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Article

Intelligent vital sign alerts based on context awareness

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Abstract: Within the framework of this research, a system that integrates IoT (Internet of Things) technology and a contextual awareness model has been developed. The purpose of the system is to collect vital signs thanks to healthypi and generate intelligent alerts avoiding false positives to medical staff, additional manage and process critical information in the clinical environment, covering aspects such as patient data, treatments, medications, vital signs, as well as information related to doctors, nurses, locations and sensors used for monitoring vital signs, among others.

Keywords: ***Context Awareness, Ontology, Healthcare Technology, IoT*.**

1. Introduction

As technology advances, it is essential that everyone has access to quality healthcare facilities equipped with essential technological tools to enhance quality of life, no matter the time or place. Primary healthcare institutions must be well-integrated with specialized facilities to ensure prompt and effective care. Although decentralization of healthcare can be accomplished through administrative actions, technological solutions are also necessary. Information and Communication Technologies (ICT) play a key role in this regard, as they enable hospitals and inpatient care facilities to leverage tools such as artificial intelligence (AI), Internet of Things (IoT), and contextual awareness. These technologies enhance healthcare services for patients with a variety of conditions [1].

Contextual awareness allows systems to gather data about their surroundings and make informed decisions based on that data. This technology has a wide range of applications, including machine learning, content delivery, access and identity management, and the development of context-aware environments [2].

In the health sector it is important the interaction of all connected physical and logical systems, currently it is customary to give simple commands to these systems, but current researchers seek to develop new forms of interactions, in the case of the IoT world is looking for ways for these systems are aware of what is happening, and intelligent decisions are made

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through contextual awareness [3]. These technologies are used with the aim of gathering information about the environment in real time and using it to improve the quality of medical care, this allows an improvement in accuracy, efficiency and personalization in patient care by enabling much more accurate and on-the-spot decision making[4]Healthcare systems need to integrate contextual awareness computing, not only to implement new tools but to define a new kind of interaction between users and patients with the environment, providing autonomy and reasoning capacity to the system.

This paper highlights the critical role of contextual awareness in healthcare and its impact on improving patient care through the integration of technologies like sensor networks. Contextual awareness enables these sensor networks to understand their surroundings, leading to the generation of intelligent alerts.

The primary goal is to minimize unnecessary travel for medical staff. By harnessing real-time information collected by the sensor network, this application of contextual awareness aims to streamline medical response and care. This approach enhances precision and efficiency in the patient care process and supports the healthcare system's autonomy and decision-making capabilities.

2. Motivation

By introducing an intelligent alert system that adapts to patients' contexts, healthcare providers can achieve more precise data collection through targeted monitoring. The rapid advancement of IoT technology is revolutionizing various aspects of daily life, particularly within hospital environments where patients are experiencing critical conditions. Continuous monitoring by medical professionals is vital in these settings. In this context, the integration of intelligent alerts and detailed monitoring enabled by IoT technology becomes a pivotal solution for enhancing the quality and efficiency of medical care, particularly in emergency situations in hospital settings [5].

In the medical field, contextual awareness in intelligent alerts for patients' vital signs is essential for enhancing care and managing medical emergencies. Modern emergency medicine can trace its origins to World War I, when military medical teams recognized the critical need for speed and organization in treating wounded soldiers. This experience led to the creation of the triage system and the broader concept of emergency care. [6].

This project offers a chance to integrate IoT technology into healthcare, thereby enhancing the quality and efficiency of care in critical hospital situations. This goes beyond a technical innovation; it is a concrete commitment to the ongoing improvement of emergency medical care.

By enabling medical professionals to receive real-time, contextualized alerts and vital signs data, this project expands the scope of traditional medical practice. It serves as a guiding light for change, leading to quicker, more precise, and more effective care.

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3. Related Works

A bibliometric analysis was conducted across various databases, including Scopus, Embase, IEEE, and ScienceDirect. The research was structured around three thematic axes, as illustrated in the table below.

