IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

ISO 3297:2007 Certified ⁜ Impact Factor 8.102 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 8, August 2023

DOI: 10.17148/IJARCCE.2023.12817

Revolutionizing Kenyan Healthcare Consultancy: Exploring IoT Innovations and other Enabling Technologies– A Case Study

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Abstract: The integration of powerful technologies such as Internet of Things (IoT) and Multi-Agent Systems (MAS) in healthcare addresses the complex nature of the industry, facilitating communication, coordination, and decision-making among various departments. This becomes particularly crucial in the context such as the COVID-19 pandemic, where developing countries faced increased demand for healthcare services, limited resources, and a lack of robust health systems. 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. This paper examined the existing Internet of Things (IoT) approaches in use in health consultancy in Kenya. The study included referral hospitals as sample units, focusing on medical consultants and utilizing scholarly literature recommendations. Three (3) Hospital facilities were selected based on their capacity for training, research, and referrals. The study respondents comprised the general superintendent, medical consultants, health system managers, medical students, and patients. Interviews and survey questions were used for data collection. The instruments average validity test score was (.84) and reliability score of (.799) based on Chronbach's Alpha. The findings of the study reveals that some hospitals have integrated IoT technology in health consultancy services in Kenya with a significant improvements in data management, diagnosis accuracy, and patient outcomes, but there is need to address concerns regarding data security, privacy, standardization and infrastructure which was pointed out to be crucial for fully harnessing its potential. It also indicates that in Kenya, a majority of healthcare facilities are using Electronic Health Record (EHR) systems and have reliable internet connectivity, although there are variations in the availability of hardware and software technology, suggesting the need for targeted improvements and investments in the healthcare technological infrastructure.

Keywords: agent-based systems, health care system, health consultancy services, internet of things, healthcare.

I. INTRODUCTION

The term Internet of Things (IoT) is used for a lot of different concepts and applications because there doesn't exist a strict definition for this term . IoT refers to the network of physical objects embedded with sensors, software, and connectivity capabilities, enabling them to collect and exchange [2]. IoT technology encompasses various components and aspects, including devices, connectivity, data collection and analytics, cloud computing, security and privacy, applications, standardization and interoperability, and edge computing. IoT devices include sensors, actuators, and embedded systems that interact with the physical world. These devices range from simple sensors to complex smart devices [2]. IoT devices rely on different communication technologies, such as Wi-Fi, Bluetooth, Zigbee, cellular networks, and Low-Power Wide-Area Networks (LPWAN), to transmit data to the internet or other devices [3]. They have ability to collect and generate vast amounts of data. Data analytics techniques, such as machine learning and artificial intelligence, are used to process and derive meaningful insights from this data [4]. They are often leverages cloud computing platforms to store, process, and analyze data. Cloud infrastructure provides scalability, flexibility, and computing resources for IoT deployments [5].

Protecting IoT devices and data is crucial. IoT security encompasses measures like device authentication, encryption, access control, and secure communication protocols to mitigate vulnerabilities and protect against cyber threats [6]. The technology finds applications in various domains, including smart homes, healthcare, transportation, agriculture, industrial automation, and smart cities. These applications aim to improve efficiency, enhance decision-making, and enable new services and experiences [7]. Standardization efforts ensure compatibility and interoperability between different IoT devices and systems. Protocols like MQTT, CoAP, and standards such as Zigbee and Bluetooth Low Energy (BLE) promote seamless integration and communication [8]. Edge computing brings computational power closer to IoT devices, enabling real-time data processing and reducing latency. Edge devices and gateways process data locally, reducing the need for transmitting all data to the cloud [9]. As IoT technology continues to evolve, driven by

DOI: 10.17148/IJARCCE.2023.12817

advancements in connectivity, data analytics, and device capabilities. It holds significant potential to transform industries, improve quality of life, and drive innovation in the digital era. Since the services can be designed to collect and analyze patient data in real-time, enabling healthcare providers to deliver personalized care to patients.

II. REVIEW OF SUPPORTIVE TECHNOLOGIES

A. IoT Technology and Healthcare Consultancy Services

The use of the Internet of Things (IoT) technology in healthcare has gained increasing attention in recent years due to its potential to improve patient care and outcomes. In the context of health consultancy services, IoT technology facilitates remote monitoring, personalized treatment, and coordination among different healthcare providers. Several studies have explored the use of IoT technology in health consultancy services. For instance, a study by [4] reviewed the different applications of IoT in healthcare, including remote monitoring, patient tracking, and health data management. The study highlighted the potential of IoT technology to improve patient outcomes, reduce healthcare costs, and enable personalized care delivery.

A study conducted by [10] investigated the use of IoT technology in developing a remote patient monitoring system. The system consisted of wearable devices and a smartphone app that collected and transmitted patient data to healthcare providers. The study found that the use of IoT technology enabled healthcare providers to monitor patient health remotely, resulting in improved patient outcomes. [11] Developed an IoT-based health consultancy service that leveraged data from wearable devices to monitor patient health. The study found that the service improved patient outcomes by providing timely interventions and personalized treatment plans.

Similarly, a study by Chiang and Yang [12] examined the use of IoT technology in telemedicine, which refers to the remote delivery of healthcare services. The study identified several benefits of IoT-enabled telemedicine, including improved patient access to care, reduced healthcare costs, and enhanced patient engagement. [13] Explored the use of IoT technology in personalized healthcare. The study proposed a model for IoT-enabled personalized healthcare that includes the collection and analysis of patient data, personalized treatment recommendations, and patient feedback. The study highlighted the potential of IoT technology to enable personalized care delivery and improve patient outcomes. In addition, [14] examined the use of IoT technology in chronic disease management. The study proposed a model for IoT-enabled chronic disease management that includes remote monitoring, personalized treatment, and patient education. The study highlighted the potential of IoT technology to improve the quality of care for patients with chronic conditions.

