Online-Journals.org

iJOE International Journal of Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 20 No. 9 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v20i09.48805

PAPER

Revolutionizing Healthcare: Convergence of IoT and Open-Source ERP Systems in Health Information Management

Imam Alihamidi[1](✉), Anass Deroussi[1], Adnane Addaim[2], Abdessalam Ait Madi[1]

[1]Advanced Systems Engineering Laboratory, National School of Applied Sciences, Ibn Tofail University, Kenitra, Morocco

[2]Department of Electrical Engineering, Mohammadia School of Engineers (EMI), Mohamed V University, Rabat, Morocco

Imam.alihamidi@uit.ac.ma

ABSTRACT

Over the last decade, health information systems (HIS) have undergone significant changes, particularly in embracing flexible frameworks for ongoing development. This evolution underscores the necessity for information technology (IT) infrastructures that rapidly align with clinical processes. The paper investigates the transition of hospital information systems to comprehensive strategies, examining the benefits and challenges involved. It also examines the increasing demands on health data management systems (HDMS) for patient care and biomedical research. The focus is on how the integration of the Internet of Things (IoT) and open-source enterprise resource planning (ERP) systems, such as Odoo, impacts health information management. The study evaluates the effectiveness and implications of combining these technologies. It provides examples of these integrated systems in action, particularly in resource-limited settings, and evaluates their potential to improve care. The document provides a comprehensive review of the current status and evolution of HIS and HDMS, highlighting the importance of integrating IoT and other cutting-edge technologies in healthcare. This is a crucial aspect for developing countries, where these advancements can significantly improve healthcare outcomes.

KEYWORDS

Internet of Things (IoT), health information systems (HIS), Odoo, framework Odoo, enterprise resource planning (ERP) open-source, Node-RED, MQTT

1 INTRODUCTION

In the last 10 years, health information systems (HIS) have undergone significant evolution, including notable advances such as the layered approach to continuous adaptation and development of these systems [1]. This evolution highlights the significance of a responsive information technology (IT) infrastructure to quickly align

Alihamidi, I., Deroussi, A., Addaim, A., Madi, A.A. (2024). Revolutionizing Healthcare: Convergence of IoT and Open-Source ERP Systems in Health Information Management. *International Journal of Online and Biomedical Engineering (iJOE)*, 20(9), pp. 83–98. https://doi.org/10.3991/ijoe.v20i09.48805

Article submitted 2024-02-28. Revision uploaded 2024-04-03. Final acceptance 2024-04-03.

information systems with clinical processes [2]. The paper delves into the evolution of hospital information systems towards a more comprehensive HIS, highlighting the advantages, obstacles, and possible strategies for overcoming these challenges. It further investigates the demands placed on health data management systems (HDMS) within the realms of biomedical research and patient care, focusing on how these systems have evolved and the driving forces behind their advancement [3], [4], and [5].

The integration of commercial projects and open-source software in HIS, particularly in developing countries, highlights the important role of HIS projects [6]. The SHARP project and the Open Three (O3) consortium are notable examples of open-source initiatives aimed at standardizing health record data and promoting e-health solutions [7], [8].

When considering the integration of commercial projects and open-source software into HIS, several challenges arise, particularly in developing countries. Azadi et al. [9] emphasize the significance of integrating medical subsystems into HIS to enhance reporting accuracy and decision-making. They assert that integrating medical and management information systems is crucial for the efficiency of HIS. S. Tian et al. [10] identified problems related to mechanisms and motivation in the vertical integration of electronic health records (EHR). They highlighted the need for coordination and appropriate incentives to overcome these obstacles.

In discussing the challenges of interoperability in HIS, D.M. Walker et al. [11] highlighted technological, organizational, and environmental issues, as well as the complexity of integrating disparate systems and policies within HIS. R. L. Altman et al. [12] investigated the challenges of implementing problem-oriented documentation in commercial EHRs and highlighted the difficulties of adapting commercial systems to meet specific clinical needs.

Integrating IoT into healthcare systems is essential for several reasons. First, it can provide a secure and scalable data management framework for IoT while addressing security and privacy concerns, as described by T. Mai et al. [13]. This approach can significantly improve data management in healthcare systems. A model for skin cancer detection using federated learning integrated with a deep generation model is proposed by X. Cai et al. [14]. In this model, the IoT is integrated to address the data shortage issue in smart medicine while protecting patient privacy.

The aim of this proposed work is to evaluate the combination of IoT technology with the open-source ERP system Odoo, specifically in the healthcare sector. The purpose of the study is to thoroughly understand the combined benefits and confront the challenges associated with this integration while presenting a detailed exploration of its practical applications in the healthcare industry. Using a case study methodology, this study focuses on the deployment and operation of Odoo in conjunction with IoT devices in healthcare environments.

This paper assesses the effectiveness of the system and its impact on the delivery of healthcare services. It provides insights into the integration of IoT with open-source ERP systems such as Odoo in healthcare information management (HIM), offering a detailed examination of the benefits, challenges, and practical implementations for healthcare organizations.

