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RESEARCH PAPER

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Multi-Agent Systems Requirements Analysis for Patient-centered Healthcare Consultancy Service

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Abstract: Agents are currently being discussed in nearly every domain of science and engineering. Through the utilization of IoT and agent-based systems, remote consultations and virtual doctors can provide essential healthcare services by analyzing patient data and medical history. The purpose of this paper is provide an analysis the requirements for multi-agent systems in patient-centered health consultancy services in Kenya. It focuses on various agent types, including hardware, hospital, human, software, database/storage, and technological/framework agents. For hardware, computers, laptops, and mobile devices need specific processing power, memory, network connectivity, storage, and security. Medical equipment must prioritize accuracy, reliability, integration with records, and regulatory compliance. Networking requires high-speed internet, security, and redundancy. Hospital agents offer comprehensive inpatient and outpatient care, categorized into general, mental health, and specialized hospitals. Human agents, like medical specialists, IT professionals, and administrators, play essential roles in healthcare consultancy. Software agents encompass Electronic Health Records (EHRs), Clinical Decision Support Systems (CDSS), Telemedicine platforms, and more. Database/storage agents include EHRs, Health Information Exchange (HIE) systems, and data encryption. Technological/framework agents involve health information systems, telemedicine platforms, decision support systems, and health data analytics frameworks. These agents enable efficient data management, remote care, evidence-based decisions, and secure data exchange.

Keywords: agents, hardware agents, health consultancy, internet of thing, multi-agents, requirements analysis, software agents

I. INTRODUCTION

Agents are currently being discussed in nearly every domain of science and engineering. An agent is a concept in the field of Artificial Intelligence. It can be viewed as a computer system integrated into a certain environment such as a physical system or internet, with flexible autonomous action [1]. An agent is a computer system within an environment and with an autonomous behavior made for achieving the objectives that were set during its design [2, 3]. Agents have behaviors, often described by simple rules, and interactions with other agents, which in turn influence their behaviors [4]. They are also able to make decisions and choose the suitable actions to reach the goal autonomously. Agents require the ability to cooperate, coordinate, and negotiate with each other, in much the same way that we cooperate, coordinate, and negotiate with other people in our everyday lives. Meanwhile, agents can have different actions, including responsiveness, pro-activeness, and social behaviors. Each agent can receive information from the external environment and react in real-time to affect or adapt to the environment.

An agent can be used to refer to different components when studying different objectives in different paradigms. Some may consider any type of distinguished parts of a program (e.g., model, system, or subsystem), or any type of independent entity (e.g., organization, firm, or individual people), to be an agent. The agent is said to be Identifiable, self-contained, and discrete with a set of characteristics and rules governing its behaviors and decision-making capability. The discreteness requirement implies that an agent has a boundary, and one can easily determine whether something is part of an agent, is not part of an agent, or is a shared characteristic. Authors of this paper perceive an agent as an entity whether software, hardware, or human in nature working on behalf or in the capacity of another entity solving the problem in real life the same way an original entity can do and Each agent has unique properties such as behavior, data, goals, and motivation.

Agent can be software and hardware that autonomous, self-directed, reactive, able to communicate, veracity, proactive, has the social ability, can learn, has sense of mobility, situated, goal-directed and flexible. [3] Perceives agents in the following types: The reactive agent, cognitive agent, intentional agent or BDI (Belief, Desire, and Intention), rational agent, adaptive agent and communicative agent [3].

Software agents are computer programs that can perceive their environment, reason about it, make decisions, and take actions to achieve a specific goal. Jennings and Wooldridge also note that the development of agent technology has led to the creation of a new paradigm in computing, which is based on the use of software and hardware agents to solve complex problems. Software agents are widely used in various domains such as e-commerce, finance, and healthcare [5]. In healthcare, software agents can be used to support clinical decision-making, patient monitoring, and disease management [6].

Hardware agents are tangible, physical devices or components designed to perform specific functions. They are made up of physical materials and are typically integrated into a larger system or environment. Examples of such agents include robots, drones, sensors, actuators, embedded devices in Internet of Things (IoT) systems, and autonomous vehicles. The have capabilities to interact with the physical world through sensors and actuators. They can perform tasks that involve manipulating objects, moving around physical spaces, gathering data from the environment, and carrying out actions in the real world. This agents are mostly constrained by their physical attributes, such as mobility, power source, and processing capabilities. Upgrading or modifying hardware agents can require physical changes. In some cases, hardware agents and software agents can work together. For example, a robot (hardware agent) can be controlled and directed by a software agent that runs on a computer, guiding its movements and tasks.

Human agents are people who are trained to perform specific tasks in a particular domain [7]. In healthcare, human agents include physicians, nurses, and other healthcare professionals who provide direct care to patients. They can also include healthcare administrators who manage healthcare systems and policies. The use of agent technology in healthcare has several potential benefits, including increased efficiency, improved patient outcomes, and reduced costs [8]. However, there are also challenges that need to be addressed, such as the need for interoperability between different agent systems, the need for standardization of agent interfaces and protocols, and the need for data privacy and security [9]. To bridge this gap, research emphasized the need for health system research in developing countries like Kenya to improve the overall healthcare system [10].

Intelligent agents are software programs that perform tasks autonomously and make decisions on behalf of their users. These agents are designed to mimic human intelligence and behavior and can be used in various applications. Intelligent agents have been used in healthcare to perform tasks such as diagnosis, treatment planning, and monitoring. They are used to provide personalized diabetes management to patients. The agent used patient data to create personalized treatment plans and provided real-time feedback to patients. [11] Used an intelligent agent to monitor and predict patient falls in hospitals. The agent was able to analyze patient data and detect patterns that indicated a high risk of falls. The agent then alerted healthcare providers, allowing them to take preventative measures. Intelligent agents have also been used in healthcare to support decision-making by healthcare providers. They are also used to support clinical decision-making in the management of chronic kidney disease. The agent provided recommendations to healthcare providers based on patient data, guidelines, and best practices. They have also been used in healthcare for patient education and engagement. One study by [12] used an intelligent agent to provide health education to patients with hypertension. The agent used patient data to create personalized education materials and provided feedback to patients. In general, intelligent agents have shown promise in healthcare for tasks such as diagnosis, treatment planning, monitoring, decision-making support, and patient education and engagement.