Schlegel et al. [15] published a paper titled "The Internet of Things for personalized health care: A feasibility study" published in the Journal of Medical Internet Research. The paper aims to investigate the feasibility of the Internet of Things (IoT) for personalized health care. The study was conducted by implementing an IoT-based platform called MyHeart, which was designed to provide remote monitoring of patients with heart failure. The platform was based on wireless sensor networks and cloud computing, and it allowed patients to self-monitor their health status through wearable sensors and a smartphone application. The study involved 20 patients with heart failure who used the MyHeart platform for six months. The results of the study showed that the MyHeart platform was feasible for use in personalized health care, and it had the potential to improve patient outcomes and reduce healthcare costs. The platform was found to be reliable and easy to use, and the patients reported high levels of satisfaction with the system. The authors concluded that IoT-based platforms such as MyHeart could revolutionize healthcare delivery by providing personalized, patient-centered care that is both effective and efficient. It was noted that IoT technology has the potential to revolutionize health consultancy services by enabling remote monitoring, personalized treatment, and coordination among different healthcare providers. However, the successful implementation of IoT technology in healthcare requires addressing several challenges, such as data privacy and security, interoperability, and user adoption.

B. Ontologies in Healthcare

The term "ontology" has its origin in philosophy and is used to specify a conceptualization. It is used to refer to the shared understanding of some domain of interest [16] also defined as a description of concepts and relationships that can exist for an agent or a community of agents [17]. The Webster dictionary [18], defines the word ontology as a branch of metaphysics concerned with the nature and relations of being; a particular theory about the nature of being or the kinds of existents; and a theory concerning the kinds of entities and specifically the kinds of abstract entities that are to be admitted to a language system. The four areas that, historically, have been prominently responsible for creating the demand for the use of ontologies in computer science, are information systems, domain engineering, artificial intelligence, and the semantic web [19].

The ontology modeling technique consists of capturing consensual knowledge; it is not just about presenting information to humans but also processing the information and reason about it. Some works have been conducted on the ontology engineering process for which the following steps are proposed: feasibility study, kick-off, refinement, evaluation, maintenance. From the following authors, [20-28] several perspectives have been drawn along the two following axes: Clear understanding of how to build ontologies systematically and building fuzzy rules into ontology. In the context of

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healthcare, ontologies are used to support knowledge sharing and integration, as well as reasoning and decision-making. [15] Explored the use of ontologies for representing patient data in electronic health records (EHRs). The authors established that ontologies could help to improve the quality and consistency of EHR data, as well as facilitate data sharing and reuse across different healthcare systems. A study by [29] focused on the use of ontologies for decision support in healthcare. The authors developed an ontology-based framework for supporting clinical decision-making in the context of chronic disease management. They found that the ontology-based approach could help to improve the accuracy and efficiency of clinical decision-making. In a review article by [30], the authors explored the use of ontologies in the context of clinical research. They found that ontologies could help to improve the interoperability of clinical research data, as well as facilitate data reuse and secondary analysis. The authors also noted that the use of ontologies could help to address the problem of data heterogeneity in clinical research. Generally, the use of ontologies in healthcare has the potential to support knowledge sharing, integration, and reasoning, as well as improve the quality and consistency of healthcare data [31]. However, there are also challenges associated with developing and maintaining ontologies, such as the need for expert domain and the difficulty of achieving consensus on terminology and classification [32].
The literature presents a comprehensive understanding of ontologies as conceptualizations used to define shared domains of interest. However, the terminology, while rooted in philosophy, is adopted for computational purposes. While the authors highlight ontologies' significance in diverse fields, including the semantic web and artificial intelligence, the definition's application in practice can be convoluted, as consensus on terms and relationships proves challenging, underscoring the inherent complexities in creating and maintaining ontologies [16, 19, 32]. It also emphasizes the potential benefits of incorporating ontologies into healthcare for data integration, knowledge sharing, and improved decision-making. However, while the studies by [15, 29, and 30] demonstrate successful applications, it is important to acknowledge that the implementation of ontologies in healthcare is not easy. The challenges in obtaining domain expertise, achieving consensus on terminology, and maintaining ontologies can be substantial barriers. These complexities are particularly relevant in the healthcare context where accuracy, consistency, and a shared understanding of medical concepts are critical [32]. The potential benefits should be balanced against the practical challenges inherent in utilizing ontologies in healthcare systems.

C. Clustering Techniques

Clustering techniques are used to group/ divide similar data points together in a dataset or knowledge into different classes or basically knowledge classification based on some similarity criteria. Similar rules are represented in the same cluster and distinct clusters of rules are formed using representatives. Several papers use this kind of technique [33-37]. In clustering, there is no predefined class or label for the objects. Instead, the algorithm discovers the underlying structure of the data based on the similarity or dissimilarity measures between objects. The clustering process aims to maximize intra-cluster similarity and minimize inter-cluster similarity.
These techniques have worked in various fields, including data mining, machine learning, image processing, and pattern recognition [38] Clustering is an unsupervised learning technique that allows for the discovery of hidden patterns and relationships in data [39]. Some of commonly used clustering techniques discussed are: K-Means Clustering which is a widely used clustering algorithm that partitions a dataset into K clusters, where K is a pre-defined number of clusters. The algorithm works by assigning each data point to the closest centroid and then updating the centroid based on the mean of the data points in the cluster. K-means clustering has been used in various applications, including customer segmentation, image segmentation, and document clustering [40].
Hierarchical Clustering, according to [41], is a method of clustering data points based on their similarity, where the clusters are organized in a hierarchical structure. This technique can be divided into two categories: agglomerative and divisive clustering. Agglomerative clustering starts with each data point as a separate cluster and then iteratively merges the closest clusters until all data points are in the same cluster. Divisive clustering starts with all data points in the same cluster and then iteratively splits the cluster until each data point is in a separate cluster. Hierarchical clustering has been used in various applications, including gene expression analysis and text clustering [42].
Density-Based Clustering, according [43], is a method of clustering data points based on their density, where the clusters are formed by areas of high density separated by areas of low density. The most commonly used density-based clustering algorithm is DBSCAN (Density-Based Spatial Clustering of Applications with Noise), which groups together data points that are in high-density areas and separates them from the low-density areas. Density-based clustering has been used in various applications, including anomaly detection and spatial data analysis.
Fuzzy clustering which is a method of clustering data points based on their membership in different clusters. Unlike traditional clustering techniques, where each data point is assigned to only one cluster, fuzzy clustering allows data points to belong to multiple clusters with different degrees of membership. The most commonly used fuzzy clustering algorithm is FCM (Fuzzy C-Means), which iteratively assigns data points to clusters based on their similarity and updates the membership degrees of the data points. Fuzzy clustering has been used in various applications, including image segmentation and data mining [44]. In general, clustering techniques have been widely used in various applications, and the choice of clustering technique depends on the nature of the data and the specific application.