The remainder of this work is organized as follows: Section 2 presents a literature review on HIS, open-source software, the IoT, open-source ERP systems, and the QuickStart Methodology. Section 3 presents the analysis and design of the proposed proof-of-concept (PoC)-based prototype design system. The conclusion of the paper is presented in Section 4.

2 RELATED WORK

2.1 Health information system

Health information systems have undergone significant evolution, with several notable advances over the past decade. A layered approach has been developed to enable continuous adaptation and evolution of these systems, focusing on an application framework and rapid application development to better meet the changing needs of the healthcare sector [1]. The research underscores the critical importance of an agile IT infrastructure capable of rapidly synchronizing HIS with clinical processes. It highlights the need to adopt a dynamic strategy based on a robust application framework and examples of integrated tools [2]. The evolution of hospital information systems into HIS was also examined, identifying benefits and challenges, as well as potential solutions to overcome these challenges [3]. Additionally, a historical perspective on HIS was presented, discussing past developments and future implications [4]. Lastly, we discussed the requirements of HDMS in the context of biomedical research and patient care, highlighting the evolution of these systems and the driving forces behind their development [5]. The results of this study emphatically underscore the necessity of adaptability, strategic congruence, and focusing on patient needs in the ongoing development of HIS. Moreover, these systems have expanded to include a wide variety of initiatives, encompassing both commercial and open-source endeavors, skillfully adapting to the evolving requirements of the healthcare sector. The SHARP project, funded by the Office of the National Coordinator for Health Information Technology (NCHIT), developed open-source services to standardize and make EHR data reusable, improving interoperability and health data management [8]. Furthermore, the O3 consortium promotes the adoption of open source in e-health with the goal of developing medical IT solutions in an integrated healthcare environment [7]. CogStack is an open-source project that demonstrates the capability of systems to process large volumes of clinical data to improve internal services [15]. The RE4CH project tackles the challenges of integrating regulatory requirements into connected health systems using agile processes. It is applied in an open-source case study [16]. These projects demonstrate how commercial and open-source approaches can be utilized to meet specific needs while fostering innovation and adaptability in healthcare.

The use of commercial or open-source solutions in healthcare IT systems varies in several ways. Commercial solutions typically involve additional expenses for licensing and technical support fees, but they also offer quality support and maintenance, sometimes incurring additional costs. Customization options may be limited depending on the functionalities offered by the service provider, but they benefit from accelerated implementation due to professional expertise. In contrast, open-source solutions are known for their financial accessibility, lack of licensing fees, and high degree of customization and adaptability. Support and maintenance for these solutions are typically provided by the community or paid third-party services. Open-source projects often have better interoperability due to the adoption of open standards, as demonstrated in the SHARP project [8]. Collaboration and community sharing in open-source projects encourage innovation [15]. In contrast, security is more transparent in open-source projects but requires specific expertise for its management, while it is robustly managed in commercial projects [6]. Commercial and open-source projects are commonly utilized in commercial integrated hospital management and EHR systems, as well as in e-health initiatives and open-source EHR systems, respectively [7]. When deciding between commercial or open-source projects for HIS, it is important to consider the needs, resources, and strategic objectives of the organization.

The following section of this paper will discuss the adoption of open-source solutions. The purpose of this guidance is to promote widespread integration, improve systemic compatibility, increase resilience, ensure accessibility and equity of health services, and expand care coverage in disadvantaged areas or those with limited resources.

2.2 Open-source healthcare software

There are significant differences between native software development and the use of open-source frameworks in terms of flexibility, cost, time to market, community support, customization, maintenance, security, and innovation. Native software is more expensive and time-consuming to develop, but it offers a higher level of customization and control that is tailored to the specific needs of a platform or environment. On the other hand, open-source frameworks enable cost reduction and faster deployment through the reuse of existing components and the contribution of a large community [17], [18], and [19]. Maintenance and security in open-source frameworks rely heavily on the robustness of the framework and community engagement, as emphasized by L. Zhao et al. [20] and J. P. Johnson [21]. Furthermore, innovation is often more dynamic in open-source environments due to the diversity of contributions and collaboration within the community, as noted by D. Spinellis et al. [22]. These factors should be considered when choosing between native software development and adopting open-source frameworks for a given project. Notable examples of open-source HIS include GNU Health and OpenEMR. GNU Health was developed to meet the diverse needs of healthcare institutions and is utilized for managing electronic medical records (EMR) [23]. OpenEMR is widely adopted in the industry and offers advanced features for hospital workflow management [24]. OpenMRS is renowned for its robustness and global adoption, showcasing its reliability and effectiveness [25]. MediBoard, which was tested in Mali, illustrates the adaptability of these systems in various contexts, including those with limited resources [26].