A. *Multi-Agent System*

A multi-agent system is a system that contains a set of agents that interact with communications protocols and can act on their environment. Different agents have different spheres of influence, in the sense that they have control (or at least can influence) on different parts of the environment [3]. These spheres of influence may overlap in some cases; the fact that they coincide may cause dependencies reports between agents. These systems have benefited from a wealth of research spanning decades with the first international conference occurring in 1995 [13]. Multi-agent systems have been shown to improve performance by distributing the workload among many agents for tasks such as natural language processing and learning [14-16] as well as load balancing [17]. Multi-agent systems have found a wide range of applications such as supply chain management [18], controlling building environments and land use [19] to name only a few.

In healthcare, MAS has been proposed as a solution to improve patient-centered care by enabling coordination and communication among healthcare agents. For instance, a MAS can be designed to facilitate the exchange of patient information among healthcare providers, improve the monitoring of patient progress, and enhance the overall quality of care. Several studies have explored the application of MAS in healthcare. One such study by [20] proposed a MAS-based approach to improve the coordination of care for patients with chronic diseases. The study demonstrated that the MAS was effective in improving the communication among healthcare providers and enhancing the quality of care. Another study by Guo proposed a MAS-based approach to optimize the allocation of healthcare resources in a hospital setting. The study showed that the MAS was effective in improving the efficiency of resource allocation and reducing the waiting time for patients. The design and implementation of a MAS require a thorough understanding of the underlying technologies, including agent communication protocols, ontologies, and decision-making algorithms. In addition, the adoption and scale-up of a MAS in healthcare require careful consideration of the legal, ethical, and regulatory frameworks. In general, MAS has the potential to transform healthcare delivery by enabling patient-centered care, improving care coordination, and enhancing the overall quality of care

B. *Agent-Based Modelling*

Computer simulation started with the entrance of computers in universities in the 1960s [21]. Since then, computing power and general accessibility have led to great advances in simulation, and in the 1990's we saw the birth of multi-agent models, which gave rise to the particular form of simulation that focus on agent-based modeling [21]. Agent-Based Modelling (ABM) is a computational modelling technique that allows simulating the behaviour of complex systems through the interactions of autonomous agents. ABM is characterized by many (potentially) highly complex agents; according [22] the "multi-agent systems" discussed by [21] is a branch of ABM that "originated from computer science and research on artificial intelligence and artificial life". Agent-based modeling is also referred to as individual-based modeling, particularly in the field of ecology [22]. The name of the approach is quite descriptive of what it is: an approach where individual agents are modeled, instead of modeling systems with variables of their own (as was done by the Club of Rome for example) [21, 22]. The "agents" may, however, be "organisms, humans, businesses, institutions, and any other entity that pursues a certain goal" [22].

Agent-based modeling and simulation (ABMS) is a relatively new approach to modeling systems composed of autonomous, interacting agents. Agent-based modeling is a way to model the dynamics of complex systems and complex adaptive systems [4].

ABM is thus not necessarily committed to methodological individualism, but here it focus mostly on the strains of ABM. So, why do (or should) we model? Some mechanisms are hard to discover or observe directly, and simulation may help us understand these underlying processes [21]. If our theories, turned into models, corresponding to the real world, we may use our simulations to predict future developments [21]. If we have established the realism of our model, we can also run sensitivity analyses, which can be very useful [21].

New worlds and new ways of interacting and organizing communities may easily be developed, and the findings may at times have interesting implications [21]. This application of ABM is perhaps most interesting for those involved in "transformative-emancipatory". With regards to critical realism, it also has an emancipatory dimension that may be of interest to all practitioners of ABM, regardless of the kinds of worlds they model [23, 24].

A typical agent-based model has three elements: namely; a set of agents, their attributes and behaviors, a set of agent relationships and methods of interaction: An underlying topology of connectedness defines how and with whom agents interact and the agents' environment: Agents interact with their environment in addition to other agents. A model developer must identify, model, and program these elements to create an agent-based model. The structure of a typical agent-based model is shown in Figure 1

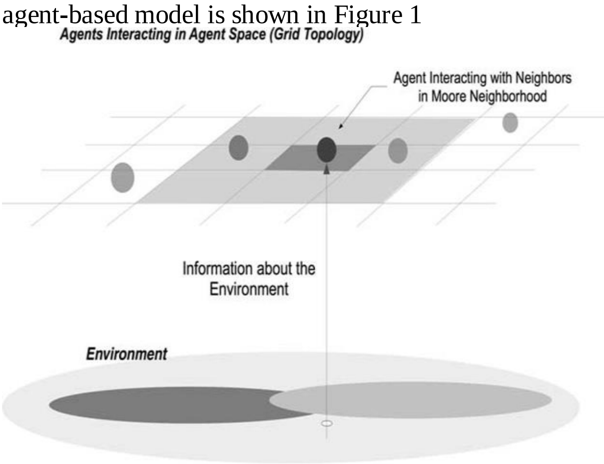

Figure 1: Agent Model (Adopted)
Source: [4]

In healthcare, ABM has been used to simulate the spread of infectious diseases, analyze the impact of health policies, and optimize resource allocation in healthcare systems. The study by [25], who developed an ABM framework to evaluate the effects of different healthcare policies on the spread of influenza. The authors used synthetic population data and calibrated the model with real-world data to simulate the disease spread in a virtual city. The study showed that the policies of vaccination, school closure, and social distancing could effectively reduce the spread of influenza. Another example is the study by [26], who developed an ABM model to simulate the impact of a telemedicine system on the healthcare system's efficiency and patient outcomes. The authors used real-world data from developed healthcare systems in the world and simulated the interactions between patients, healthcare providers, and the telemedicine system as simulated on Figure 2.

