either a static or a dynamic topology. In the former the agents' positions and locations remain fixed, while in the latter they continuously change; agents may move or leave, and they may be combined with other MAS.

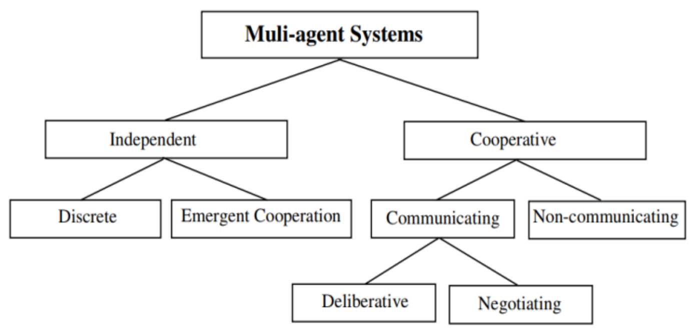

Fig. 4. Characteristics of the MAS environment [13].

IV. AI in Healthcare

Recently, the use of AI has increased across all industries. As a result, AI has the potential to significantly change the field of medicine, thereby benefiting both patients and practitioners [14].

A. Benefits of AI in Healthcare Field

Artificial intelligence helps doctors streamline tasks, improve operational efficiencies, and simplify complex procedures. For instance, AI systems have significantly increased efficiency for radiography tasks, such as cardiac function assessment [15][16] and mammography interpretation [17][18].

In the field of pathology, there are still issues with how to quickly and automatically assess and determine an appropriate diagnosis from practical pathology images when the situation necessitates an immediate fix. Accordingly, AI has made significant progress in this field [19], and many scholars have improved blueprints in this regard, such as: [20], [21], [22], and [23]. Moreover, AI has made significant progress in diagnosing diseases, including several cancer types, such as gastrointestinal cancer [24], breast cancer [25], and colorectal cancer [26]. Another AI field, medical expert systems (ES), completes rather commonplace tasks in medical diagnostics [27]. The ES can be defined as "a computer program capable of automating decisions by asking questions and providing answers or conclusions" [28]. Medical expert systems were created out of the need to assist with diagnosis and treatment of ailments. They can also inform and notify doctors and patients [29]. Examples of well-known ES include the following:

- MYCIN [30]: a computer-based system used to diagnose patients with bacterial infections.
- DERMIS [31]: a prompting system to diagnose skin disease.
- GIDEON [32]: a computerized system designed to diagnose patients with infectious etiology diseases.
- PNEUMONIA [33]: an improved system to diagnose community-acquired pneumonia.

In addition to diagnostic tasks, the recent development of AI has led to a significant improvement in the drug industry, in which it has played a role in the assembly and discovery of novel drugs [34][35].

B. Drawbacks of AI in the Healthcare Field

Despite AI's great benefits in health care, such as helping doctors diagnose diseases, saving time, and reducing costs, many studies have shown that defects can result from the employment of AI in the medical field, and some studies consider AI a disruptive tool [36]. For example, the authors of [37] showed multiple aspects of AI's limitations:

- Data Collection Issue: It is known that some AI techniques, such as machine learning (ML) and deep learning (DL), require massive amounts of data to learn and produce accurate predictions. However, information accessibility in the healthcare sector may be challenging [38] since most are confidential.
- Social Concerns: The widespread use of AI always generates many concerns among health practitioners, as many believe they may lose their jobs and be replaced by AI tools and technologies.
- Clinical Implementation Concerns: Trust in AI-based medications is not completely possible due to the lack of empirical data that could validate these medications, which was an obstacle to successful deployment.
- Ethical Concerns: Due to the lack of universal guidelines for the moral use of AI and ML in healthcare, there is still debate about how far AI may be ethically used in the medical domain.

V. MAS IN HEALTHCARE

Currently, MAS are used for many purposes in the medical field. These systems decrease the workload of healthcare professionals and gather data about a single patient from many specialties to enable them to make more accurate decisions [39]. Many other factors, as provided by [40], help to explain the benefits of using MAS in healthcare.

