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Multi-Agent System Applications in Healthcare: Current Technology and Future Roadmap

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Abstract

One of the most rapidly evolving government sectors in any country is the healthcare industry. Today, the healthcare system of developed nations is facing the various challenges presented by an aging population. Increasing demand for health services presents a challenge for the existing healthcare industry, as vast amounts of resources will be required. The Multi-Agent System (MAS) approach provides a powerful platform for modeling and solving real world problems such as healthcare. This makes it possible for patients to remain at home and consequently reducing costs. This paper presents developed MAS applications in healthcare, as well as explores the future of developed MAS applications. In particular, it will be argued that these health based MAS applications can provide a reasonable way to mitigate the cost due to increased demand for services.

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Keywords: Multi-Agent Systems; Healthcare Technology; Wireless Sensor Networks; Body Area Networks

1. Introduction

In many developed nations around the world the healthcare industry is constantly evolving and adapting to new technologies and trends. Specifically, governments are interested in new methods of mitigating the cost of providing healthcare services. With the aging of the baby boomer generation, the percentage of the population who are elderly

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is expected to increase to 1 in 4 by 2036[1]. On average, the elderly make up a large portion of the consumers of health services. Therefore, it is foreseeable that an increase in demand for healthcare and related services is imminent given the trend described. Canadian seniors are used to high quality service, but the average waiting time to see a doctor is larger than other developed nations[2]. This increased demand will put considerable strain on the current healthcare system, and ultimately result in costly expenses for the government. Several obvious solutions to this problem can be considered: 1) to reduce overall cost the amount or quality of healthcare services provided could be cut back. Unfortunately, the tradeoff with this approach is that some citizens requiring healthcare will suffer. 2) To meet the increased demand for service, foreign doctors and healthcare professionals may be recruited. The disadvantage to this is the expense and difficulty. 3) Alternatively, new technologies and methodologies can be applied to the current model of healthcare to achieve the required levels of service, with the given infrastructure.

This paper focuses on new technology being developed to provide the next generation of healthcare service. Specifically, technology using the Multi-Agent System (MAS) approach that allows elderly citizens to maintain their independent lifestyle is examined.

2. MAS and Healthcare

The Multi-Agent System (MAS) approach provides a powerful platform for modeling and solving real world problems. Logically, this methodology can be extended to model the domain of healthcare. Before considering what can be achieved by applying this paradigm to healthcare, a lose definition of what constitutes a MAS must be defined.

2.1. A Multi-Agent System?

Various definitions from different disciplines have been proposed for the term multi-agent system (MAS). From a distributed artificial intelligence perspective, MAS are a loosely coupled network of problem-solver entities (or agents) that work together to find solutions to problems that are beyond the individual capabilities or knowledge of each entity[3]. More recently the term has been given a more general meaning, and is used to describe all types of systems composed of multiple autonomous components showing the following characteristics[4]. Each agent has incomplete capabilities to solve a problem. There is no global system control; Data is decentralized; Computation is asynchronous. An agent, in the context of multi-agent systems, could be software, hardware, or human in nature. Each agent has unique properties such as behaviour, data, goals, and motivation[5]. A simple analogy would be that of a soccer team; each player on the field works together to reach the common goal of scoring. In fact, this exact scenario has become an annual competition for programmers all over the world known as the Robot World Cup (Federation of International Robot-Soccor Association, 2014). The important property to remember is that by itself, an agent does not have the full knowledge or capability to solve a specific problem or task at hand. Therefore, to complete goals agents must work together, which by definition is a multi-agent system.

Figure 1 illustrates an intelligent agent system designed to independently collect information and automatically implement actions[6]. The task manager and communicator components form the control structure for the system. Task manager breaks problems into subtasks for specific agents, recombines information from various agents, as well as interfaces with the user solving problems. The communicator is responsible for providing input to agents in an understandable format and in return receiving meaningful output from agents in the system. Lastly, the agents may employ various methodologies to achieve the goal of monitoring specific data and acting accordingly.

Two specific technologies well suited for modeling healthcare problems with agents are: Wireless Sensor Networks (WSN), and Body Area Sensor Networks (BASN).