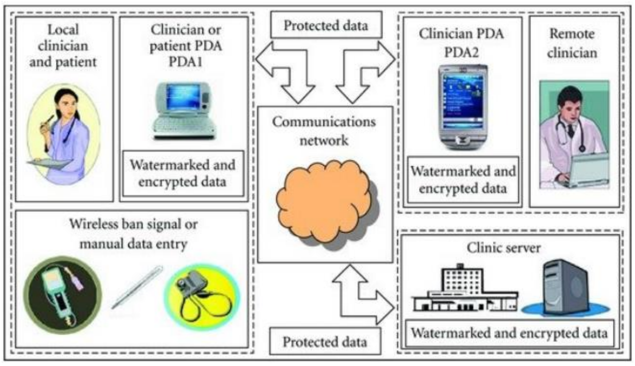

Figure 2: Interacting Agents in Healthcare Environment

The study various studies indicated that the telemedicine system could significantly reduce the healthcare system's burden and improve patient outcomes. ABM has also been used to optimize resource allocation in healthcare systems. For example, [27] developed an ABM model to simulate the emergency department (ED) patient flow and optimize the allocation of medical resources. The authors used real-world data from a Chinese hospital and simulated the interactions between patients, healthcare providers, and medical resources. The study showed that the ABM model could effectively optimize resource allocation and reduce patient waiting time.

C. Agent Development Frameworks

Agent Development Frameworks (ADF) are tools and environments used to build intelligent agents and multi-agent systems. They provide a structured way of developing and managing agents, making it easier to design and deploy them in various application domains [2, 28]. A methodology aims to prescribe all the elements necessary for the development of a software system, some common types of agent methodology include MasCommonKads, Passi, Tropos, Gaia, Jade and Prometheus among others. This section looks at Gaia and Prometheus Methodology as it provides guidelines for the proposed multi-agent environment.

Gaia is a methodology initially proposed by Wooldridge, Jennings, and Kinny in the article "A Methodology for Agent-Oriented Analysis and Design" (1999). Recently, a new version of Gaia has been proposed by Wooldridge, Jennings, and Franco. The new version extends the range of applications to which Gaia can be applied. Gaia is a methodology for agent-oriented analysis and design. The Gaia methodology is both general, in that it applies to a wide range of multi-agent systems, and comprehensive, in that it deals with both the macro-level (societal) and the micro-level (agent) aspects of systems. Gaia is founded on the view of a multi-agent system as a computational organization consisting of various interacting roles. Gaia does not explicitly deal with the activities of requirements capturing as in Figure 3.

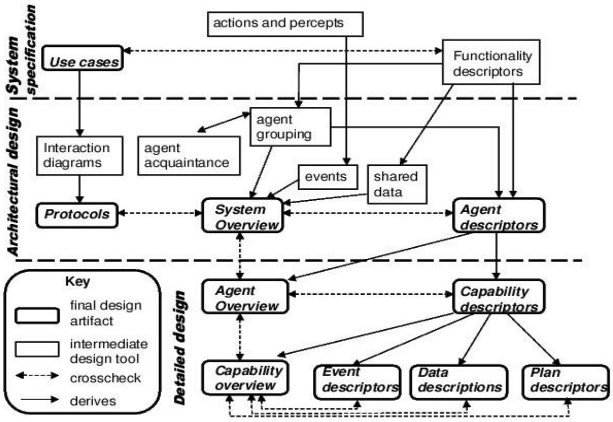

Figure 3: Gaia methodology
Source: Adopted

The Prometheus methodology is a detailed process for specifying, designing, and implementing intelligent agent systems. This method was used in the system specification, system design, and implementation. This methodology distinguishes itself from other methodologies by supporting the development of intelligent agents which use beliefs, goals, events, and plan [29]. Prometheus provides start-to-end support, (from specification to detailed design and implementation), Prometheus is a detailed process, it Uses an iterative process over software engineering phases rather than a linear "waterfall" model, it evolved out of the practical industrial and pedagogical experience, and has been used by both industrial practitioners and by undergraduate students. The methodology is made up of three phases namely; System specification, architectural design, detailed design. An overview of the methodology, including its phases, deliverables, and intermediate products, is depicted in Figure 4.

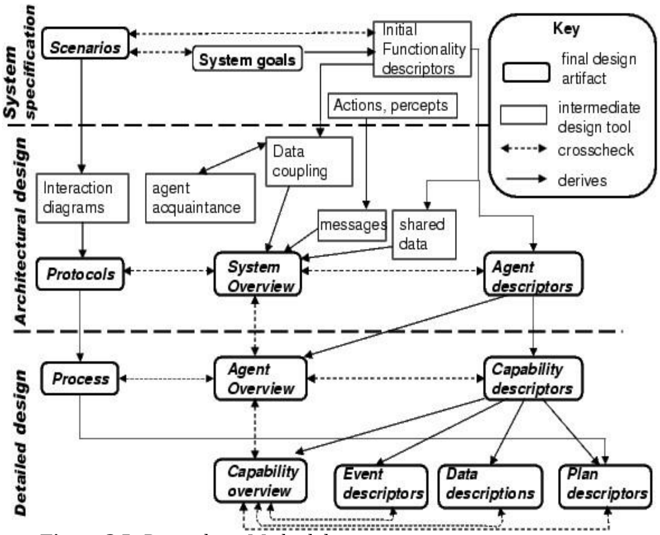

Figure 2.5: Prometheus Methodology
Source: Winikoff (2002)

The methodology consists of three phases. The system specification phase which focuses on identifying the basic functionalities of the system, along with inputs (percepts), outputs (actions), and any important shared data sources. The architectural design phase which uses the outputs from the previous phase to determine which agents the system contain and how they interact. The detailed design phase which looks at the internals of each agent and how it accomplish its tasks within the overall system. Researchers the study used this framework to assess current status and to identify key issues that need to be addressed to guide development of model.