TABLE 1. INFORMATION ON THEMATIC AXES

Primary shaft	Characteristics	Search parameters	Proposed equation
	Data collection	context awareness	
Context	Data analysis	medicine	"Context awareness" OR "medicine" OR
awareness	Decision-making	internet of things	"internet of things"
	Machine learning		
	Interoperability	Semantic representation	
Semantic	Accessibility	Medicine	"Semantic representation" AND "medicine"
representation	Reuse	Internet of things	AND "internet of things"
	Interpretation		
	Continuous Measurement	monitoring	
Medical	Precision	medicine	"monitoring" AND "medicine" AND
monitoring	Alerts	internet of things	"internet of things" AND "heart rate"
	Reliability	heart rate	

A five-year analysis period was defined, spanning from 2018 to 2023. VOSviewer software will be utilized to conduct a bibliometric analysis [7], identifying the co-occurrence of keywords and their interrelations. A network map featuring 7 clusters was created, as illustrated in the image below from VOSviewer.

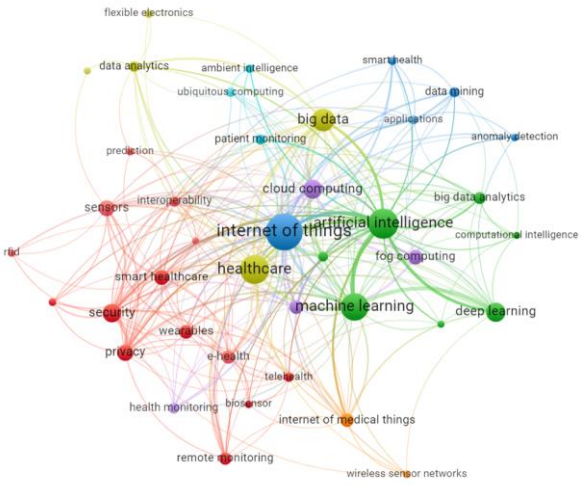

Figure 1. Network Map

After conducting a literature review using VOSviewer, it is clear that numerous studies have been carried out in the field of interest. Network visualization has identified key

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thematic areas and their interconnections, including the Internet of Things, healthcare, artificial intelligence, machine learning, big data, cloud computing, security, privacy, deep learning, fog computing, sensors, contextual awareness, and more. Additionally, a trend has been observed towards the adoption of specific research methodologies and techniques. Overall, this analysis offers a comprehensive overview of the field and can help pinpoint potential areas for future research.

Xianli Zhang and colleagues conducted research that leveraged contextual awareness and attention mechanisms to model the relationships between inputs and outputs in electronic health records (EHRs). The study introduced a model based on two self-attention modules: one focusing on context-aware information and the other on time-aware representation. Furthermore, the model demonstrated interpretability, enhancing its reliability as a tool for supporting clinical decision-making [8].

The need for efficient, real-time monitoring of patient health and has led to the development of innovative solutions. A context-aware IoT-based wearable smart health system presents itself as a promising solution in this area. Leveraging the portability and economy of electronic sensors, a system is able to track patients in their daily routines. A multipurpose design, low cost and high quality, makes it an essential tool for monitoring the health of patients with diseases. In addition, using Raspberry-Pi and HealthyPi, and the implementation of a logic system, it allows to accurately determine the physical and health status of the individual. The results obtained evidence its ability to identify anomalies in health status and accurately detect the mode of physical movement, which reinforces its relevance and potential in the field of health [9].

Li and Xiao developed a public health crisis early warning system grounded in contextual awareness. The system gathers situational data from public spaces using sensors, and it integrates and analyzes this information alongside real-time health data and networked public opinion data to deliver intelligent early warning services. This approach supports epidemic prevention and control efforts.