DOI: 10.17148/IJARCCE.2023.12817

D. Natural Language Processing (NLP)

Natural Language Processing (NLP) is a tract of Artificial Intelligence and Computational Linguistics so that computers and humans can talk seamlessly [45]. It came into existence to ease the user's work and to satisfy the wish to communicate with the computer in natural language. Since all the users may not be well-versed in the machine-specific language, NLP caters to those users who do not have enough time to learn new languages or get perfection in it. NLP is applied in the medicine field as well, have been used for tasks such as information extraction, text classification, and question-answering systems in healthcare. The Linguistic String Project-Medical Language Processor is one of the large scale projects of NLP in the field of medicine [46]. The LSP-MLP helps to enable physicians to extract and summarize information of any signs or symptoms, drug dosage, and response data with aim of identifying possible side effects of any medicine while highlighting or flagging data items [46]. The National Library of Medicine is developing The Specialist System [47]. It is expected to function as an Information Extraction tool for Biomedical Knowledge Bases, particularly Medline abstracts. The lexicon was created using MeSH (Medical Subject Headings), Dorland's Illustrated Medical Dictionary, and general English Dictionaries.

The Centre d'Informatique Hospitaliere of the Hospital Cantonal de Geneve is working on an electronic archiving environment with NLP features [47]. In the first phase, patient records were archived. At a later stage, the LSP-MLP has been adapted for French [48] and finally, a proper NLP system called RECIT [48] has been developed using a method called Proximity Processing [49]. Its task was to implement a robust and multilingual system able to analyze/comprehend medical sentences and to preserve a knowledge of free text into a language-independent knowledge representation [50]. The Columbia University of New York has developed an NLP system called MEDLEE (MEDical Language Extraction and Encoding System) that identifies clinical information in narrative reports and transforms the textual information into structured representation [51].

A study conducted by [52] used NLP techniques to automatically extract information from clinical notes to support medical research. The authors used a rule-based system to extract medication information from clinical notes and found that the system was able to accurately extract (93%) of the medication-related concepts. Another study by [53] used NLP to automatically classify radiology reports into categories based on the likelihood of a malignancy. The authors used a machine learning approach to train a classifier using features extracted from the reports. The system achieved an accuracy of (93.7%) in classifying the reports. NLP has also been used in the development of clinical decision support systems (CDSS). For example, a study by [54] used NLP techniques to extract smoking status information from clinical notes to support CDSS for smoking cessation. The authors found that the system was able to accurately identify smoking status in (87%) of cases. In addition, NLP has been used in the development of question-answering systems in healthcare. A study by [55] used NLP techniques to automatically answer clinical questions based on medical literature. The authors used a machine learning approach to identify relevant articles and extract the answer from the text. The system achieved an accuracy of 68% in answering questions from a test set. Generally, NLP has shown great potential in the field of medicine for tasks such as information extraction, text classification, and question-answering systems. With the increasing amount of textual data generated in healthcare, NLP techniques are likely to become even more important in the future.

E. Drone Technology and Healthcare

Computer vision technology along with AI has given rise to drone technology which aims to mimic visual perception and hence decision making based on it. A drone is a pilotless aircraft that was initially used exclusively by the military but is now also used for various scientific purposes, public safety, and commercial industries [56]. Drones were first used in the late 1800s and early 1900s for various military operations. The first non-military deployments of drones occurred following major disasters, where they supported damage assessments in the affected areas [57]. Their ease of use and ability to bypass road closures and fly over rugged terrains without risk to flight crews made them ideal for such deployments. Drones have subsequently been used to deliver small aid packages to communities affected by major disasters, including the 2010 earthquake in Haiti, the 2012 hurricane (Superstorm Sandy) that affected the northeastern United States, Canada, and the Caribbean, the 2015 category 5 cyclone (Pam) that struck the islands of Vanuatu, and the 2015 earthquake (Gorkha) in Nepal [58]. A study that was conducted in the Netherlands considered the use of an ambulance drone designed to deliver an AED directly to heart attack victims [45].

In Papua New Guinea, the organization' Doctors Without Borders' used drones to transport dummy tuberculosis (TB) test samples from a remote village to a large coastal city [59]. This application of drones was significant because the country has a large TB burden with an increasing incidence of multidrug-resistant TB. Similarly, drones have been used in the fight against the human immunodeficiency virus (HIV), which has long posed a challenge to third-world nations [60]. In Malawi, Africa—a nation with one of the highest rates of HIV infections in the world—the United Nations Children's Fund (UNICEF) delivered HIV testing kits using drones, thereby dramatically reducing the time required to test infants living in rural areas. If drone use is acknowledged as more cost-effective and efficient than current delivery methods using diesel motorbikes, the delivery process for medical testing kits and supplies will be revolutionized in Africa. [61] Conducted a study in Malawi to explore the feasibility of using drones to deliver HIV testing supplies. The

DOI: 10.17148/IJARCCE.2023.12817

study found that drone delivery of HIV testing supplies was faster and more cost-effective than traditional ground transportation methods.

National Aeronautics and Space Administration (NASA) recently tested a medical supply delivery to a small clinic in rural Virginia using a drone [62]. Supplies included medications for asthma, high blood pressure, and diabetes. The testing of the feasibility of this state-of-the-art technology for such a purpose was a tremendous success, as it proved to be safe and dramatically reduced the delivery time. In Rwanda, Africa, drones are used to transport blood products and medicines to critical access hospitals and remote regions [63]. The drones navigated using the Global Positioning System (GPS) and Rwanda's cellular network. Hospitals ordered blood and medicines via text messages and received the supplies within 30 minutes. The ability to transport blood is important; a single patient with massive bleeding can easily deplete the blood supply in medium-sized hospitals, and larger hospitals can run low on certain blood types [64].