D. Agent-based Medical Systems

Agent-based medical systems refer to the integration of agent technology into medical systems for the purpose of decision support, patient monitoring, and other healthcare-related tasks. This technology has the potential to improve the quality of care and reduce costs in healthcare settings [2]. One of the earliest works in the field of agent-based medical systems was the development of the Prodigy system in the early 1990s. Prodigy is a rule-based expert system that uses an agent-based architecture to provide clinical decision support. It was designed to support primary care physicians in making evidence-based decisions, and has been shown to improve adherence to clinical guidelines [30].

Recently, there have been developed agent-based medical diagnosis systems that eliminate some disadvantages of medical expert systems. Motivations of the use of agents for different medical problem-solving consist of the proprieties of the agents, like increased autonomy in operation, the capacity of communication, autonomous learning capacity, and capacity to interact with the environment. Intelligent agents used in medicine may increase the accuracy of diagnostics elaborated by physicians (an agent may help a human medical specialist in medical decisions elaborations, also he may verify medical hypothesis elaborated by the human medical specialists) and may improve the solving of medical tasks that must be fulfilled in healthcare processes. As examples of applications of the agents for fulfilling medical tasks are: patients management and healthcare, ubiquitous healthcare and web-enabled healthcare [31], telehealth, spreads simulation of infectious disease analyze different aspects of the multi-agent systems specialized in medical diagnosis. Understanding of such systems requires a high-level visual view of how the systems operate as a whole to achieve some application-related purposes.

OnkoNet mobile agents have been successfully used for patient-centric medical problems solving [31]. It is introduced the notion of ubiquitous healthcare, addressing the access to health services by individual consumers using mobile agents. This access requires medical knowledge about individual health status. The presented work emerged from a project covering all relevant issues, from empirical process studies in cancer diagnosis/therapy, down to system implementation and validation.

Clinical decision support systems form a significant part of the field of clinical knowledge management technologies, being interactive computer programs, which are designed to assist physicians and other health professionals with decision-making tasks. Agent-oriented techniques are important new means in analyzing, designing, and building complex software systems. In the paper by Gabriela, an intelligent multi-agent system, named IMASC, for assisting physicians in their decision-making tasks. The system was proposed for assisting physicians in diagnosing heart disease.

In Unland proposed a medical diagnosis multi-agent system that is organized according to the principles of swarm intelligence. It consists of a large number of agents that interact with each other through simple indirect communication. The proposed multi-agent system's real power stems from the fact that a large number of simple agents collaborate in a reliable way to elaborate diagnostics. The intelligence of the proposed system can be considered based on the agents' capacity to learn.

More recently, agent-based medical systems have been used for a variety of tasks, including patient monitoring and management, disease diagnosis, and drug discovery. For example, a multi-agent system was developed for monitoring patients with chronic obstructive pulmonary disease (COPD) and providing personalized treatment recommendations. The system used a combination of physiological sensors and mobile devices to monitor patients in real-time, and was able to detect early signs of exacerbation and provide timely interventions [11]. Another example is the development of an agent-based system for diagnosing skin cancer. The system uses image analysis and machine learning techniques to classify skin lesions, and is able to achieve high levels of accuracy in diagnosing melanoma.

Agent-based systems have also been used for drug discovery, where they can assist in identifying potential drug candidates and predicting their efficacy. One example is the use of a multi-agent system for virtual screening of compounds for anti-cancer activity. The system uses a combination of machine learning and molecular dynamics simulations to screen large libraries of compounds and identify those with the potential for anti-cancer**.** Generally, agent-based medical systems have shown promise in a variety of healthcare-related tasks, including decision support, patient monitoring, disease diagnosis, and drug discovery. These systems can improve the quality of care and reduce costs in healthcare settings, and are likely to play an increasingly important role in the future of healthcare.

II. FINDINGS

In healthcare delivery, there are multiple entities and participants involved, each with unique roles, interests, and concerns related to medical services. Therefore, it is crucial to assess and analyze requirements by considering input from various stakeholders, rather than relying on a single perspective. These entities were classified as human agents (such as doctors, nurses, and pharmacists) and non-human agents, including software agents, hardware, storage or database agents, and technological and framework agents. This section focuses on discussing these agents and multi-agents in the context of healthcare consultancy services using Kenya as the study area. The data collection techniques used were questionnaire and interviews. Each agent was thoroughly analyzed to understand its specific service, responsibilities and the corresponding requirements documented. The requirements are categorized based on human agents, software agents, database or storage agents, technological and framework agents, and the integration process.

A. Hardware Agents and Requirements

The objective of this section was to investigate the role of hardware agents used by healthcare consultants in Kenya. Through interviews with consultants, key insights were uncovered, shedding light on the specific requirements and considerations associated with these hardware agents. The findings was as discussed in Table I.

Table I. Hardware Agents and Requirements

Hardware Agent	Description	Requirements
Computers and Laptops	Identified as essential tools for enabling consultants perform data analysis, generate reports, communicate, and handle documentation	Sufficient processing power, memory, reliable network connectivity, and adequate storage capacity. Security features for protecting patient information
Mobile Devices	Particularly smartphones and tablets	Good processing power, memory, secure network connectivity, storage capacity, and compatibility with healthcare-specific apps and platforms.
Medical Devices and Equipment	Play a vital role in diagnostic testing, data collection, and vital sign monitoring.	Accuracy, reliability, integration capabilities with electronic health record systems, compliance with regulatory standards, user-friendly interfaces, and regular maintenance and calibration.
Networking Infrastructure	Enabling communication, data exchange, and access to remote resources.	high-speed and reliable internet connectivity, network security measures, sufficient bandwidth, and redundancy and backup systems
Sensor Agents and Remote Patient Agents	Collecting vital signs through monitoring devices	None

To address this, the study introduces the concept of a remote patient agent, which acts as a communication intermediary between the patient and the doctor. The remote patient agent transmits real-time vital sign data from the sensors to the doctor, enabling prompt medical intervention when needed. This enhances communication, collaboration, and efficiency in remote patient monitoring, ultimately improving the quality of healthcare provided to patients.