The research explores four key forms of crisis early warning: direct, qualitative, quantitative, and long-term warnings. Additionally, it emphasizes the significant ethical challenges involved and the need for ethical standards and guidelines when applying fusion technology to public health crisis early warning. [10]

Taiwo & Ezugwu Describe a remote patient monitoring system designed to support medical care during COVID-19 quarantine. The system uses the Internet of Things (IoT) to monitor patient health and transmit the data to healthcare providers remotely. The architecture is based on a series of wearable devices, including a temperature sensor, pulse oximeter, and blood pressure monitor, which connect to a mobile device via Bluetooth. Health data are collected on the mobile device and transmitted via a secure Internet connection to a server in the cloud. [11]

Mostafa et al, conducted research describing the design of a multi-agent system to monitor the movement of elderly people in their home. This system uses multiple sensors and

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actuators and employs an adjustable autonomy approach to adapt to the user's needs. This approach is based on fuzzy logic, which allows establishing fuzzy rules and relationships between variables to make decisions. The system has three levels of autonomy: low, medium, and high. At the low level, the system monitors the user's movement and provides tracking information. At the medium level, it can alert a caregiver if it detects abnormal behavior. At the high level, the system can take preventive measures, such as turning off a stove if it detects that it has been left on. In addition, the system uses a multi-agent approach, where each agent oversees a specific area of the home, and they communicate with each other to coordinate monitoring and response actions. This system was tested in a laboratory environment and proved to be effective in detecting and preventing risky situations. [12]

Quinde et al, presents an approach called ADAPT, which is concerned with developing personalized and contextually aware solutions for asthma management. This approach incorporates context dimensions that enable the customization of preventive and reactive features of an asthma management solution, considering both health and non-health characteristics of the patient. In addition, the approach uses case-based reasoning and a virtual assistant to support asthma management. The paper describes the methodology used in the development of ADAPT and presents a validation of the approach with real users. It also discusses the use of case-based reasoning in healthcare in general and presents a case study of a context-aware virtual assistant for personalized asthma management. In addition to this, other studies related to indoor localization are discussed, and a validation questionnaire for the ADAPT virtual assistant is included. [13]

Yan & Wong conducted work with contextual awareness, applied in the field of biomedical event detection using deep learning techniques. The authors propose a neural network model that focuses on understanding the context in which biomedical events occur. This implies that the model not only identifies events per se, but also considers the context and relationships between different elements in the biomedical text. "Contextual awareness" helps the model understand the relevance and meaning of an event in terms of its environment, which improves the accuracy and efficiency of biomedical event detection. This approach is especially useful in biomedical text mining, where accurate understanding of context is essential for extracting relevant information from medical and scientific documents. [14]

Saranya and Fatima Propose a method to improve health data prediction using IoT and machine learning techniques. The method includes preprocessing, data fusion, feature extraction, feature selection, and classification using an ensemble-based machine learning model, which achieves high accuracy in health data prediction. It also reviews recent techniques for IoT-based healthcare applications and suggests areas for future research. He discusses various methods and techniques for using IoT devices to collect and analyze patient health data where he highlights the importance of data fusion and machine learning algorithms in improving the accuracy and reliability of health predictions.

The proposed method includes a dual filtering methodology for data preprocessing, an improved dynamic Bayesian network for inference, improved principal component analysis

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for feature extraction, and an ensemble-based machine learning model for prediction. On the other hand, it discusses the limitations of current methods and suggests areas for future research. The use of improved context-aware data fusion (ICDF) models and extended random forest ensemble (ERFE) models for analyzing patient health data in IoT is discussed. The ICDF model uses a dynamic Bayesian network (DBN) and a hidden Markov model (HMM) to filter and analyze data, while the ERFE model uses random forest algorithms to classify data. The use of particle filters and Laplace correction in the ICDF model is considered, as well as the parameters and processes involved in the construction of an HMM. [15]

4. Materials and Methods

To accomplish the objectives of this research, 5 phases were conducted, as described below:

Phase 1: We conducted a comprehensive review of the existing literature to gain an up-to-date understanding of research related to contextual awareness systems applied in clinical settings. This analysis allowed us to identify major advances and gaps in the field, which in turn helped us to define the system design more precisely.