- MAS's components could operate on various machines spread throughout many locations. Each agent may have access to some of the information needed to solve the issue, such as patient data stored in several hospital departments or across many hospitals, clinics, and surgeries. As a result, MAS could handle distributed problems.
- As the MAS can actively discuss how to divide an issue and how to distribute the necessary subtasks among them, MAS have the ability to decompose complex problems.
- Agents could provide information for patients and medical professionals because some agents are designed to gather and analyze data from various sources.
- Another crucial agent characteristic is proactivity—agents can perform actions that can be advantageous for the user, even when that user has not explicitly asked that they be done. For instance, if the agent is aware that the user is traveling abroad and that the user has experienced heart issues, the agent can determine which nearby medical facilities have a cardiology department in case the user urgently requires this information.

This study presents many previous works that have employed MAS in five fields of the healthcare domain, as shown in Fig 5. Moreover, Tables II and III provide a combined view of these studies by displaying the publication year, main field or domain, and research focus.

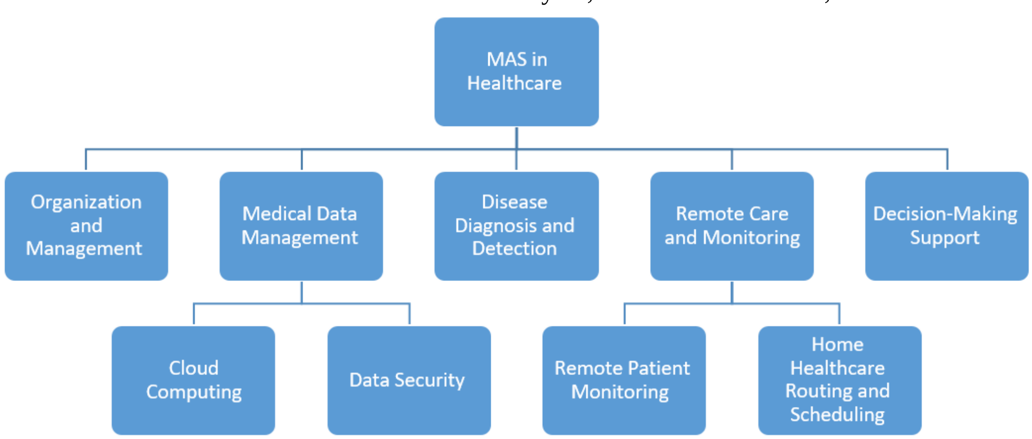

Fig. 5. The covered domains.

TABLE II. MAS FOR DIFFERENT PURPOSES

Main Field	Ref	Year	Research Focus	Main Field	Ref	Year	Research Focus
Orgnisation and Management	[41]	2015	Organization between hospital wards	Decision-Making Support	[49]	2022	Show the superiority over applied of a single-stage approach in the decision-making process.
	[42]	2015	Control patient flow and resource allocation		[50]	2017	Show the superiority over applied of a single-stage decision-making process in the healthcare delivery system.
	[43]	2019	Control patient flow for emergency status		[51]	2015	Use visualization techniques and MAS to improve IDSS
	[44]	2017			[52]	2020	Improve IDSS by use MAS to classify different types of cancer diseases
	[45]	2020	Scheduling of patients and resources		[53]	2021	Use MAS to simulate the surgery operating rooms to ensure timely decisions can be made”
	[46]	2020	Manage the maintenance workflow		[54]	2021	Use self-organizing multi-agent approach to extract probabilistic fuzzy rules from numerical data
	[47]	2020	Mange the unreasonable growth of medical expenses	Remote Care and Monitoring	[57]	2016	Home Health Care (HHC) Routing and Scheduling Problem
Medical Data Management	[55]	2017	Use semantic search approaches with MAS		[58]	2016	
	[56]	2016	MAS and Cloud Computing		[59]	2017	
	[60]	2021			[61]	2018	
	[62]	2018			[63]	2019	
	[64]	2021	MAS and Healthcare Data Security		[65]	2020	Remote Patient Monitoring
	[66]	2016			[67]	2017	
	[68]	2019			[69]	2021	
	[70]	2021			[71]	2015	
	[72]	2020			[73]	2015	