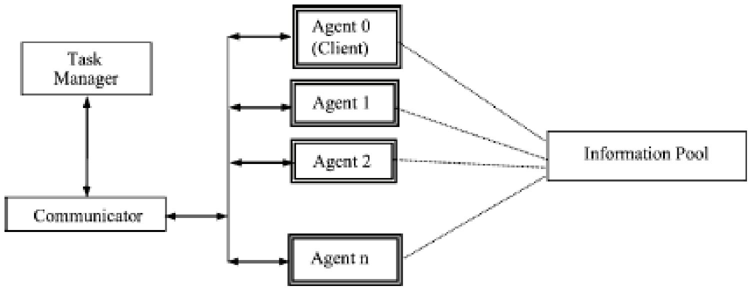

Figure 1: An example of a Multi-Agent System for decision support[6].

2.1.1. Wireless Sensor Networks

A wireless sensor network is a collection of nodes organized into a cooperative network, where each node is capable of sensing, processing, and communicating[7]. This classification is a subset of MAS and shares many of the same technical and software challenges, however wireless sensor networks have two distinct properties (Stankovic, 2008): 1) agents are homogenous. This property implies that all agents, or nodes, are the same. Meaning they share the same hardware, software, and ability. 2) Agents are numerous. This property makes more sense when a real world application is considered. For example, a WSN that keeps track of the status of widgets will grow linearly with the number of widgets ever produced. To visualize this, consider the system presented in Figure 1. In a WSN context, each agent would be responsible for sensing data and reporting back to a central coordinator.

These systems have the potential to revolutionize our lifestyle with applications in healthcare, entertainment, travel, retail, industry, dependent care, and many others[9]. One real world WSN example is VigilNet: a program created to alert military command and control of the occurrence of enemy movement events in real time using infrared camera equipped nodes[8].

2.1.2. Body Area Sensor Networks

A Body Area Sensor Network (BASN) is a specific type of Wireless Sensor Network with the goal of gathering information about a human body using sensors located in and on the target body, illustrated in Figure 2[7]. Again, they share many of the same technical and physical challenges, but BASN have some distinguishing properties[9]:

- Agents are heterogeneous. This property results from the requirement that nodes must be placed in or on the body, and therefore must be built to be as small and unobtrusive as possible. This limits the functionality of each node to only what is required for the task at hand. To illustrate this point, consider two BSAN nodes: one for measuring brainwaves and another for measuring heart rate. Both must be able to communicate, but it would be redundant in size, cost, and power consumption to have the hardware for sensing both stimuli built into each.
- Agents are few in number. This property also follows from the requirement that nodes must be placed in or on the body and made to be small and unobtrusive. Therefore, agents must be few in number because there is no room for multiple nodes of the same functionality. The argument can be made that this reduces the overall redundancy of the system. However, using more nodes requires more power to be expended by the system as well as more equipment to be worn by the user, both of which are ultimately undesirable results.
- Wireless signal quality is variable. This property is a constraint of the environment in which BASN operate. The human body is not a conductive medium for wireless signals and can physically block or interfere with signal transmission between nodes[10]. This problem is challenging, as the body is a dynamically moving object. Therefore, to be truly robust and efficient a BASN system must take this into account when communication between nodes occurs.

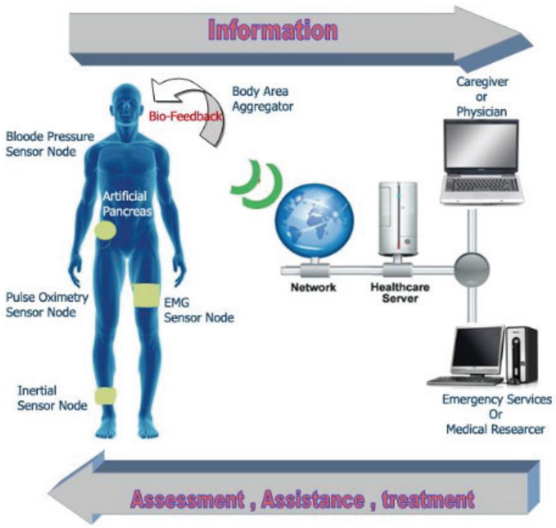

Figure 2: Example of a Body Area Sensor Network for patient monitoring[9].