The interviews with healthcare experts highlighted the importance of considering local regulations, interoperability with existing systems, and adherence to data security and privacy standards when deploying hardware agents in healthcare provision. These factors ensure compliance with relevant guidelines and promote seamless integration with the healthcare ecosystem. This findings underscore the significance of hardware agents in supporting the delivery of healthcare consultancy services in Kenya. By fulfilling the specific requirements and considerations identified through these interviews, healthcare consultants are likely and effectively utilize hardware agents to provide secure healthcare services.

Hospital Agents

Hospitals have historically played a vital role in the healthcare industry, offering a wide range of medical, diagnostic, and treatment services primarily to inpatients. These licensed establishments are equipped with specialized facilities, expert medical professionals, and advanced technology and equipment, allowing them to deliver comprehensive healthcare services.

The primary focus of hospitals is on inpatient care, where patients receive round-the-clock medical attention and treatment. However, hospitals also provide secondary services such as day care, outpatient care, and home health services, depending on the specific requirements and regulations of each country. The tasks and services provided by hospitals can vary

from one country to another and are typically governed by legal requirements. Some countries may have additional criteria, such as minimum bed capacity and medical staff size that need to be met for a facility to be officially recognized as a hospital.
The SHA 2011 classification system is commonly used to categorize hospitals based on the scope of medical treatments offered and the specificity of diseases or medical conditions treated among inpatients. It classifies hospitals into three main categories: general hospitals, mental health hospitals, and specialized hospitals.

General hospitals are dedicated to providing comprehensive diagnostic and medical treatment, including both surgical and non-surgical procedures, to inpatients with a wide range of medical conditions. These hospitals offer additional services such as outpatient care, anatomical pathology services, diagnostic X-ray services, clinical laboratory services, operating room services for various procedures, and pharmacy services. These services are not only utilized by internal patients but also by patients who visit the hospital from outside for specialized treatments or consultations.

Human Agents

During the interview with healthcare experts, valuable insights were gathered on the roles and responsibilities of human agents in healthcare consultancy services. This section reports the key findings, emphasizing the importance of human agents and their collaborative efforts (roles) in enhancing healthcare delivery.

The interview highlighted various human agents involved in healthcare consultancy services. Healthcare consultants, including medical doctors, nurses, and pharmacists, who pass specialized knowledge and expertise to specific areas of healthcare. They provide valuable insights, advice, and recommendations to improve healthcare strategies, develop specialized programs, and optimize resource utilization as in Table II.

Table II: Human Agents in Healthcare Domain

Human Agent	Example(s)	Role
Medical specialists	cardiologists, neurologists, and oncologists	Offer medical expert opinions and guidance. Collaboration with other agents ensures comprehensive care and optimal outcomes for patients.
Public health experts	focus on population health, epidemiology, and disease prevention	Their expertise contributes to improving health outcomes and overall community well-being.
Healthcare administrators and managers	hospital administrators, clinical managers, health information managers, health services managers, nursing home administrators, medical practice managers, health policy analysts	They play a critical role in strategic planning, organizational design, financial management, and quality improvement initiatives.
IT professionals	Database, systems and network administrators	Their efforts focus on improving healthcare delivery, facilitating decision-making processes, and ensuring the accuracy and security of healthcare data.
Patient advocates and support staff	Patient Care Technicians/Assistants, Medical Office Assistants/Receptionists, Social Workers and Patient Navigators	They address patient concerns, provide education and guidance, and help navigate complex healthcare systems.
Research analysts	Clinical Research Analysts, Health Policy Analysts, Market Research Analysts	Contribute to healthcare consultancy services through research studies, data analysis, and evidence-based insights.

Software Agents

During the interview, the focus was on software agents utilized in healthcare consultancy services. These agents play a vital role in supporting and enhancing healthcare delivery. Several software agents were mentioned and documented for reporting, including Electronic Health Record (EHR) systems, Clinical Decision Support Systems (CDSS), Telemedicine platforms, Health Information Exchange (HIE) systems, Clinical Research and Data Management Systems, Health Monitoring and Wearable Devices, and Health Analytics and Business Intelligence Tools.

EHR systems serve as software agents that electronically store and manage patients' medical records, providing healthcare consultants with comprehensive patient information. CDSS software agents offer real-time guidance and recommendations based on patient data and clinical guidelines. Telemedicine platforms utilize software agents to facilitate remote consultations between healthcare consultants and patients. HIE systems enable the sharing and exchange of patient health information among healthcare providers. Clinical Research and Data Management Systems support consultants involved in research studies, assisting with data collection and analysis. Health Monitoring and Wearable Devices allow remote monitoring of patients' health parameters. Health Analytics and Business Intelligence Tools aid in analyzing and interpreting large volumes of healthcare data.

During the interview, two specific software solutions were also highlighted: SoftClinic GenX, a hospital information management software, and LabWare's Biorepository Solution, which simplifies specimen management.

The study noted that the specific software agents used in healthcare consultancy services varied depending on level of the health care facility preferences and requirements. However, these agents and solutions collectively contribute to the efficient and effective delivery of healthcare consultancy services, improving patient care and overall healthcare outcomes.

Storage Agents

During the interview conducted with healthcare experts, insights were gathered regarding the crucial role of database and storage agents in healthcare consultancy services. This section reports the key findings from the interview, highlighting the significance of these agents in managing and safeguarding healthcare data. The key findings included:

Electronic Health Record (EHR) Systems which emerged as a pivotal database agent in healthcare consultancy services. These systems act as centralized repositories for comprehensive electronic patient records, including medical history, diagnoses, medications, lab results, and treatment plans. Healthcare consultants benefit from streamlined data management, improved collaboration, and evidence-based decision-making facilitated by EHR systems.