TABLE III. MAS FOR DISEASE DIAGNOSIS

Ref	Year	Disease Type					Reseach Focus
		Diabetes	Cancer	Heart Diseases	COVID-19	Other Diseases	
[74]	2020	*					Produce mobile application integrated within the CareWare architecture and the existing diabetes ontologies
[75]	2015		*				Enhance gene expression analysis through the automation of tasks related to cancer gene identification
[76]	2015		*				Identify genes that provoke triple negative breast cancer (TNBC)
[77]	2020	*					Investage the performance of machine learning algorithms based on the diabetes database
[78]	2020				*		Use MAS to simulate the spread of contagious disease during the COVID-19 outbreak
[79]	2021				*		
[80]	2020				*		Develop MAS to fight and handle COVID-19
[81]	2021				*		Adopt MAS to identfiy the plasma donors for COVID-19 patients
[82]	2020	*					Diagnosing diabetes using multi-agent data mining system
[83]	2016					*	Employ MAS for diagnosis of mental disorders
[84]	2015	*					Help type 2 diabetic patients
[85]	2017			*			Detect cardiovascular disease using Adaptive Neuro-Fuzzy Inference System and MAS
[86]	2021		*				Provide a customized support system for cancer survivors
[87]	2019		*				Adopt MAS for distributed classification tasks in cancer detection
[88]	2016			*			Design MAS for analysis and diagnosis of cardiac patients
[89]	2017					*	Adopt MAS for analyze and monitor diuresis
[90]	2019					*	Review the use of agents for sickle cell disease (SCD)
[91]	2022					*	Use MAS for disease detection using human eye images
[92]	2016					*	Use MAS for detection of autoimmune diseases

A. MAS for Organization and Management Problems

The special characteristics of MAS make them sufficient solutions for controlling and managing different kinds of organization and management problems, such as patient flow and services in the healthcare sector. Therefore, many researchers have mainly focused on this aspect.

A MAS-based system called MMAS (Medical Multi-Agent System) has been proposed in [41] to solve hospital challenges, such as collaboration between different units, elaborations of diagnostics, and the collection of patient information. Two layers of agents have been used: the super agent's layer and the Swarm layer. As a result, many services can now be completed remotely, such as patient appointments, patient registration, remote consultations, and others, which prove the effectiveness of the proposed system.

To control patient flow and emergency services, various agent technologies systems, such as multi-agent facility management systems, patient-centered MAS, and other systems have been proposed. For instance, a patient-centered MAS has been proposed by [42] to improve the ability to deal with unexpected issues, as well as reduce the costs and waiting time for patients, by supporting both the medical staff and the hospital managers and optimizing the distribution of resources. Therefore, the system architecture is constructed with two levels: patients from the higher level and shared resources from the lower.

In [43], emergencies such as natural disasters or accidents are handled by presenting a MAS that uses agents to direct the patient to the nearest hospital based on their current location. In addition, each patient is assigned a room more quickly than when using traditional methods. Similarly, the authors of [44] aimed to automate the prehospital emergency process using the multi-agent concept by categorizing the specialized care in keeping with the state of affairs at the right time for reducing patient mortality and morbidity. As a result, the proposed system provides intelligent decision-making capabilities due to the use of interactive agents.

The authors of [45] represent the outpatient clinic as a MAS and produce an intelligent real-time scheduler that schedules the patients and resources based on the current status of departments. Furthermore, all system entities are mapped to agent roles, either passive or active. As a result, performance measures such as waiting time, cycle time, and utilization notably improved.

To improve the maintenance management process, the authors of [46] suggested using MAS to shift from centralized systems into distributed systems that efficiently manage maintenance requests. Thus, a multi-agent facility management system (MAFMS) was conceptually proposed in which the agents belong to two categories: human resource agents and building components agents. The simulation results confirmed that the advantages of the proposed system outweighed the current systems.

Besides the well-known management problems in the healthcare sector, the increase in medical costs charged by public hospitals is another issue. Therefore, a MAS model was proposed in [47] to provide useful suggestions for managing the immoderate increase in medical costs in China. The results suggested that these expenses can be reduced by using the community first-visit system and improving the government's financial investment.

B. MAS for Decision Making Support

The healthcare decision-making process is complex, risky, and essential, and it requires careful consideration of various factors. Therefore, it is crucial to have a tool that helps make accurate and correct decisions based on real-time data [48]. Recently, MAS have been pivotal in supporting and making decisions in the healthcare sector.