Several prior studies have demonstrated that drones are a safe method for transporting blood products, donated blood, and vaccines using samples containing microbes [65-67].

[68] Conducted a systematic review of studies that explored the use of drones in healthcare delivery in low- and middle-income countries. The review found that drones have the potential to improve access to healthcare services in remote and hard-to-reach areas. [69] Conducted a study in Nigeria to explore the use of drones in healthcare delivery. The study found that drone delivery of medical supplies was faster and more cost-effective than traditional methods. [70] Conducted a study in Taiwan to explore the use of drones in emergency medical services. The drones can be used to provide rapid transportation of medical supplies, blood products, and organs for transplant. [71] Conducted a systematic review of studies that explored the use of drones in healthcare delivery in India. The review found that drones have the potential to improve access to healthcare services in remote and underserved areas. [72] Conducted a study in Rwanda to explore the use of drones in delivering vaccines. The study found that drone delivery of vaccines was faster and more cost-effective than traditional methods.

Reviews revealed that Drones technology have potential applications, in medical centers that are large or undergoing renovation, drones are used to transport blood samples and medications within the facility i.e. intra-hospital delivery [45]. Expansion of conventional pneumatic transport systems are costly; perhaps, drones provides a more cost-effective floor-to-floor transport capabilities for specimens and medications. Intra-hospital drone use faces unique challenges related to potential GPS or radiofrequency communication interference, an increased need for proper and safe navigational programming, and equipment size and cost constraints. Ultimately, however, drones have the potential to improve overall patient care in hospitals. Considering the unique mobility needs of the elderly people and senior populations, the use of small, robot-like drones with manipulator arms that can aid in bringing medication and water or performing household chores is currently being investigated [45]. In addition to demonstrating effectiveness and reliability, these drones must account for patient psychology and be accepted as part of a patient's daily life. Exposing patients to an environment where drones are flying about can compromise their safety and security. Expanding their involvement in the development of potentially life-saving equipment, the technology giant Google was recently granted a patent to develop a system capable of deploying drones carrying specialized medical equipment in response to medical emergencies. Users of the system simply need to press a button to call for help. Such innovations in drone technology are expected to continue.

These reviews demonstrate the potential of drone technology to improve access to healthcare services, particularly in remote and hard-to-reach areas. However, there are still challenges to be addressed, such as regulatory and logistical issues, to ensure the safe and effective use of drone technology in healthcare delivery especially in Kenya where Drone technology has not been exploded [73].

III. Methodology

Research design is the overall plan for obtaining answers to the questions being studied and for handling some of the difficulties encountered during the research process [74]. [75] and [76] describe a research design as the arrangement of conditions for collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy in procedure. This study employed a design science research design. Design science research was used as a "lens" or set of synthetic and analytical techniques and perspectives (complementing positivist, interpretive, and critical perspectives) for performing research in Information Systems [77]. It involved two primary activities to improve and understand the behavior of aspects of Information Systems: (1) the creation of new knowledge through the design of novel or innovative artifacts (things or processes) and (2) the analysis of the artifact's use and/or performance with reflection and abstraction. The aim was pursuing a scientific study and the creation of artefacts to be used by people to solve practical problems of general interest. The study was carried out in Kenya health care. Kenya is found in Eastern Africa. It borders the Indian Ocean to the southeast, it is situated along the equator and is bordered by five countries: Somalia to the northeast, Ethiopia to the North, South Sudan to the northwest and Uganda to the West, and Tanzania to the South.). Since the study was being conducted in Kenya, target population included human population: healthcare providers and patients in Kenya and non-human population including the various technological facilities in use in this health care. The study sample comprised general superintend, medical consultants, medical students and patients of

ISO 3297:2007 Certified ⁜ Impact Factor 8.102 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 8, August 2023

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sampled level 4, level 5, and level 6 hospitals currently operating as teaching and research in Kenya. The sample units included the referral hospitals and various scholarly literature- which were selected based on recommendations and initial feasibility study that was conducted. The criteria for inclusion of a hospital facility was based on the capacity of serving as a training, research and referral center or services.

The study sample had total of (163) units which comprises (30%) of the study population from (3) hospitals. Since students population was not constant (was expected to vary at the time of the study), and the nature and status of patients which as unpredictable at the time of data collection/ prototyping or testing the model, the researcher approached the patients through medical consultants. Besides having a purposive sample of hospitals and medical consultants, this study also sampled a focus group consisting of ICT experts and medical consultants, survey questionnaire randomly used. Kakamega general was sampled for prototyping and model testing. The study used survey questions, focus group and guided interviews. The study involved descriptive statistics, which was concerned with organizing and summarizing data at hand, to render it more comprehensible and inferential statistics which dealt with the kinds of inferences that were made when generalizing from data, as from sample data to the entire target population (Mouton, 1996).

IV. FINDINGS AND DISCUSSION

The focus was on understanding the process for the implementation of IoT approaches to enhance personalized services. The first task was to conduct an interview on medical consultants (MDC: denoting specialized healthcare professional who provides expert advice) and general superintendent (AD: who were responsible for the overall management and operations of a healthcare facility). The interview took place in the three sampled health care facilities that is Moi teaching and Referral, Kakamega General and Webuye County Hospital.

The responses from MDC1, MDC2 and administrators AD1 revealed fascinating insights into the patient-centric health consultancy system that utilizes the power of IoT devices. They noted that:

"…….We are working on upgrading our healthcare systems by integrating cutting-edge wearable devices like smartwatches and fitness trackers, which track patients' activity levels, heart rate, and sleep patterns. Additionally, we employ smart scales, blood pressure monitors, and glucometers to collect vital signs and health metrics."