2.2. Geriatric Healthcare Applications

At all levels, the healthcare domain is characterized by shared and distributed decision making and management of care, requiring complex and diverse communication between groups of healthcare professionals[11]. Therefore, the idea of autonomous intelligent, proactive, collaborative entities interacting in a distributed environment lends itself well to solving problems of this domain. In the context of this paper, MAS applications that allow elderly citizens to maintain an independent lifestyle will be presented. The argument being the longer seniors are able to live safely comfortably on their own, the less stress the healthcare system will experience. Proposed systems often fall into one of the following categories: telemedicine, daily living and monitoring, and detection and assistance.

2.2.1. Telemedicine

Applications in this category are capable of remote biomedical patient monitoring as well as real time communication with a physician. Sensor nodes attached on or in the patient's body facilitate the monitoring of various biological properties. These properties can be made available in real time to a physician capable of communicating directly with the patient. Communication could take place over different medium such as phone, email, or video conferencing technology. Applications like this have been proposed to provide dependent patients in remote areas with access to health services.

2.2.2. Daily Living and Monitoring

Applications in this category use wearable and implantable sensors for unobtrusive monitoring of patients vital signs[12]. Typically, these systems are designed to keep historical information, provide insight and report abnormality. Medical cases such as diabetes, tumor, cancer, or physical disabilities may benefit from such an application.

2.2.3. Detection and Assistance

Applications in this category are arguably the same as daily living and monitoring applications, with the added functionality of providing assistance for the patient, when deemed necessary. For instance, an application to detect and identify falls and provide assistance could help allow elderly citizens with walking difficulty lead an independent life.

Ultimately, the goal of these MAS applications is to prolong the independent lifestyle of the elderly, and in turn reduce the overall cost to the healthcare system.

3. Developed Applications

Currently, there is much research and interest in the field of healthcare related MAS applications. Many interesting current MAS applications in healthcare focus on: fall detection, gait analysis, heart rate monitoring using electrocardiogram (ECG), pulse oximetry, and detecting Parkinson's episodes and their severity[13]. An interesting development worth noting is that commercial products are available, for example Human Recorder Co. LTD and LifeSync are two competing wireless ECG monitors. There are further commercial products available for fall detection made by Well- core and Philips[13]. These systems use three dimensional motion sensors to determine body orientation, and are able to improve the lives of elderly or disabled people who are alone and worried about falling down by providing a means to get help[12]. The existence of these commercial products would not be possible without the increased availability of low-cost, powerful, hardware. The examples highlighted below were chosen for their potential to alleviate the burden elderly citizens place on the healthcare system.

3.1. TeleCARE

The TeleCARE project[14] is aimed at the design and development of a configurable framework focused on virtual communities for elderly support. These virtual communities will allow the elderly to stay at home, and keep, to a certain extent, their typical lifestyle. In[14], the authors proposed a solution that has to be seen as complementary to other initiatives for the integration of elderly in the society. The TeleCARE system proposed the multi-agent paradigm as a base infrastructure instead of TCP/IP over the Internet for two main reasons:

1. Moving the code to the place where actions are required enables real-time response, autonomy and continuity of service provision with reduced dependency on network availability and delays;
2. Since new mobile agents can be built and sent for remote execution whenever needed, higher levels of flexibility and scalability are achieved.

With different organizations developing different products and services, in a variety of different areas, there is a need for a common platform into which all these developments may be plugged so that interoperability is possible. As such, TeleCARE attempts to be as open as possible so that new devices may integrate with the platform as they are developed. Figure 3 shows the TeleCARE architecture demonstrating interconnected virtual communities.