Phase 2: We conducted an analysis of available technologies in the field of contextual awareness that can be used in the implementation of our solution. This included the evaluation of different devices and applications available for monitoring patients' vital signs, as well as communication and localization systems. This phase allowed us to determine the suitability of these technologies in terms of their advantages and disadvantages, with the aim of selecting the most suitable for our project.

Phase 3: We meticulously implemented the methodology in the development of the system and configured the necessary devices to carry out patient monitoring in clinical settings. This stage is essential to ensure that the system works effectively and accurately.

Phase 4: Training of the I Model, in this phase, we focus on training the artificial intelligence (AI) model that will be an integral part of our monitoring system in clinical settings. Key stages of this phase include:

4.1 Data Collection: We collect a set of relevant and contextually meaningful clinical data that will serve as the training base for our AI model. This data may include medical records, vital sign readings, patient histories, and other relevant data.

4.2 Data Preprocessing: We perform a rigorous data cleaning and preprocessing process to ensure data quality and consistency. This may include outlier removal, data normalization, and coding of relevant features.

4.3 Model Selection: We carefully select the type of AI model that best fits our patient monitoring problem in clinical settings. This may include neural networks, deep learning algorithms, or traditional machine learning models, depending on the nature of the data and the goals of the project.

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4.4 Model Training: We use the preprocessed data to train the AI model. During this stage, we adjust the hyperparameters and evaluate the model performance through relevant metrics, such as accuracy, sensitivity, and specificity.

4.5 Validation and Tuning: We validate the trained model using independent data to ensure that it generalizes effectively in real clinical settings. If necessary, we adjust the model and repeat the training process until the desired results are achieved.

4.6 System Integration: Once the AI model has been successfully trained and validated, we integrate it into our real-time monitoring system. We ensure that the model works consistently and adapts to clinical needs.

Phase 5: We carried out the implementation, deployment and execution of the real-time monitoring system designed, both in terms of hardware and software, for use in hospital environments. During this phase, we evaluate the effectiveness of the implemented warning and control systems and study the interaction of the system with the different users in the clinical environment. This allows us to measure the effectiveness of the system and its usefulness for all users involved.

5. Context-Aware Alerting Architecture

In the development of the intelligent alert architecture, three essential layers have been implemented and designed. The first of these is the backend, which houses the core logic of the solution. Contextual awareness has been achieved through artificial intelligence algorithms, integrated with Express, a JavaScript framework. The second component corresponds to the frontend, developed with React. Finally, the IoT sensor network uses Healthypi configured with Python. The schematic provides a clear visualization of the communication between these crucial elements.

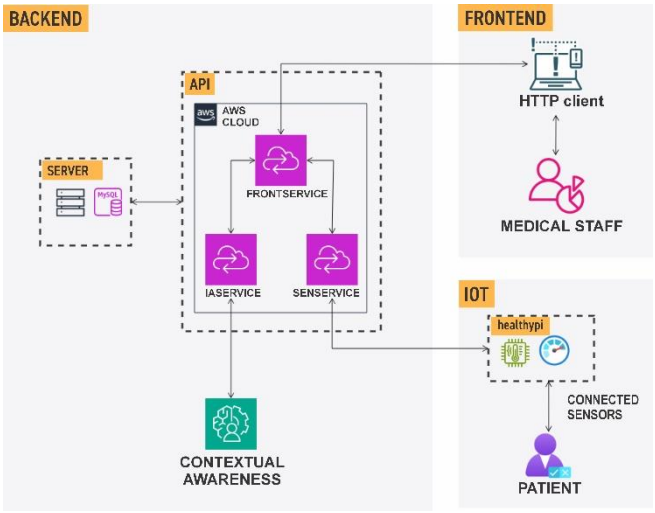

Figure 2. Architecture Diagram

Sequence diagram.