Furthermore Research Medical Agent (RMA) in his division explained the role of incorporating intelligent agents within the system, stating that:

"… if we incorporate these agents, say a scheduling agent, monitoring agent, and recommendation agent, they will be able to manages the collected IoT data. …the scheduling agent will efficiently arranges appointments with healthcare providers, while the monitoring agent will be able to tracks patients' health status. The recommendation agent will provide personalized suggestions based on the analyzed data… I know I have never interacted with software agents but I have heard of IoT in various forums and discussion groups"

According to the interviewees, the integration of IoT technology in healthcare is likely to bring a about significant improvements. One interviewee stated that:

"The use of IoT technology is likely to streamline our data management processes, reducing the reliance on manual record-keeping and minimizing errors."

Another interviewee emphasized the impact on patient care, saying that:

"The implementation of IoT technology is likely to enhance the accuracy and timeliness of diagnosis, leading to improved patient outcomes."

Data security and privacy emerged as major concerns among the interviewees. One interviewee expressed the need for stronger regulations, saying, "The government policies regarding patient data protection need to be strengthened to ensure the privacy and security of sensitive medical information since the convention regulations in use may be violated when technology is exclusively used." Another interviewee highlighted the importance of ethical data use, stating, "Strict data protection measures and regulations should be enforced to maintain patient privacy and ensure the responsible use of IoT devices or new technologies."

Standardization and interoperability were also discussed by the interviewees. One interviewee emphasized the need for protocols and guidelines, stating, "Standardization of IoT devices and protocols is crucial for interoperability and effective data exchange between different healthcare systems." Another interviewee highlighted the benefits of seamless integration, saying, "There is a need for standardized protocols and interoperability between different IoT devices and systems to build trust and encourage the widespread adoption of IoT technology in healthcare."

The interviewees emphasized the importance of infrastructure development and government support. One interviewee stated,

"The government should set aside funds in order to upgrade its technology infrastructure (especially in health sector) to fully take advantage and the benefits of IoT in patient care."

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

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Another interviewee highlighted the need for incentives and collaboration, saying,
"The government should provide incentives, training and support for the implementation of IoT technology in healthcare to drive its widespread adoption because I believe, there is where we are heading."

This interview findings are supported with latest research on supporting the transformative potential of IoT technology in health care. The groundbreaking study conducted [78] highlighted how IoT implementation enables patients to receive customized care promptly. This not only empowers individuals to take charge of their well-being but also equips healthcare providers to deliver highly effective and efficient services.

Moreover, the seamless integration of IoT technology in health consultancy services unlocks a realm of personalized care by leveraging interconnected devices and cloud analytics. This revolutionary approach, as elucidated by the interviewee, facilitates efficient remote monitoring and paves the way for the creation of intelligent healthcare environments that enhance patient well-being.

Interview responses emphasized that IoT's transformative potential lies in its ability to provide timely interventions and drive improved patient outcomes. The unification of IoT devices and cloud analytics empowers healthcare providers to offer tailored care that significantly enhances the overall efficiency of health consultancy services.

Generally, the findings from the interviews acknowledged that IoT technology is there and if well utilized, it has positive impact in healthcare while expressing concerns regarding data security, privacy, standardization, and infrastructure. It is clear that proactive measures, such as stronger regulations, standardized protocols, and government support, are necessary to address these concerns and fully harness the potential of IoT in healthcare.

Delving deeper and based on expert requirements, the analysis categorizes the findings into various intriguing aspects, such as IoT technology, its operation principles, data collection and conversion, healthcare applications, and the overarching impact of IoT. The study's findings, elegantly summarized in Table 1 summarizes diverse IoT technologies in health consultancy services.

Table 1: Summary of IoT Technology in Health Consultancy services

Task	IoT Devices	Use or Function	Patient Data Captured	Function Description
• Remote Patient Monitoring	• Wearable • sensors • connected medical devices	• Remotely monitor patients' vital signs	• Heart rate • Blood pressure, and • oxygen levels	• Allows healthcare providers to track patients' health status in real-time and intervene early if necessary
• Telemedicine or Tele-monitoring of vital signs		• remote consultation and diagnosis • eliminating-person visits • Reduce healthcare costs	• Blood pressure • heart rate • oxygen saturation • blood glucose	• patients remote areas • monitor patients heart failure, diabetes, hypertension, recovering from surgery or other medical procedures
• Medication Management	• IoT-enabled pill dispensers or Smart pill dispensers and • smart medication packaging	• Enable patients manage their medications more effectively	• remind patients to take their medication on time • monitor patients compliance	• notify healthcare providers if patients miss a dose • reduce medication errors • improve patient outcomes, and • lower healthcare costs
• Asset Tracking		• track medical equipment and supplies, • guarantee availability		• Help healthcare providers reduce costs, improve efficiency, and minimize waste
• Personalized Car		• provide personalized care to		• customized treatment plans

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	patients based on their individual health data	• recommendations for lifestyle changes, and • tailored medication regimens

Table 1 presents the findings obtained through interviews conducted for this study, focusing on telemedicine and Remote Patient Monitoring (RPM). The interviews revealed that healthcare providers are increasingly incorporating IoT-enabled devices, including wearables, sensors, and mobile apps, into their telemedicine practices. These devices play a crucial role in facilitating remote medical consultations by allowing patients to collect and transmit their health data to healthcare professionals for analysis and diagnosis.

During the interviews, it was observed that telemedicine services were available in some hospitals in Kenya, providing patients with the opportunity to access medical consultations with doctors and specialists remotely. This has been particularly beneficial for patients who prefer the comfort of home monitoring, as it allows for continuous health monitoring without the need to visit a hospital. Notably, various monitoring devices such as glucose meters, pulse oximeters, and weight scales are being utilized for remote monitoring. This enables patients with chronic conditions to effectively manage their health from the convenience of their own homes. Though, most of these devices are recommended by doctors and it's the patients to buy them hence favoring only well off patients and marginalizing patients who are financially constrained.

Furthermore, the analysis highlighted the presence of several IoT-enabled health and wellness apps in Kenya. These apps empower users to track various aspects of their health, including diet, exercise, sleep patterns, and other relevant metrics. By providing tools for self-management and promoting proactive healthcare practices, these apps contribute to improving overall health and well-being.