Health Information Exchange (HIE) Systems which play a vital role as database agents in healthcare consultancy services. These systems enable secure exchange and sharing of patient health information across different healthcare organizations and providers. Healthcare consultants can access and retrieve patient data from multiple sources, ensuring seamless information exchange and promoting continuity of care.

Clinical Research Databases that are instrumental storage agents in healthcare consultancy services. These databases store and manage research data collected during clinical trials, observational studies, and other research initiatives. Researchers and healthcare consultants utilize these databases to store, manage, and analyze research data, facilitating evidence-based decision-making and generating valuable insights.

Cloud Storage Services: in which the interview highlighted the increasing adoption of cloud storage services in healthcare consultancy services. These services offer scalable and secure storage solutions for healthcare data, providing flexibility and easy accessibility from different locations. Cloud storage services often include robust security measures, backup mechanisms, and disaster recovery capabilities, ensuring the safe storage and availability of healthcare data.

Data Encryption and Security Agents which are crucial components in healthcare consultancy services. These agents ensure the protection of sensitive patient data by encrypting data stored in databases or transmitted over networks. Encryption mechanisms enhance data security, safeguarding healthcare data from unauthorized access and maintaining compliance with data privacy regulations.

In general the interview findings emphasized the pivotal role of database and storage agents in healthcare consultancy services. Electronic Health Record (EHR) systems, Health Information Exchange (HIE) systems, clinical research databases, data warehouses, cloud storage services, local storage solutions, and data encryption and security agents were identified as key components in managing and securing healthcare data. These agents contribute to streamlined data management, improved collaboration, evidence-based decision-making, and enhanced data security, ultimately leading to the provision of high-quality healthcare consultancy services.

The study further visualized finding as in Figure 5 and 6 for the interaction process within and between healthcare agents.

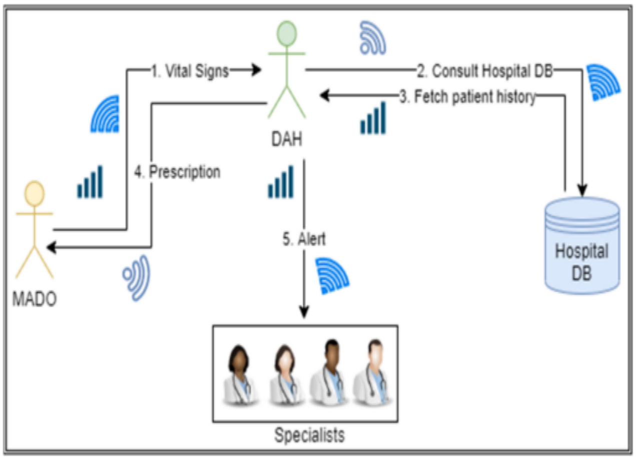

Figure 5: Role of Development Assistance for Health (DAH) in providing healthcare facilities.

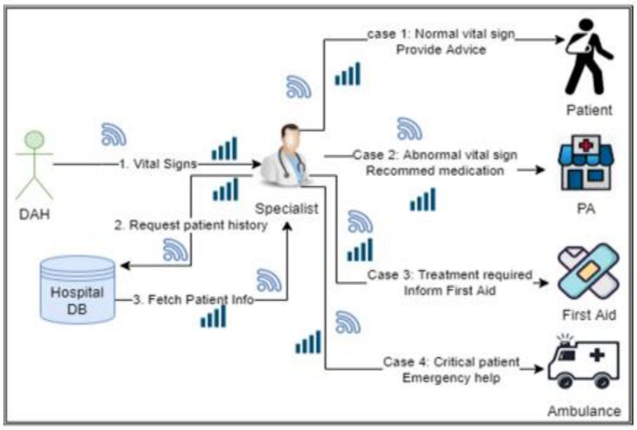

Figure 6: Agents Interaction in health care domain

Supportive Descriptive

The study also analyzed data in order to understand the reaction and conversant of the health practitioners with IoT and associated technology in health care.

To understand the IoT usage in the Facility surveyed, the study collected data as summarized in Table III.

Table III: IoT usage in the Facility

		Frequency	Percent
Valid	Yes	34	97.1
	No	1	2.9
	Total	35	100.0

The Table III presents data on IoT (Internet of Things) usage in a facility. Out of the total respondents, (97.1%) reported using IoT, while only (2.9%) indicated not using it. This indicates a high adoption rate of IoT in the facility, suggesting that IoT technologies are likely being utilized to enhance various aspects of facility management, such as monitoring, automation, and data analysis, which can lead to improved efficiency, productivity, and decision-making in the facility.

The study also collected data on the perceived benefits of IoT and MAS as in Table IV.

Table IV: Perceived Benefits of IoT and MAS

		Frequency	Percent
Valid	To a small extent	5	14.3
	To a moderate extent	9	25.7
	To a large extent	21	60.0
	Total	35	100.0

The table IV presents data on the perceived benefits of IoT (Internet of Things) and MAS (Multi-Agent Systems). Out of the total respondents, (14.3%) reported perceiving the benefits to a small extent, (25.7%) perceived them to a moderate extent, and (60.0%) perceived them to a large extent. This indicates that a majority of the respondents highly recognize and appreciate the benefits associated with IoT and MAS, suggesting that these technologies are perceived to contribute significantly to positive outcomes or improvements in various aspects, such as efficiency, automation, and decision-making within the context of the surveyed facility or system.

The study went further and collected data on patients which is presented and analyzed as in Tables V to X.

Table V: Familiarity with IoT Technology

		Frequency	Percent
Valid	No	15	37.5
	Yes	25	62.5
	Total	40	100.0

The Table V presents data on the familiarity of patients with IoT (Internet of Things) technology. Out of the total respondents, (37.5%) indicated that they are not familiar with IoT technology, while (62.5%) reported being familiar with it. This suggests that a majority of the patients surveyed have some level of knowledge or awareness about IoT technology, which could potentially influence their understanding and engagement with healthcare solutions that incorporate IoT devices or systems.