Due to the interrelated nature of decisions in the health field, [49] proposed an interrelated decision-making model (IDM) for an intelligent decision support system (IDSS) in healthcare that aims to produce an effective decision using MAS (known as IDM-IDSS-healthcare). Eight diabetes treatment datasets were used to conduct the experiments, and the results showed an improvement in decision-making efficiency with the proposed model, where the accuracy increased up to 56%.

For the same purpose, a CARE concept that uses MAS technology was introduced by [50] to support decision making in the healthcare delivery system. That system mainly consists of five stages; therefore, five corresponding agents have been developed: primary care agent, secondary care agent, tertiary care agent, quaternary care agent, and palliative care agent.

Visual data mining technology can play a vital role in a dynamic environment. For this reason, a new architecture was proposed in [51] to produce a visually intelligent clinical decision support system that uses MAS to resist nosocomial infections. The proposed agents are User interface, Coordinator, Data preparation, Data mining, Visualization, Evaluation, Knowledge integration, and Database. The evaluation of the proposed prototype noted some advantages, such as the presentation of the graphical data, which in turn reduced the complexity, and using agents guaranteed communication and cooperation between different modules.

The IDSS is a fundamental aspect of Computer Aided Diagnosis (CAD), and because of the need to construct decision-making systems that work in parallel, the authors of [52] suggested developing a CAD system that combines MAS with IDSS. The new system was proposed for cancer disease classification by gene expression profiles of DNA microarray datasets. Therefore, the contributing agents are Gene filtering, Diagnosis, Master, Inquiry, and Result. As a result, the proposed system has proved its practical ability to quickly classify different types of cancer diseases.

Because of the sensitivity of some hospital departments, such as operating theaters, making timely and well-reasoned decisions can be a critical issue that may require a tool. Thus, the emergency processes in the operating room have been modeled using an interactive support system decision embedded with MAS, in which the agents assist in allocating appropriate human and medical resources and planning elective surgery. Three types of agents are included: Supervisor, Service, and Coordinating. The simulation confirmed that the proposed application could take full advantage of all the communication possibilities between the service agents [53].

Recently, efficiency and scalability have been considered essential attributes in decision support systems, for which the complexity of the dataset continues to grow. To handle dataset issues such as inconsistency, a Distributed Probabilistic Fuzzy Rule Mining (DPFRM) algorithm for clinical decision-making was proposed in [54]. The proposed algorithm used a self-organizing multi-agent approach to extract probabilistic fuzzy rules from numerical data. It used six agents (a1 to a6) that can communicate and exchange information with their neighbors. The results confirm that handling inconsistencies within the datasets by DPFRM can increase the accuracy and improve the training time due to the use of a parallel computer.

C. MAS for Medical Data Management

Nowadays, a massive amount of data and information is generated in the healthcare field. Therefore, MAS have emerged as a powerful platform for managing and controlling how these data re exchanged.

The process of information exchange between a range of hospitals is a considerable challenge due to the lack of traditional information retrieval systems. Accordingly, the multi-agent concept has been adopted by the Statistics and Collaborative Knowledge Exchange (SCKE) system, within which the proposed MAS uses semantic search approaches to handle such problems. The pivot component is mainly hospital agents, where each agent represents an individual hospital. Thus, these agents can use the hospital database to accept and search queries to retrieve and exchange information. The system performance is examined, and its efficiency is proven by an in improvement in the accuracy, regardless of the number of queries [55].

1) MAS and cloud computing: With the advent of mobile devices and cloud computing in different domains, the healthcare industry is shifting from direct care services to cloud computing. In addition to the reliability of cloud computing, MAS have proven to be effective in treating medical problems. For that reason, applications designed using cloud computing and MAS are expected to become more plentiful in the healthcare sector.

In [56], the authors suggested combining mobile cloud computing (MCC) with MAS to produce a Medical Mobile Cloud Multi-Agent System (2MCMAS), which takes advantage of both concepts to provide efficient care. The proposed architecture consists of agents grouped into two layers, Super-agent and Swarm agent, that interact in the environment, such as Expert, Search, Discharge, Access, Calendar, Doctor, Nurse, and Patient agents. The proposed system ensures flexibility by distributing knowledge between intelligent agents.