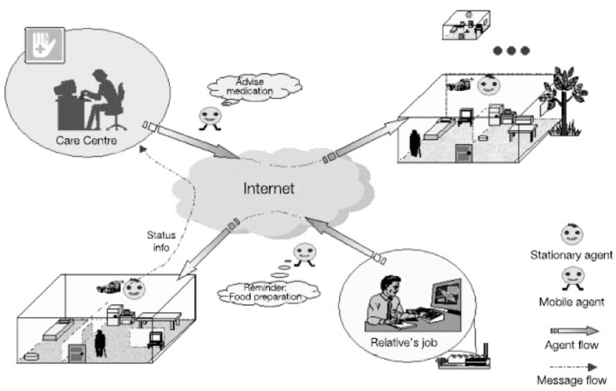

Figure 3: TeleCARE System interconnected digital communities. (Camarinha-Matos & Afsarmanesh, 2004)

3.1.1. Implementation

The TeleCARE infrastructure to support collaboration in the elderly care virtual organization is shown in Figure 4. The basic platform is installed at each node of the TeleCARE network, while the specialized components have a distributed implementation over the TeleCARE network. The three levels of infrastructure are described next.

External Enabler Level: Supports the communication over the network and interfacing to external devices. Specifically, this level is responsible for safe communication between network nodes. A virtual private network is used to ensure safe transmission of critical data[14]. Furthermore, this level abstracts communication between sensors, acting as a bridge for the system to interface with many different *intelligent homes* or other ad-hoc networks.

Core Multi-Agent System Platform Level: Is the main component of the basic platform supporting the creation, launching, reception, and execution of stationary and mobile agents as well as their interactions[14]. Additionally, the storage and manipulation of data and information to be handled within TeleCARE is done at this level. A catalog of all devices and services supported in the system is maintained at this level.

Vertical Services Level: This is the application level and consists of two sets of specialized services: base horizontal services and vertical services. Base services provide functionality for the other vertical services, including the following: web service access, virtual community support, and specialized interfaces for the elderly. The vertical services build upon the basic TeleCARE services to support different interactions within the system. The initially developed vertical service applications include: agenda reminder, time bank, entertainment, and living status monitoring services[14].

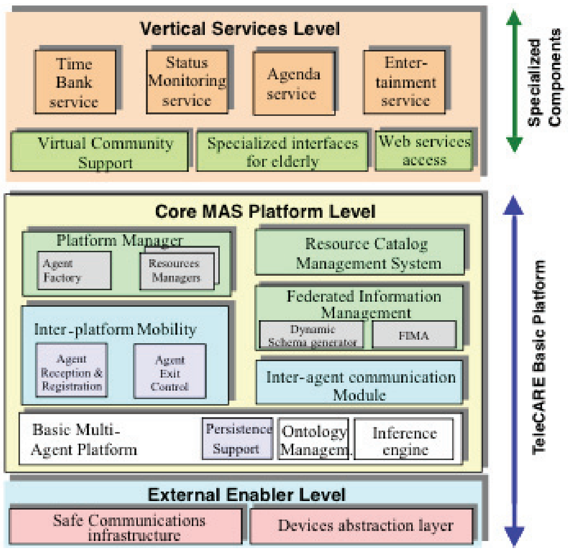

Figure 4: The TeleCARE infrastructure block diagram. (Camarinha-Matos & Afsarmanesh, 2004)

3.1.2. Drawbacks

The proposed TeleCARE system is still a prototype, and requires thorough testing before it can be released to the public domain. Issues such as system throughput and scalability must be explored and tested with the proposed architecture before any measure of efficiency can be determined.

3.1.3. Results

Due to the inherent openness and efficient communication features, the TeleCARE system provides an attractive and robust platform for creating healthcare applications. This system would allow elderly citizens to maintain socially active and independent lifestyles, while maintaining a safety net of healthcare services when needed. With continued research regarding scalability and real-world performance of this system, TeleCARE could become a viable application.

3.2. MADIP

Combining existing technologies such as Wireless Sensor Networks (WSN) and Body Area Sensor Networks (BASN) together as one coherent system is sometimes referred to as a unified body sensor network[10]. One notable example of this is the Multi-Agent Distributed Information Platform (MADIP) presented in[15]. The resulting system is *able to notify the responsible care-provider of abnormality automatically, offer distance medical advice, and perform continuous health monitoring for those who need it*[15]. As such, this platform is well suited for daily living and monitoring, as well as detection and assistance applications for the elderly. Figure 5 shows the high level architecture of the system[15].