Table VI: Use of IoT devices or Applications in Healthcare

		Frequency	Percent
Valid	Undecided	15	37.5
	Never used	1	2.5
	Often used	9	22.5
	Rarely used	5	12.5
	Sometimes used	10	25.0
	Total	40	100.0

The table VI presents data on the usage of IoT (Internet of Things) devices or applications in healthcare among respondents. The findings reveals that (37.5%) of the total respondents were undecided about their usage, (2.5%) reported never using IoT devices or applications, (22.5%) indicated often using them, (12.5%) reported rarely using them, and (25.0%) reported sometimes using them. This suggests a mixed level of engagement with IoT technology in healthcare among the respondents, with a significant portion being undecided about its usage.

Table VII: Reliable Internet Connectivity

		Frequency	Percent
Valid	Excellent access	3	7.5
	Limited access	4	10.0
	Moderate access	10	25.0
	No access	6	15.0
	Reliable access	12	30.0
	Unreliable access	5	12.5
	Total	40	100.0

Table VII presents data on the access to reliable internet connectivity among respondents. Out of the total participants, (7.5%) reported having excellent access, (10.0%) reported limited access, (25.0%) reported moderate access, (15.0%) reported no access, (30.0%) reported reliable access, and (12.5%) reported unreliable access to the internet. This indicates that while a significant portion of the respondents have reliable access to the internet, there are still individuals who face limitations or lack access altogether. This information is crucial when considering the feasibility and effectiveness of digital healthcare solutions that rely on internet connectivity**.**

Table VIII: Familiarity with the availability and accessibility of IoT infrastructure in healthcare facilities

		Frequency	Percent
Valid	No	15	37.5
	Yes	25	62.5
	Total	40	100.0

Table indicates that out of the total respondents, (37.5%) answered "No" when asked about their familiarity with the availability and accessibility of IoT infrastructure in healthcare facilities in their area, while (62.5%) responded "Yes." This suggests that a majority of the respondents have some level of knowledge or awareness regarding the availability and accessibility of IoT infrastructure in healthcare facilities. It's important to note that this information is specific to the surveyed population and may not reflect the overall situation in all areas.

Table IX summarizes the respondents' awareness of the government regulation to use of IoT approaches

Table IX: Awareness government policies or regulations related to IoT Approaches in healthcare

		Frequency	Percent
Valid	No	15	37.5
	Yes	25	62.5
	Total	40	100.0

Table IX indicates that out of the 40 respondents, (37.5%) answered "No" when asked if they were aware of any government policies or regulations related to IoT technology in healthcare. However, (62.5%) of the respondents indicated that they were aware of such policies or regulations. This suggests that a majority of the respondents have knowledge or awareness of government policies or regulations pertaining to IoT technology in healthcare.

Table X: Government promoting of the Adoption of IoT Technology in Healthcare Services

		Frequency	Percent
Valid	No	15	37.5
	Yes	25	62.5
	Total	40	100.0

Table X indicates that out of the 40 respondents, (37.5%) answered "No" when asked if they feel that the government is actively promoting the adoption of IoT technology in healthcare services. However, (62.5%) of the respondents indicated that they do feel the government is actively promoting the adoption of IoT technology in healthcare services.

Classification Analysis

To perform a classification analysis, the study categorized the information based on different themes and concepts collected. Classifications was centered on the core objectives as in table XI.

Table XI: Classification Analysis

Category	Subcategory	Specific Requirements
Agents in Healthcare Consultancy Services	Human agents	Healthcare consultants, physicians, specialists
	Hardware agents	Medical devices, equipment, sensors
	Software agents	Health information systems, telemedicine platforms, decision support systems
	Database/storage agents	Systems for secure data storage and retrieval
Requirements for Multi-agents in Healthcare Consultancy Services	Communication requirements	Interoperability, secure communication, real-time, communication, scalability, reliable communication, collaboration tool, notification mechanisms, data integration and mobile communication support
	Technical requirements	System integration, data standardization, data security and privacy, scalability and performance, robust infrastructure, communication protocols and middleware, AI and data analytics capabilities, user interface and user experience, mobile accessibility compliance with regulatory requirements
	Regulatory requirements	Data protection and privacy laws, HIPAA GDPR, ethical guidelines, local healthcare regulations, institutional policies and procedures
Predictive Analysis		Increased adoption of IoT and AI, expansion of telemedicine, emphasis on data security and privacy, integration of analytics and predictive modeling, collaboration and interoperability, regulatory advancements, continued professional development

Table XI provides three main categories: Agents in Healthcare Consultancy Services, Requirements for Multi-agents in Healthcare Consultancy Services, and Predictive Analysis. Each category is further divided into subcategories, and specific requirements are listed under each subcategory. This classification helps organize and summarize the information presented in the framework. By performing this analysis, there was a better understanding of the main categories and concepts collected. This organizes and summarizes the information presented, making it easier to identify key themes and extract meaningful insights that informed this study.

Cause-Effect Analysis

In this section, several causes and their corresponding effects were identified and explored as cause-effect relationships. Table XII summarizing the cause-effect relationships identified in this study.