The wide spread of cloud computing has caused the emergence of different models, such as fog computing and edge computing, which will minimize end-to-end delays in the network. However, the fog-cloud-enabled network still suffers from some issues for healthcare applications. Therefore, a Critical Healthcare Task Management (CHTM) model for ECG monitoring that uses MAS is proposed in [60]. The MAS is involved in managing the network from edge to the cloud and providing an efficient resource scheduling scheme. The MAS system consists of four kinds of agents: personal agent (PA), master personal agent (MPA), fog node agent (FNA), and master fog node agent (MFNA). As a result, network usage, response time, network delay, energy consumption, and instance cost are significantly reduced, as shown in the simulation.

Despite the effectiveness of cloud computing techniques, some researchers have reported the advantages of integrating MAS and Internet of Things (IoT) techniques to produce cloud-based applications to control medical data. Accordingly, the authors of [62] have designed a cloud-based system that collects and processes data to make accurate and timely decisions. The patient data are collected using three agents that form the mobile clients—Periodic analyzer, Manual handling, and Emergency agents—to be sent to the cloud module. The agent implementation used a pulse-oximetry sensor with Raspberry-pi hardware for the experiments. Thus, two simple periodic agents (a heart rate simple periodic agent and a SpO_2 simple periodic agent) were combined to represent a complex agent (Complex periodic agent - BPM and SpO_2). The strengths of the model include scalability and the use of complex agents; however, the model suffers from hardware limitations.

2) MAS and healthcare data security: As mentioned in the previous sections, the MAS has been widely adopted to control the process of collecting, managing, and exchanging healthcare data remotely. However, medical data are private and sensitive and should not be accessed by anyone not specifically authorized to do so. To this end, many researchers have reported on how to protect data against external attacks.

In [64], a secure framework for remote healthcare systems was proposed to secure remote healthcare against some healthcare network attacks. The proposed architecture was constructed using two steps. The first step is to create and plan the environment's agents, which will collect the patient data from a sensor network and interact with each other; the contributing agents are Patient, Database, Ambient, Physician, and Nurse agents. The second step is to integrate the agents into groups according to the energy level of the corresponding sensors and the sensitivity of their data. To secure the sensor network, an Intrusion Detection System (IDS) is then instituted and monitored for each group. The experiment results prove the efficiency and effectiveness against the attacks frequently experienced by healthcare networks, such as Smurf, Buffer overflow, Neptune, and Pod attacks.

In healthcare organizations, the data are gathered from multiple sources and shared with other organizations or researchers using a common clinical data warehouse (CDW). However, preserving data privacy from source to destination remains a challenge. In response, the authors of [66] have proposed a multi-agent architecture for knowledge discovery for Evidence-Based Medicine (EBM), which is the modern standard for clinical decision-making known as Multi-Agent

Privacy Preserving for Medical Data (MAPP4MD). The agents are employed within three layers: local health organization agent (LHOA) in the local organization layer, broker agent (BA) in the coordination layer, and repository agent (RA) in the storage layer. The MAPP4MD evaluations prove that the privacy of medical records can be preserved at the source before they are integrated into a larger dataset, which resolves privacy issues that come with integrating medical data into a centralized data repository.

In [68], a novel MAS called the Access Control Security Model (IBAC) is proposed to maintain the security and privacy of eHealthcare data during the transmission phase. The system is mainly composed of three phases: User phase, Agent phase, and Information phase. The agent's role is concentrated in the second phase, in which it verifies user data and establishes an authenticated connection. The system workflow depends on several agents, such as a user interface agent, which is connected to the website or mobile application. The customer username and password are verified using an authentication agent. Finally, the user and server connection is established using the establishment agent and connection management agent. As a result, the proposed framework can provide secure, efficient, and easy eHealth services.