2.3 Open-source healthcare ERP

Nowadays, an organization's primary operations are coordinated and unified through an integrated management software package, known as ERP. The ERP system acts as the central core, ensuring process consistency across manufacturing, inventory management, finance, and human resources management by consolidating information within an integrated platform. The primary objective of an ERP system is to enhance seamless communication among various internal departments and streamline interactions with external partners. The benefits of an ERP system are numerous. They include optimizing efficiency by reducing manual tasks, providing real-time access to an overview of activities, and strengthening cooperation by unifying procedures. Additionally, ERPs offer flexibility to evolve as needed in parallel with the company. These include cost, the difficulty of integrating and customizing with current systems, and the time and effort needed for implementation. Despite the challenges, ERPs are crucial for companies aiming to consolidate and enhance their operational processes. In the healthcare industry, it is essential to implement open-source ERP frameworks to provide scalable and cost-effective solutions. In the field of integrated solutions for patient management and system customization, PatientOS and ERP5 stand out as notable examples [27], [28]. In addition, Tryton, a variation of OpenERP, illustrates the versatility of open-source ERP frameworks for developing customized hospital information systems [23]. These systems offer cost-effective and scalable solutions, which are crucial for continuous improvement in the healthcare sector. Among these frameworks, GNU Health and ERP5 stand out as open-source HIS designed for managing EMR and offering integrated solutions for patient management. They meet the diverse needs of healthcare establishments [23], [27]. Additionally, Tryton, a variant of OpenERP, showcases the flexibility and adaptability of open-source ERP frameworks for creating customized hospital information systems [23]. These frameworks play an essential role in continuously improving healthcare by providing robust, scalable, and economically viable platforms.

When comparing open-source ERP frameworks like GNU Helath, ERP 5, Tryton, and Odoo, significant differences exist in terms of specialization, flexibility, community support, customization options, cost, ease of use, and target. GNU Health is specifically focused on the healthcare sector and offers high customization and adaptability to meet the needs of healthcare institutions [23]. ERP5, which also focuses on healthcare, enables integrated patient management and system customization [27]. Tryton, a variant of OpenERP, is characterized by its flexibility in developing hospital information systems. In contrast, Odoo presents itself as a versatile ERP platform suitable for a wide range of business applications, with an intuitive user interface and high flexibility [29]. While the first three frameworks are completely free and open source, Odoo offers a free (community) version as well as a paid enterprise version. These variations distinguish the array of possibilities in the open-source ERP sector, offering enterprises a range of solutions tailored to their specific needs.

Many industries, especially the medical field, could greatly benefit from Odoo, which is one of the top open-source ERP systems available. Hospital purchasing and inventory management processes have been integrated and automated with the assistance of Odoo, enhancing operational efficiency and decision-making in the healthcare sector. For example, a study demonstrated how Odoo was utilized to develop an integrated e-purchasing system for a hospital department, enhancing the efficiency and responsiveness of purchasing processes [30]. Another example is the integration of an enterprise asset management system for a smart hospital, where Odoo was used to manage asset maintenance and integration with the inventory sector [31]. These examples illustrate how Odoo benefits the healthcare industry by providing an affordable and adaptable ERP system that can be tailored to meet the specific needs of healthcare institutions. For the rest of this paper, we have chosen Odoo as our ERP system for integrating IoT. Odoo stands out due to its open-source nature, versatility, and a vast array of over 4,500 modules, including those for advanced business intelligence. Its compatibility with multiple programming languages, such as Python, JavaScript, and XML, makes it highly adaptable for various IoT applications. Odoo excels in custom module development, enabling the rapid creation of tailored solutions. It also provides diverse user interfaces, enhancing accessibility across various devices. This feature set, combined with Odoo's suitability for small to medium-sized businesses through integrated business management tools, makes it an ideal platform for our IoT-ERP integration, promising efficiency, scalability, and alignment with modern technological practices [32], [29], [33].

2.4 Internet of Things for healthcare

Also known as the Internet of Medical Things (IoMT), the IoT in healthcare is transforming the industry. By interconnecting medical devices, IoT enables real-time monitoring [34], [35], [36], efficient patient information management, and enhanced medical care. S. M. Riazul Islam et al. [37] highlighted the promising technological, economic, and social prospects of IoT-based healthcare solutions in redefining modern healthcare. Fog computing technologies have been proposed for patient health monitoring at home, aiming to enhance real-time response and decision-making based on health data [38]. IoMT elevates healthcare by enabling consistent, accurate, and efficient monitoring, leading to proactive patient care. Implementing appropriate measures can effectively tackle security and privacy challenges.

2.5 QuickStart methodology

The Odoo QuickStart methodology is a specific approach for the rapid and efficient implementation of Odoo ERP software. It aims to accelerate the deployment process in organizations by focusing on key steps for successful implementation. A study conducted by N. Irianis et al. [30] found that Odoo's QuickStart methodology is effective in improving purchasing processes and responsiveness in day-to-day operations in an Indonesian hospital department. A study applied the QuickStart methodology to create a versatile production planning system within Odoo's manufacturing module for a textile company [39]. These examples demonstrate how the QuickStart technique can be utilized to integrate ERP solutions across various industries, such as manufacturing and healthcare, to enhance corporate decision-making and streamline company processes. Applying the Odoo QuickStart methodology involves several key steps to ensure efficient and rapid implementation of the Odoo ERP system. According to a study conducted by N. Irianis et al. [30], this methodology comprises five main steps that demonstrate the structured and effective approach of Odoo's QuickStart methodology for implementing ERP solutions in various business contexts.