In terms of the integration of IoT technology in Health cares, it was noted that some hospitals in Kenya have embraced IoT advancements to enhance patient care and optimize hospital operations. For instance, IoT-enabled sensors are deployed to monitor temperature and humidity levels in hospital rooms, ensuring a comfortable environment for patients. Additionally, wearable devices are utilized for remote management of patients' health conditions. There was need to integrate these devices continuously monitor vital signs and transmit the data to healthcare providers, enabling personalized treatment adjustments based on real-time information.

During an interview with a medical consultants (MDC4) at Moi Teaching and Referral Hospital in Kenya, they explained: *"We are prototyping telemedicine services to facilitate remote medical consultations….the system will be able to collect patients health related data using IoT-enabled devices such as wearables and sensors. This data will be then transmitted to us for analysis, diagnosis and decision making.*

Fig. 1 and Fig. 2 illustrate the connectivity and integration of IoT devices in health consultancy services. They provide a visual representation of how IoT-enabled devices, such as wearables, sensors, and other medical devices, need to be interconnected to facilitate remote monitoring, data transmission, and analysis.

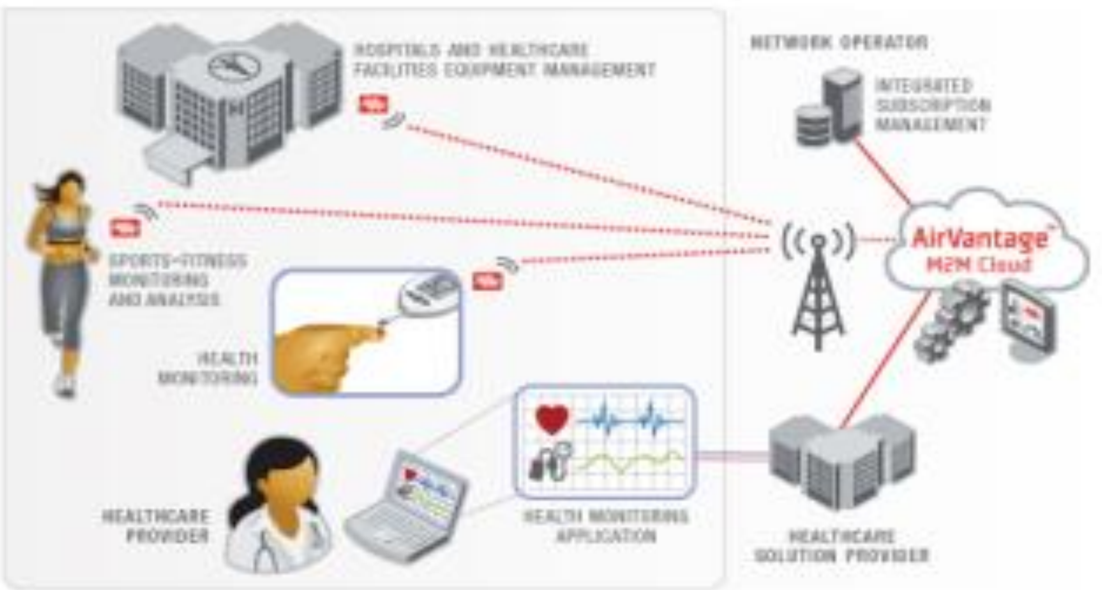

Fig. 1: Real time monitoring of patient health through IoT

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified ⁙ Impact Factor 8.102 ⁙ Peer-reviewed / Refereed journal ⁙ Vol. 12, Issue 8, August 2023
DOI: 10.17148/IJARCCE.2023.12817

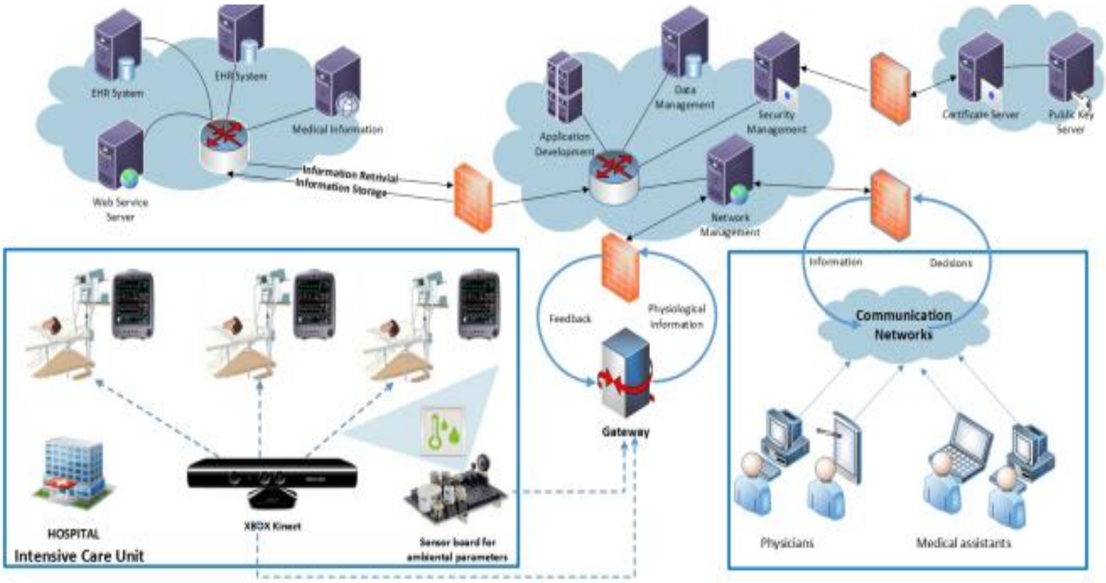

Fig. 2: IoT Components for Intensive Care Unit (ICU) Monitoring of Patients at Risk