Similarly, the authors of [70] proposed MAS that combines both multi-agent concepts and fuzzy logic to monitor and protect data from unauthorized access and enable conversation between patients and professionals. The system consists of the following phases: Domain/ Information phase, Action/Computational agent, Customer phase, Operative phase, and Communication phase. The agents are employed as expert systems with their own functions. In addition, a healthcare database is used to keep all login credentials for authorized users and to retrieve and analyze data. The user interface agent determines the policies and procedures. Next, the users are validated using a user identification agent, and accordingly, the data transmission agent and a connection management agent establish an authorized connection. User authentication is performed by employing token-based authentication using fuzzy logic. The proposed architecture can prevent many types of outer attacks.

In [72], the authors took advantage of both MAS and Distributed Ledger Technology (DLT) blockchain to increase the protection and security of the eHealthcare databases. The multi-agent role is presented using two types of agents: the user interface agent and the DLT-based authentication agent. Moreover, the proposed system includes a server that is treated as a database to store the patient's health information. The user interface agent is responsible for defining the access rules, receiving the username and password, and establishing the connection between the users and the authentication agent. Then, the user information will be received by the DLT authentication agent to check whether it belongs to the users in the database. According to the verification process, it produces a digital certificate for the user. The research's conclusions will assist in directing the creation of new methods for processing data securely and effectively that combine AI and multi-agent-based systems supported by DLT technology.

D. MAS for Remote Care and Monitoring

Home health care (HHC) encompasses a wide range of health care services given to patients at home due to illness or injury. This reduces the cost of health structures. However, HHC's caregivers usually face routing and scheduling problems due to the increasing population. In order to deal with this kind of problem, many researchers have proven that using MAS can efficiently manage routing issues [57], [58].

In addition to routing problems, some patients reside in underserved or difficult-to-reach areas, and quick and accurate diagnoses are essential to starting therapy and addressing problem. Employing MAS to solve these kinds of problems has achieved notable success [65].

E. MAS for Diseases Diagnosis and Detection

A reliable, cost-effective, and quick computer-based medical diagnosis is still a challenge because medical diagnosis has always been a critical and complex topic [93]. The MAS approach helps to promote the creation of a readily scalable system. It implements scenarios for evaluating the functional condition of the human body, depending on the goal of the medical research and the available indications of the human body state [94]. Accordingly, many researchers have extensively employed and improved the MAS concept to detect, diagnose, and analyze various types of diseases. The MAS have proved their superiority over other traditional methods. This review investigates different studies related to those systems, including diabetes, cancer, heart diseases, COVID-19, and other diseases. Table III summarizes these studies with a focus on the publication year, type of disease, and the study's main objective.

VI. Challenges in the Future

Despite the wide spread of MAS and their application, there are still some challenges involved in applying MAS, such as coordination between agents, security, and task allocation [5]. Moreover, the employment of MAS in the healthcare field may face the following challenges:

- Security issues: Due to the nature of MAS, sensitive data can be feasibly used by more than one resource, which may reduce the security and privacy of patients' data. There are some concerns about identity theft. Moreover, in the case of a geographically distributed environment, healthcare systems must interact with other systems. However, trusting the data provided from diverse resources can be a challenge.

- Implementation cost: Although it is assumed that MAS could reduce medical costs, some areas require more costs to employ AI techniques. For example, the instruments needed to collect data for AI systems can be quite expensive [14].

- Technical problems: Many issues may result from the development of MAS, such as those related to user expectations and acceptance, safety, and trust issues, as well as how to accurately manage the interactions between software agents, humans, and the preexisting healthcare systems [40].

- System reliability: The MAS needs to have a range of characteristics that gain users' trust. For example, the set of regulations is changed continuously, which requires more flexible and improved systems to adapt to these changes. Moreover, the MAS in this field are mainly used by many users with different technical abilities; therefore, the MAS needs to be easy to use and integrate with existing services.

VII. Conclusion

This review sought to provide fundamental knowledge about multi-agent systems and MAS-related studies in the medical field. We have demonstrated how MAS has been applied to address various medical-related issues; starting with a brief description of the intelligent agents, their main characteristics, the diversity of environments, and the variety of agent types, followed by an introduction to AI and MAS in the medical field and an in-depth investigation of studies on the use of MAS in the medical sector from 2015 to 2022. Finally, the paper concluded with discussion of future challenges related to this topic. It is our hope that this review of medical MAS applications will be helpful to future researchers in this field.

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