- **Analysis:** During this stage, the company's unique requirements are identified, and the deployment of the ERP system is planned to meet these demands.
- **Configuration:** Based on the requirements analysis, this stage involves customizing the Odoo ERP system to fit the company's specific business operations and adjusting its features.

- **Training:** After the configuration is complete, users undergo training to ensure they comprehend how to operate the system. Tests are also performed to confirm that the system meets specifications.
- **Deployment:** Once satisfactory testing and user training are completed, the system is deployed for use in the company's regular operations.
- **Support and Maintenance:** Following deployment, continuous assistance is provided to address any issues, and regular upgrades are conducted to keep the system up-to-date.

3 ANALYSIS AND PROPOSED SYSTEM DESIGN

3.1 Analysis

In the management of health facilities, several key problems have been identified that require innovative solutions. The complexity and dynamics of health systems require adaptive approaches to manage this intricacy. M. Gray [40] suggests developing complex adaptive systems to meet this requirement. Another major issue is the disparity between simplified financial transactions and intricate medical procedures. Y. Bar-Yam [41] suggests creating separate systems for repetitive and complex tasks to improve the efficiency of care. The governance of integrated systems, according to G. T. Savage et al. [42], requires a two-tier governance structure that is responsive to internal and external stakeholders. Finally, due to the lack of integrated information systems, F. C. G. Southon et al. [43] recommend implementing integrated information systems to enhance the effectiveness of care. These solutions represent important steps toward improving the management and efficiency of health structures.

3.2 Class diagram

The development section will outline the various classes we considered for constructing the proposed prototype using a general-purpose visual modeling language called UML. It will also illustrate the interactions between their classes, as depicted in Figure 1. The diagram presents a conceptual data model for a hospital information system. Person is the base class for **Doctor, Patient**, and **Contact Person** because they share common attributes such as name, address, and contact information.

Doctors have specific work schedules (doctor schedule) and may undergo changes in their history (history changing doctor), indicating shifts in responsibilities or patient transfers. Patient visits record the details of each visit, including the attending doctor. Patients may also have IoT devices that record health data as well as analyze tests performed and diagnose specific diseases.

This model enables a complex, interconnected relationship between entities, reflecting the multidimensional nature of healthcare and patient follow-up in a hospital environment. Relationships between classes are indicated by "has many" and "belongs to" associations, representing one-to-many and many-to-one connections, respectively. This allows great flexibility in how data can be linked and queried.