Cause	Effect
Advancements in Technology	Increased adoption of IoT devices and AI-powered solutions in healthcare consultancy services
	Improved data collection, analysis, and decision support.
Accessibility and Convenience	Expansion of telemedicine platforms in healthcare consultancy services
	Greater access to healthcare consultations, especially in remote areas
Concerns for Data Security and Privacy	Emphasis on data security and privacy measures
	Investment in robust cybersecurity measures, encryption protocols
	Compliance with data protection regulations to safeguard patient data
Analyzing Large Datasets	Integration of data analytics and predictive modeling techniques
	Analysis of large datasets, identification of patterns, and prediction of disease trends
	Optimized treatment plans, resource allocation, and better population health management
Collaborative Approach	Improved collaboration and interoperability among different agents and systems
	Seamless communication, data sharing, and coordination between stakeholders
	More efficient healthcare service delivery
Regulatory Frameworks	Regulatory advancements for ethical and responsible use of healthcare data
	Implementation of regulations specific to healthcare consultancy services
	Protection of patient rights
Continuous Professional Development	Healthcare consultants updating skills and knowledge
	Continuous professional development programs and training
	Adaptation to emerging technologies, best practices, and regulatory requirements

	High-quality healthcare consultancy services

Table XII provides a clear overview of the causes and their corresponding effects in the context of healthcare consultancy services. It demonstrates how advancements in technology, accessibility and convenience, data security and privacy concerns, analyzing large datasets, collaborative approaches, regulatory frameworks, and continuous professional development contribute to improving healthcare consultancy services and patient outcomes. These cause-effect relationships highlight the driving forces behind the developments and changes in healthcare consultancy services in Kenya. By understanding these causes and their effects, stakeholders have platform to make informed decisions, implement appropriate measures, and foster positive outcomes in the healthcare sector.

Requirements for Integration of Healthcare Consultancy Services

Integrating healthcare consultancy services is a complex process that requires careful planning and consideration of various factors. The goal of integration is to ensure seamless collaboration between healthcare consultancy providers and healthcare organizations to improve patient outcomes, operational efficiency, and overall healthcare quality. Table XIII provide a summary of the requirements needed for integration process.

Table XIII: Integration of Healthcare Consultancy Services in Kenya

Item	Agent/Activity	Requirements
Main Components	Human Agents	Healthcare consultants, physicians, specialists.
	Hardware Agents	Medical devices, equipment, sensors.
	Software Agents	Health information systems, telemedicine platforms, decision support systems.
	Database/Storage Agents	Systems for secure data storage and retrieval.
Integration Steps	Data Collection	Hardware agents collect patient data through sensors and medical devices.
		Data is stored securely in the database/storage agents.
Data Processing and Analysis	Software Agents	Analyze and process the collected data.
		Employ AI and data analytics for insights and predictive modeling.
Consultation and Decision Making	Human Agents	Utilize processed data and AI insights for expert guidance and advice.
		Provide consultations to patients and healthcare organizations.
Communication and Collaboration	Software Agents	Enable communication and collaboration between different agents.
		Telemedicine platforms facilitate remote consultations and information exchange.
Compliance and Ethical Considerations		Follow regulatory requirements and ethical guidelines.
		Implement data protection, privacy, and security measures.
Predictive Analysis	Future trends and advancements	Increased IoT and AI adoption, expansion of telemedicine, emphasis on data security and privacy.
Desired Outcomes		Improved patient care, accurate diagnoses, personalized treatment plans.
		Enhanced accessibility and convenience through telemedicine.
		Optimal resource allocation and population health management.
		Collaboration and interoperability among agents.
		Compliance with regulatory requirements and ethical standards.

Integration steps they follow, and the desired outcomes they aim to achieve. It highlights the role of human agents, hardware agents, software agents, and database/storage agents in collecting, processing, analyzing, and utilizing patient data to provide improved care, communication, compliance, and predictive analysis in healthcare consultancy.

Simulating the Agent Interaction

To simulate the integration of different components in providing healthcare consultancy services a Python program was used to represent the flow of data and interactions between various agents. Below is a program Skeleton.

```
# Defining the different agents in healthcare consultancy services
class HumanAgent:
    def _ _init_ _(self, name):
        self.name=name

 def  provide_consultation(self, data):
        # performing consultation and make decision based on the data
        print(f “{self.name} providing healthcare consultation base on the data”)
```

```
class HardwareAgent:
    def _ _init_ _(self, name):
        self.name=name

 def  collect_data(self, data):
        # simulating data collection from hardware devices
        print(f “{self.name} collecting data from sensors and devices.”)
        return “collected data”

class SoftwareAgent:
    def _ _init_ _(self, name):
        self.name=name

 def  process_data(self, data):
        # simulating data processing and analysis
        print(f “{self.name} process and analyzes data.”)
        return “processed data”

def  facilitate_communication(self, agent1,agent2):
        # simulating communication and collaboration between agents
```

```
        print(f "{self.name} facilitating communication between {agent1.name, agent2.name}")
        return "processed data"
class DatabaseAgent:
    def _ _init_ _(self, name):
        self.name=name

 def  store_data(self, data):
        # simulating storing data in the database
        print(f "{self.name} storing the data securely.")

# creating instances of the agents
human_agent= HumanAgent("Healthcare Consultant")
hardware_agent= HardwareAgent("Hardware Agent")
software_agent= SoftwrewareAgent("Software Agent")
database_agent= DatabaseAgent("Database Agent")

# Simulating the integration process
data=hardware_agent.collect_data()
processed_data=software_agent.process_data(data)
database_agent.store_data(processed_data)
software_agent.store.facilitate_communication(human_agent, database_agent)
human_agent.provide_cunsultation(processed_data)
```

This program defines classes for each agent type and simulates their functionalities. The HumanAgent represents a healthcare consultants, the HardwareAgent represents hardware devices for data collection, the Software Agent represents software systems for data processing and communication, and the DatabaseAgent represents the database for data storage. The program then creates instances of these agents and simulates the integration process by calling methods to perform data collection, processing, storage, communication, and consultation.

I. CONCLUSTION

The study identified the specific requirements for successful implementation of multi-agent systems in patient-centered health consultancy services. These include hardware, software, ontology, medical agents and experts, interoperability, data security, privacy, scalability, and user-friendly interfaces. The study emphasized the importance of engaging various stakeholders, including healthcare professionals, technology experts, and policymakers. Collaborative efforts ensures that the requirements meets the needs of all stakeholders and enhances the delivery of healthcare services.

II. RECOMMENDATION

This paper recommends the collaboration among relevant stakeholders, including government agencies, healthcare organizations, technology companies, and researchers, which is vital. There is also need to developing collaborative frameworks to establish guidelines, standards, and regulations will support the safe and effective use of IoT technology in healthcare and foster innovation while safeguarding patient well-being.

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