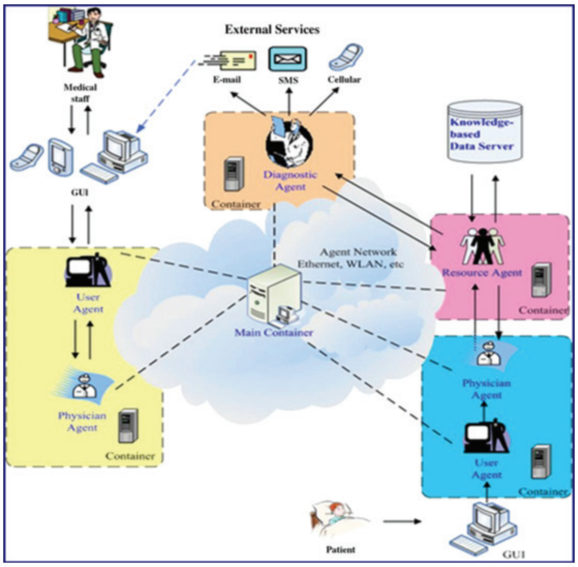

Figure 5: The MADIP system architecture.

3.2.1. Implementation

MADIP is composed of six types of components which map to the corresponding human agent in the real world scenario: 1) User agent, 2) Resource agent, 3) Physician agent, 4) Diagnostic agent, 5) Knowledge-based data server, and 6) External services[15].

User agents act as an intelligent gateway interface for physicians and patients. They derive and execute the required system actions based on user requests. The Resource agent mediates agents' access to resources within the system and as such operates at a higher level of trust. The Physician agent is a mobile agent used by medical staff to perform tasks. Being a mobile agent means it will unobtrusively monitor a patient without the physician being around. The Physician agent operates asynchronously and independent of the sending program, or put another way, after dispatching an agent a physician may carry on with other work while awaiting information.

The Diagnostic agent (DA) is stationary that can be considered as a data-analysis engine. The main task of the DA is to analyze the data from patients and indicate or predict sudden change in patients' status. The Knowledge-based data server consists of two information repositories: user status and profiles. Both repositories are used to store physiological information collected by a physician agent. The first contains collected information relating to the patient physical status (i.e. heart rate, pulse oxygen saturation values) and the second contains up-to-date electronic records for patients. Records being the limits of monitored parameters and basic patient information. When the resource agent receives patient' monitoring data, it stores the data in the user status repository and sends a copy to the diagnostic agent for analysis. This component could be considered the most critical in the entire system, as "efficient and effective healthcare monitoring is highly dependent on disseminating time-critical information[15]".

Figure 6[15] demonstrates a usage scenario from a physician's perspective. Lastly, the external services component contains the environment hardware and services such as email, mobile phone, and short message services.

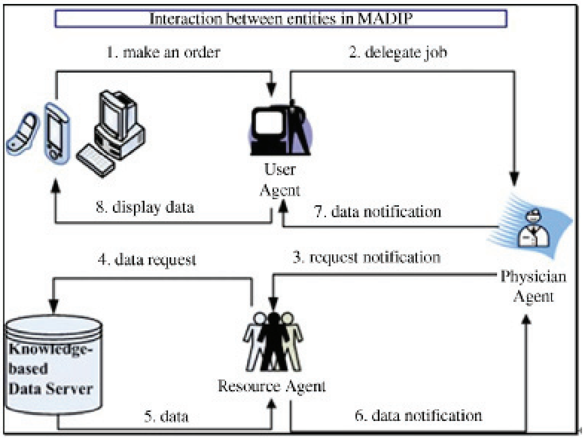

Figure 6: Interaction between entities in MADIP.

3.2.2. Drawbacks

MAS are difficult to evaluate, because there are no specific metrics, widely accepted, for the assessment of their architectural integrity and the performance of their implementation. As such, the proprietors of MADIP focused on usability and readability of the system, because one of the most important key-points would be its contribution to the ubiquitous patient care. A usability survey was conducted to show the effectiveness of the proposed system, consisting of 20 physicians and 30 patients[15]. While the overall survey was positive, the sample size is very small. Furthermore, privacy and security issues must be investigated, as well as testing the throughput and physical limitations of the MADIP system.