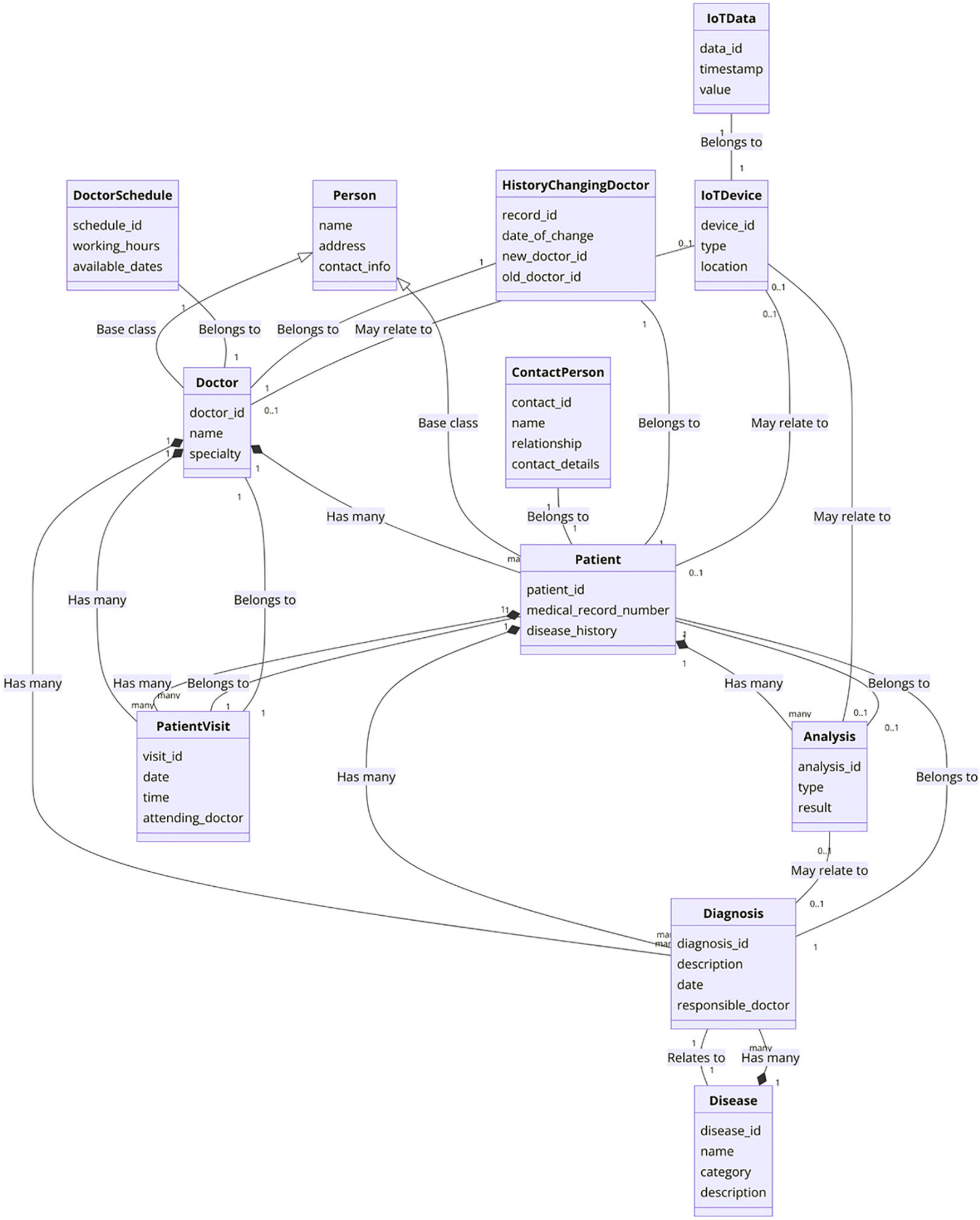

Fig. 1. UML class diagrams

3.3 Proposed system architecture design

This section presents the architecture of the proposed system, including its main components and their interactions. The project involves several layers, including user interfaces, business logic, data management, and IoT device integration. To provide a simplified overview, we propose an architecture, as shown in Figure 2, which can be summarized in three points:

1. **Sensor networks** are essential for patient monitoring and are designed for flexible deployment in both hospitals and homes. This configuration enables efficient monitoring of vital parameters using the MQTT IoT protocol. Although the DHT11 sensor is primarily utilized for environmental monitoring because of its capability to measure temperature and humidity, it can also be applied for medical purposes. However, in this context, it supports patient health monitoring by providing critical environmental data that may be relevant to certain health conditions. Our system integrates it through an adaptable IoT gateway, showcasing our dedication to innovative and cost-effective healthcare monitoring solutions that cater to a wide range of patient needs and scenarios.
2. **Hospital network:** This represents a network of hospitals that can be accessed through a web browser or mobile application to manage patients, healthcare professionals, and medical devices.
3. **Server or cloud:** This level represents the data storage and processing component, which can be managed either by a cloud or a dedicated server.

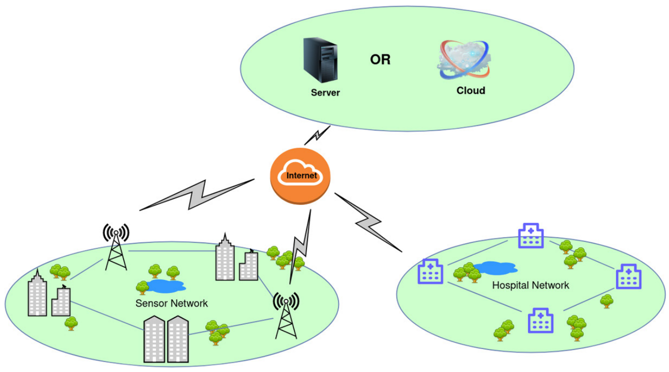

Fig. 2. Architecture of the proposed solution

3.4 Configuration

The summary of the software and hardware used in this proposed prototype is provided in Table 1.

Table 1. Minimum requirements in terms of software and hardware

Technology	Minimum Requirement
Hardware	• 2 × 8 CPU (Server) • 8 GB RAM (Server) • SSD 500 GB (Server) • quad-core Cortex-A72 (ARM v8) (Gateway IoT: Raspberry Pi4) • 4GB RAM (Gateway IoT) • ESP32 • DHT11 (Sensor)

(Continued)

Table 1. Minimum requirements in terms of software and hardware *(Continued)*

Technology	Minimum Requirement
Software	• Ubuntu 22.04.3 LTS (Server) • PostgreSQL Server (Server) • Python Version 3.10 (Server) • PyCharm (Server) • Project Odoo 17 (Server) • Node-Red (Gateway) • Raspberry Pi OS

As seen in Figure 3, which illustrates the configuration and testing phases of the proposed idea, the configuration was completed in three steps.

1. Step 1: The DHT11 sensor was connected to the ESP32 and programmed to read the temperature from the sensor. Subsequently, the operating systems Ubuntu 22.04 and Raspberry Pi OS were installed on the server and IoT Gateway, respectively.
2. Step 2: The development environments for the server and the gateway were prepared. This involved the installation of PyCharm, PostgreSQL Server, the Odoo 17 project for the server, and Node-RED, along with the necessary libraries for communication between Node-RED and ESP32 via the MQTT protocol for the gateway.
3. Step 3: The communication with the ESP32 was successfully tested after configuring the IoT gateway. The application was developed using the Odoo framework in PyCharm. It was based on the class diagram depicted in Figure 1.