Figure 2 provides an overview of the essential IoT components required to create a smart environment for monitoring patients at risk in the Intensive Care Unit (ICU). These components work together to ensure efficient and accurate monitoring, minimizing false alarms and enabling timely intervention. Intensive Care Unit Bedside Monitors component are already in use in hospital units and are designed to monitor and record multiple physiological parameters of patients. They play a crucial role in collecting real-time data such as heart rate, blood pressure, respiratory rate, and oxygen saturation levels. The Microsoft XBOX KinectTM device is utilized to monitor patient movement within the ICU. Equipped with sensors, it helps eliminate situations where patients may inadvertently detach wires or trigger false alarms. The device specifically detects movements when the sensor itself is unable to measure contact resistance with the patient. Sensor Board for Environmental Parameters employs a sensor board to monitor environmental parameters within the ICU. It collects data on temperature, humidity, atmospheric pressure, and various gases present in the environment. This information helps maintain optimal conditions for patient care and safety. Computer Server and Database is where all health records and measurements from the ICU monitoring devices are stored. This centralized storage ensures data integrity, accessibility, and security. Doctors and nurses access the data through an appropriate user interface, enabling them to review patient information and monitor trends over time. A web-based health monitoring application processes and analyzes the data collected from the ICU devices. It provides real-time updates to doctors and nurses concerning vital parameter changes, patient movement, and significant variations in environmental parameters. This timely information allows healthcare professionals to take preventive measures and provide appropriate care promptly. The integration of these IoT components enables a comprehensive monitoring system in the ICU, ensuring continuous surveillance of patients at risk. The combination of physiological monitoring, patient movement detection, environmental parameter monitoring, and data analysis enhances patient safety and facilitates early intervention whenever necessary.

A. Tele-monitoring of Vital Signs

The study collected data in order to understand how tele-monitoring of patient's vital signs works. This was also a useful application of IoT concept in remote monitoring of human's vital signs, such as blood pressure, electrocardiographic signal, oxygen saturation, body temperature and heart rate. This process is managed through means of embedded medical sensors and autonomous wireless technology. Table.2 summarizes how tele-monitoring is achieved across various groups in healthcare.

Table 2: Tele-monitoring Across Various Groups

Group	Type of IoT	IoT devices	Role	Connection protocols
Patients	Wearable	Wearable biosensor	monitor :Temperature, Heart rate, Breathing rate	Bluetooth LE, Wi-Fi, Z-Wave, ZigBee
		Connected inhalers	Manage respiratory conditions	None identified
		Oximeters		None identified

		Smart watch (series4, Apple watches)	measure oxygen saturation level and heartrates	None identified
		Smart thermometer Armpit patches	Measure body temperature	
		Automated Insulin Delivery (AID) system (AI pancreas System)	Diabetes people	None identified
		Moodables (Medtech)	Improve moods and cognitive abilities using Medtech.	None identified
Physicians	Wearable	Phone	Transmit patients to a staff at the virtual hospital.	None identified
		AID systems	Controlled by receives remotely via smartphone.	None identified
Hospitals	Tagged with sensors	Phone		None identified
Health insurance company	Connection			None identified
Storage	Cloud server	Cloud Application and Environment	Data analysis and visualization	None identified

To achieve productivity using data from Table 2, the following steps are required:
Step 1: Deployment of interconnected devices including sensors, actuators, monitors, detectors, camera system etc. these device are used to collect data.
Step 2: Aggregating and converting data collected or captured from devices listed in step 1 and other from their original analog form to digital form for data processing
Step 3: Aggregated and digitized is pre-processed, standardized and moved to data center or cloud server.
Step 4: Data management, analyzed at required level using advanced data analytics tools for insight and effective decision making.

B. IoT Operation Principles

This section analyzed collected based on principles of operation. The study identified several principles which are summarized in Table 3 under sub-headings: principles, description, quantity measures, enabling component and activities involved.

Table 3: Principles Operation

Principles	Description	Quantity Measured	Enabling components	Activities
Sensors and Actuators	IoT devices use sensors to collect data from the environment	temperature, humidity, and motion	use actuators	turning on and off lights and monitor temperature of a room
Connectivity	IoT devices are connected to each other and to the internet		Wi-Fi, Bluetooth, and cellular networks	enables data exchange of between devices and systems
Data Collection and Analysis	IoT devices collect data from sensors and other sources and transmit it to cloud-based servers for storage and analysis		Machine learning and artificial intelligence algorithms	used to analyze the data and derive insights
Automation	IoT systems can be automated to perform specific tasks based on data analysis and other inputs	temperature	a smart thermostat	adjust the temperature of a room based on occupancy and weather conditions

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified ⁜ Impact Factor 8.102 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 8, August 2023
DOI: 10.17148/IJARCCE.2023.12817

Security	IoT devices and systems must be secured to prevent unauthorized access and protect data privacy	security measures	encryption, authentication, and access control
Scalability	IoT systems must be designed to scale up or down depending on the number of devices and the amount of data being generated	careful planning and architecture	ensure that the system can handle increasing levels of traffic and data

In overall, the operation of IoT devices and systems in table 3 is based on a complex set of principles and technologies that enable the collection, transmission, analysis, and automation of data.

In healthcare service provision, the Internet of Things (IoT) operates based on several principles to enable efficient and effective healthcare delivery. This study discussed a few IoT operation principles that are or can be utilized in healthcare domain: IoT devices are utilized to continuously monitor patient vital signs, health parameters, and other relevant data remotely. This principle allows healthcare providers to gather real-time information about patients' health status without the need for frequent physical visits. Remote monitoring helps in early detection of abnormalities and timely intervention. It also facilitates telemedicine by enabling remote consultations and virtual visits between healthcare professionals and patients. IoT devices have the potential to transmit video, audio, and patient data securely, enabling healthcare providers to diagnose, prescribe treatments, and monitor patients from a distance.

IoT wearable devices, such as fitness trackers, smartwatches, and biosensors, allow individuals to monitor their health and collect data on activities, sleep patterns, heart rate, and more. These devices provide insights into personal health and support preventive healthcare practices. Moreover, IoT integration in medical devices like glucometers, blood pressure monitors, and medication dispensers enhances functionality and connectivity. These smart medical devices automate data collection, share information with healthcare providers, and provide reminders or alerts for medication schedules and dosage management. IoT enables efficient tracking and management of medical assets such as equipment, supplies, and medication. Utilizing sensors and tracking systems, healthcare facilities can monitor the location, condition, and availability of assets, ensuring their optimal utilization and preventing loss or theft. It also streamline healthcare workflows by automating various processes. For instance, IoT-enabled systems can monitor patient flow, optimize bed allocation, manage appointments, and improve inventory management. This principle enhances operational efficiency and reduces errors. By combining IoT-generated data with advanced analytics, predictive models can be built to forecast disease outbreaks, patient deterioration, and healthcare resource demand. This principle supports proactive decision-making, resource planning, and early intervention strategies. Given the sensitivity of healthcare data, IoT systems must adhere to strict security and privacy protocols. Robust encryption, secure data transmission, access controls, and authentication mechanisms are essential to protect patient information and ensure regulatory compliance. These IoT operation principles contribute to improved patient care, remote monitoring, preventive medicine, and efficient healthcare delivery.