3.2.3. Results

Ultimately, the goal of this application is to provide near real-time healthcare services and monitoring for a population. Adapting this system to provide healthcare services for the elderly would enable them to maintain independent lifestyles without worry of being unable to get medical help when needed. Furthermore, such a system would cut down on waiting and processing times for both patients and doctors in the healthcare system.

4. Future Applications

Given the complex technological challenges coupled with the social and ethical constraints these systems have predicting the future of healthcare and multi-agent system applications is challenging. Ultimately, new or revised techniques will be put forth to improve the ability, efficiency, and reliability of the next generation of human-computer healthcare systems. This section focuses on new ideas being explored in the areas of: implantable sensors, power harvesting, wide-scale integration, and disease diagnosis/prediction.

4.1. Advances in Implantable Sensors

Implantable biosensors are an important class of biosensor based on their ability to continuously measure metabolic levels, without the need for patient intervention and regardless of the patient's physiological state (sleep, rest, *etc*.). These sensors are implanted into the human body and require no further interaction from the user to operate. The main reasons implanted sensors are more desirable than their on-body counterparts are that they: do not limit patient mobility, and cause fewer skin infections[9]. For example, such a sensor would represent a highly desirable solution for diabetes management where traditional means of glucose tracking involves pricking a finger for blood and testing it with a strip. It has been estimated that "the range of implantable biomedical devices will increase substantially over the next decade, thanks to improved technology in MicroSystems technology achieved during the last decade[9]". Increasing the variety of sensors will only lead to more sophisticated and user-friendly applications. The major challenge of developing implantable sensors is the hardware used to create the sensors; it must be small to be implanted unobtrusively in the body and contain the power required to sense and communicate.

4.2. Advances in Power Harvesting

Energy consumption in BASNs is considered one of the crucial problems and challenges, and deeply needs investigations and solutions[9]. Although the microelectronics industry has faithfully adhered to Moore's frenetic pace, advancements in commercial battery technology have been gradual; therefore, a growing number of trends in research deal with the idea of power harvesting[7]. This is a technique in which implanted or wearable sensor nodes gather energy from their surroundings. Using harvested energy to recharge batteries could not only extend battery life, but also simplify use of the system (from the perspective of a user)[7]. The authors in[16] analyze WNS node power consumption, and identify several energy sources to fill those demands: heat engine, radioactive (Ni63), solar outside, solar inside, temperature, human power, air flow, pressure variation, and vibrations. While the lack of capable, miniature, hardware prevents some of the sources of energy from being utilized such as radioactive decay, a feasible piezoelectric vibration-based energy generator is presented[16]. Further advancements in this area will allow for long lasting implantable and wearable sensors.

4.3. Wide-Scale Healthcare Integration

Advances in MAS healthcare technology will ultimately lead to the emergence of wide-scale integrated healthcare systems[13]. These systems will contain MAS technology on multiple levels with the purpose of providing pervasive and ubiquitous healthcare services for anyone from anywhere[7]. The levels can be broken down into: 1) BASN for individual monitoring, 2) Inter-Body Networks for communication between BASNs, 3) Intranet for communicating with larger communities of BASNs, and finally 4) Internet for communication between communities[7]. Glossing over the ethical, technical, and social design challenges at each level, the resulting system will enable interconnected, real-time, support and monitoring for entire populations.

4.4. Disease Prediction/Prevention

Finally, once long-lasting implantable sensor nodes are feasible and infrastructure for BSN communication is pervasive, a next generation of healthcare applications can be realized. Nodes capable of genetic analysis could be used for disease detection and prediction[13]. Furthermore, genetic or other biological data from entire populations could be examined and mined for medical research. Such an application would be useful in the fight against cancer and other genetic diseases.

5. Conclusion

With the aging of baby boomer generation the healthcare industry is faces an increase in demand for service over the next couple of decades. Consequently, the cost of providing health services will rise in accordance with the demand. However, the multi-agent system approach can be used to model the healthcare domain, and provide a new platform to help meet the demand for health services. Specifically, healthcare based multi-agent system applications designed to prolong the independent lifestyle of seniors will help reduce stress on the healthcare system, as well as the cost of providing services. Furthermore, as advancements in biomedical sensor nodes and power harvesting techniques are made, resulting healthcare based multi-agent system applications will become easier to use and more capable.

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