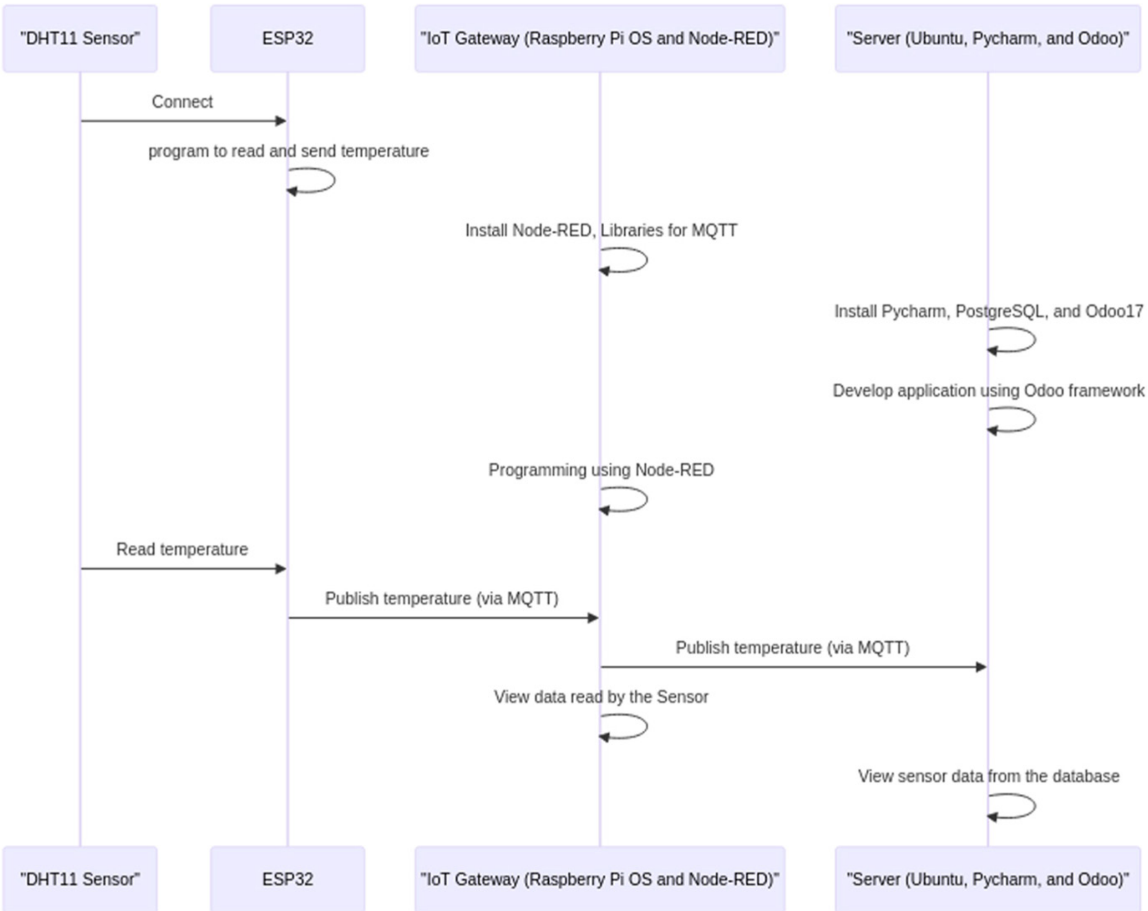

Fig. 3. Configuration and testing phase

Therefore, we can define the functional part of our system as shown in Figure 4.

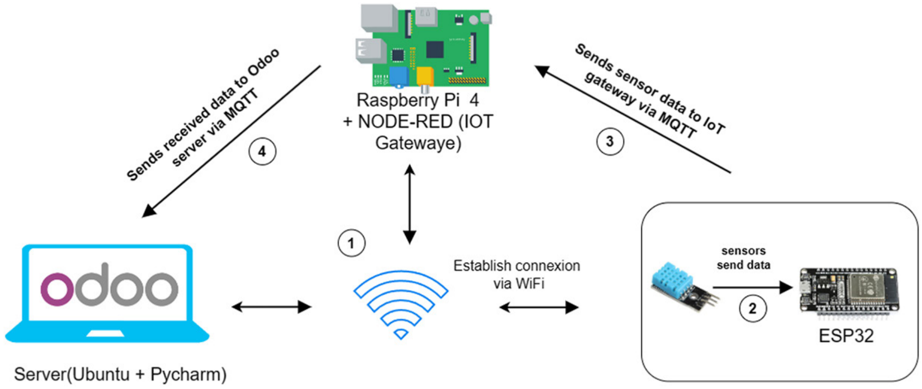

Fig. 4. Functional architecture of our system

3.5 Deployment

During the deployment phase of our project, we conducted rigorous functional testing to verify that every component of the system worked as intended. We also conducted performance tests to evaluate the system's responsiveness and stability, allowing it to run for several hours. This was especially important for our integration of IoT devices with the Odoo platform, where real-time data handling was essential. However, we faced challenges in integrating IoT with Odoo. Iterative testing and improved implementation of the MQTT protocol allowed us to overcome these challenges. The feedback from these tests was invaluable in optimizing the system configuration for optimum performance.