C. Health Data Ontology

The field of healthcare has witnessed the utilization of ontologies and data ontologies to enhance the organization, retrieval, and analysis of healthcare-related information. The study linked the analysis of IoT-enabled data collection to healthcare ontology, which provides a structured representation of healthcare concepts and their relationships. It is a representation of medical knowledge that facilitate data integration, interoperability, and semantic understanding. By doing so, the study enhanced the understanding and interpretation of the collected data in the context of healthcare domain knowledge. This enabled the study to establish a semantic framework that aligns the technological aspects of IoT with the domain-specific knowledge and terminology of healthcare. This integration facilitates informed decision-making and improved patient care.

The sensory layer of IoT devices, was equipped with various sensors for data collection, and linked to healthcare ontology's concept of "biomedical sensors" or "vital signs monitoring." These concepts describe the specific types of data captured from the patients, such as temperature, heart rate, and motion, and their relevance to healthcare monitoring and diagnosis. The network layer, is responsible for connectivity and data transmission, it was connected to healthcare ontology's concepts of "health information exchange" or "telecommunication infrastructure." These concepts highlighted the importance of secure and efficient data transmission in healthcare settings. The cloud-based platforms and edge computing, this is where data is processed, stored, and analyzed, was linked to healthcare ontology's concepts of "health data management" or "health analytics." These concepts emphasize the utilization of data for insights generation, decision-making, and improving healthcare operations.

The data analytics techniques applied to the collected IoT data, such as statistical analysis, machine learning, and artificial intelligence algorithms, was associated with healthcare ontology's concepts of "data mining" or "clinical decision support

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

ISO 3297:2007 Certified ⁜ Impact Factor 8.102 ⁜ Peer-reviewed / Refereed journal ⁜ Vol. 12, Issue 8, August 2023

DOI: 10.17148/IJARCCE.2023.12817

systems." These concepts focus on the utilization of data analytics to extract valuable insights, identify patterns, and support clinical decision-making. The storage of collected IoT data in databases or data lakes was connected to healthcare ontology's concepts of "electronic health records" or "health data repositories." These concepts highlight the importance of structured data storage and retrieval in healthcare settings. Lastly, the data security and privacy measures, such as encryption, access controls, and user authentication, was linked to healthcare ontology's concepts of "health data privacy" or "data security standards." These concepts emphasize the ethical and responsible handling of healthcare data to protect patient privacy and comply with regulatory requirements such as MoH.

D. Data Conversion

The study investigated the process of data conversion in the context of healthcare. Data conversion was identified as an essential component in technological lifecycle, in transforming data from one format to another, involving changes in file format, data structure, or encoding. In the healthcare domain, data conversion was essential to ensure compatibility with specific software, systems, or devices, particularly in the case of IoT devices that utilize different communication protocols. It was also noted that data conversion was crucial when migrating from one system to another, such as during software upgrades or transitioning data to the cloud. In these instances, data collected, by various IoT devices, need to be converted to a format suit. To facilitate data conversion, interconnected and portable devices such as cameras, detectors, sensors, monitors, and equators had potential to be utilized. These devices captured input in analog format, which then needed to be converted into digital format to undergo further processing. This conversion process was essential to ensure seamless integration and compatibility within the healthcare ecosystem. Data collected and analyzed from IoT devices regarding data conversion were summarized in Table 4, presenting key insights into the various conversion tasks and techniques employed in the healthcare setting.

Table 4: Conversions Used in

Conversions Technique	Explanation	Device use	Nature of Data
Analog-to-Digital Conversion (ADC)	Many sensors in healthcare IoT devices generate analog signals	ADC is used to convert analog signals into digital	ADC quantizes the continuous analog signal into discrete digital values
Digital-to-Analog Conversion (DAC)	In certain cases, IoT devices may need to produce analog output signals	DAC is employed to convert digital data into analog signals	digital signals are converted to analog waveforms to control the delivery of medication or therapeutic interventions
Signal Conditioning	IoT devices often require preprocessing or conditioning of sensor data to enhance accuracy and reliability	amplification, filtering, and calibration techniques to remove noise, adjust signal levels	This step ensures that the data is suitable for further analysis and interpretation
Unit Conversion	IoT devices may measure physical quantities in different units depending on the sensor or application	Unit conversion is performed to standardize the collected data into a consistent unit system	converting temperature blood pressure readings (mmHg) to kilopascals (kPa).
Data Compression	IoT devices often operate with limited storage and bandwidth capabilities	Data compression techniques are employed to reduce the size of the collected data.	Huffman coding, run-length encoding used to minimize data size
Data Aggregation	In healthcare IoT deployments where multiple sensors or devices are involved, data aggregation combines or summarizes data from different sources	Aggregation can involve averaging, summing, or statistical calculations to provide a consolidated view of the collected data	a population health monitoring or system-level analytics

Table 4 summarizes data conversion techniques which ensure that the collected data from IoT devices in healthcare is in a standardized, compatible, and usable format. The transformed data can then be efficiently processed, transmitted, and analyzed for various healthcare applications, including remote monitoring, decision support, predictive analytics, and personalized patient care.

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V. CONCLUSION

The study underscores the potential of integrating IoT and multi-agent systems in healthcare services in Kenya. By addressing the technological, regulatory, and collaborative aspects, the study aims to contribute to the development of an advanced and patient-centric healthcare system in the country. Based on the objectives stated for this study and the findings herein the study reveals and recognizes the potential of IoT approaches being used in healthcare services for data collection, monitoring, and communication. Most of required IoT devices are available and are used selectively, some are not locally found hence not used.

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