After finalizing our setup, we embarked on a testing phase to assess our system's capabilities. Upon activating the ESP32, gateway, and server, we accessed our application through a browser using the specific IP and port (127.0.0.1:8016). The application, designed with Odoo for its robustness and adaptability, features a user interface with six tabs (see Figure 5): main, schedules/visits, diseases, reports, analysis, and create appointments. Each tab serves distinct functions: Main manages doctors and patients; schedules/visits organize medical schedules; diseases categorize illnesses; reports generate essential documents; analysis visualizes data; and creates appointment schedules for patient meetings. Created for healthcare professionals, the application facilitates efficient hospital management and patient care. It leverages Odoo's flexibility and IoT integration capabilities to deliver a state-of-the-art healthcare management tool.

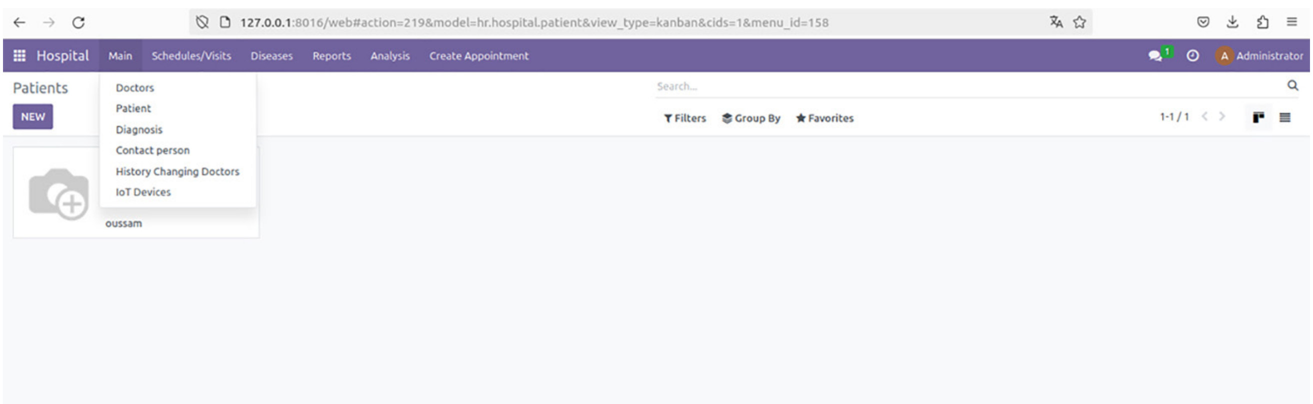

Fig. 5. Various functions of the proposed application

For example, we connected to the application as an admin, but the framework natively offers the possibility of managing users once the application has been created. To accomplish this, we included a doctor, a patient named "Imam," and an IoT device in our database (see Figure 6). We then connected the additional device to the simulated patient (imam) to demonstrate the communication between the sensor and the Odoo database (server). In addition, we will be able to visualize the data collected by the sensor, as shown in Figure 7.

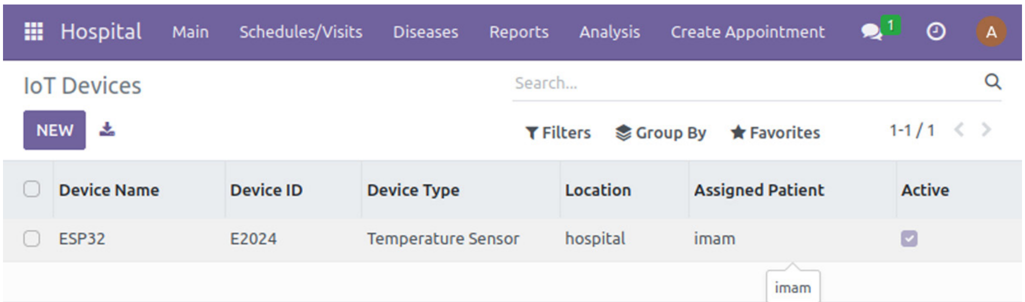

Fig. 6. List of IoT devices already assigned to patients

After configuring the device and assigning it to the patient, we can validate the reception of data as shown in Figure 7. Remember that the sensor was placed in a room to demonstrate the effective functioning of the communication component.

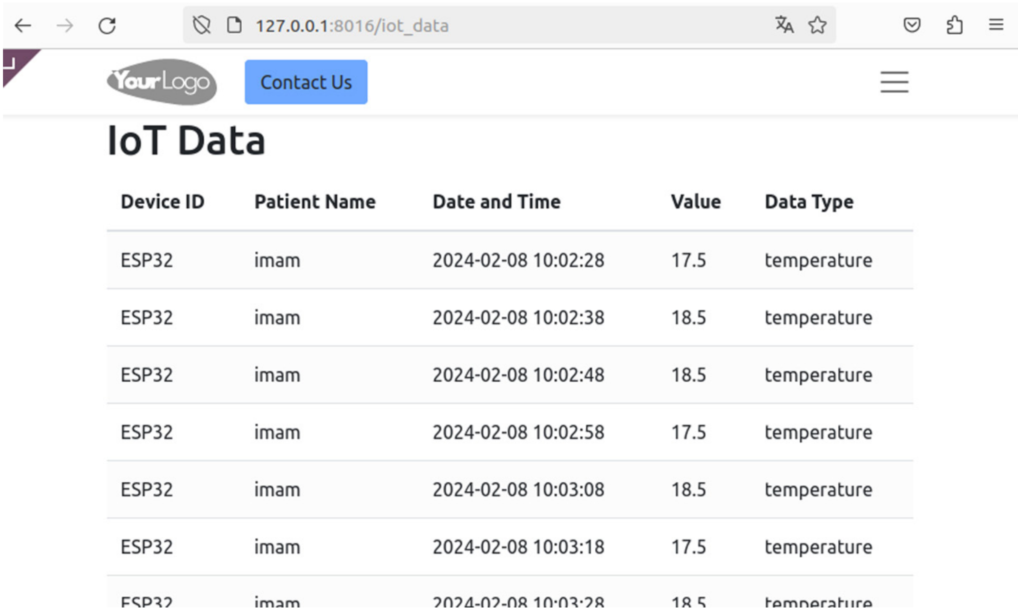

Fig. 7. Example of PoC test results

4 CONCLUSION

It focuses on the evolution and impact of health information technology. It emphasizes the importance of adaptable, strategically aligned, patient-centered systems and compares commercial solutions with open-source solutions. The paper highlights the flexibility, cost-effectiveness, and community innovation offered by open-source frameworks. Evaluating healthcare software and open-source ERP systems, such as

GNU Health and OpenEMR, indicates that they are highly flexible, cost-effective, and capable of continuous healthcare improvement. This paper also explores the potential uses of IoT in healthcare, focusing on the benefits of real-time monitoring and data-driven patient management. Our project primarily focuses on developing and deploying an ERP system with IoT integration. It is important to note that we are not considering the processing of collected data in the Odoo database. The integration process involves utilizing IoT devices, such as the DHT11 sensor with ESP32, to gather real-time data and communicate with the Odoo server through protocols such as MQTT. The data is processed and stored in the Odoo database, enabling real-time monitoring and efficient data management. Additional technical details, such as data flow and processing in the Odoo database, can enhance understanding of our system's capabilities and are valuable for future enhancements. For future work, we will focus on enhancing the security aspect by integrating blockchain technology to demonstrate the reliability and scalability of the system. Additionally, we will simulate high workloads to evaluate the system's performance under maximum usage scenarios.

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6 AUTHORS

Imam Alihamidi is a PhD student at the National School of Applied Sciences (ENSA) of Ibn Tofail University in Kenitra, Morocco. He is also an associate member of the Advanced Systems Engineering Laboratory. His research focuses on the Internet of Things and blockchain for the hospital of the future. He is interested in the applications of Information and Communication Technologies (ICT) to enhance the quality of life, well-being of individuals, and healthcare. He obtained his state engineering diploma in networks and telecommunication systems from ENSA in 2018 (E-mail: imam.alihamidi@uit.ac.ma).

Anass Deroussi received his Master's diploma in 2018 in Networks and Telecommunications Systems from the National School of Applied Sciences of Kenitra at Ibn Tofail University Kenitra (ENSAK), Morocco. Currently, I am a PhD student and an associate member of the Advanced Systems Engineering (ASE) Laboratory at Ibn Tofail University. His main interests are the Internet of Things (IOT), artificial intelligence (AI), and the world of embedded systems (E-mail: anass.deroussi@uit.ac.ma).

Adnane Addaim received his Master's diploma in 2001 and his Ph.D. degree in 2008, both in satellite communication from Mohammadia School of Engineers (EMI), Morocco. From 2002 to 2003, he was employed at SIEMENS AG as an engineer responsible for implementing of the supervision network of the Meditelecom GSM Network in Morocco. From 2010 to 2020, he was a professor at ENSA Engineering School in Kenitra, Morocco. He is working as a Professor at the EMI Engineering School in Rabat, Morocco. His current research interests include signal processing, wireless communication networks, and satellite communication systems (E-mail: adnane.addaim@uit.ac.ma).

Abdessalam Ait Madi was born in Morocco. He received a degree in teaching engineering in electronics from the ENSET of Mohammedia. He received the Master's and Ph.D. degrees at Faculty of Sciences and Technologies from the Sidi Mohamed Ben Abdellah University of Fez in Morocco. He received the Habilitation degree from the Faculty of Sciences at Ibn Tofail University. He is an Associate Professor at the National School of Applied Sciences of Ibn Tofail University in Kenitra, Morocco. His current research interests include information theory, channel coding, embedded systems, and IoT technologies, and renewable energy (E-mail: abdessalam.aitmadi@uit.ac.ma).