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The sequence diagram is important to understand alert management. This diagram represents the interaction between several key elements, including devices, sensors, patients, machine learning algorithms and the process of sending notifications. This relationship is visualized in detail in the illustration below.

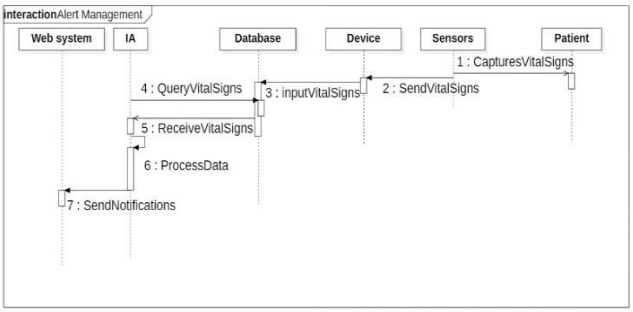

Figure 3. Sequence diagram.

Contextual awareness in the capture of vital signs.

For the development of the AI algorithm capable of context understanding it is necessary to perform, Context acquisition, context modeling, and context reasoning.

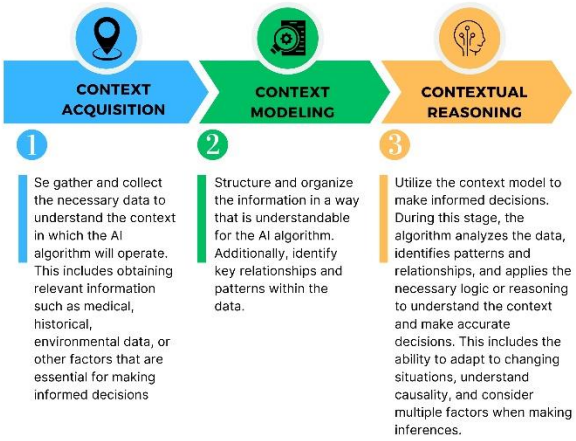

Figure 4. Contextual Awareness Methodology

6. Ontological Model

The ontology was developed by the authors, for its modeling the NeOn methodology applied in [15] was used, the proposed system consists of classes and subclasses that identify the dimensions of the context of management and processing of critical information in the clinical environment. A brief description of each of them is presented below:

Cardiovascular Unit: Describes the information of the services provided in the cardiovascular unit.

Clinical Laboratory: Describes information on clinical laboratory services, such as the type of study performed.

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Device: Describes the devices, both software and hardware, in context.

Diagnosis: Describes the diagnostic information given to patients, as well as the studies applied to arrive at the diagnosis and the Medicals involved.

Diagnostic Imaging: Describes the information of the studies performed by means of diagnostic images.

Diagnostic studies with sensors: Describe the information of the sensors used both for monitoring vital signs and for studies that require it.

Emergency: Describes the types of emergency services offered, the attending Medicals and the patients admitted.

Environment: Describes information about the environment for people, Medicals, and patients.

Hemodialysis: Describes information about the type of hemodialysis provided.

Hemodynamics: Describes information about the hemodynamics rooms, attending Medicals and inpatients.

Hospitalization: Describes information on the location of hospitalized patients, attending Medicals and inpatients.

ICU: Describes the information of the Intensive Care Unit, the attending Medicals, and the admitted patients.

Interface: Describes the interface of the sensors and the studies that are applied.

Localization: Describes the context location of all the elements that compose the model.

Person: Describes the information of the persons involved in the context, such as Medicals (those who attend and direct the services provided in the clinical setting) and patients (those who receive the medical service in the clinical setting).

Medical Specialties: Describes the type of specialty that the Medical has.

Net: Describes the characteristics of the network connectivity of the devices owned by the actors (Medicals and patients) involved in the process.

Outpatient Consultation: Describes the information of the services provided in the outpatient consultation.

Pharmaceutical Service: Describes information on the types of medications, prescribing Medicals, and patients receiving the service.

Physical Therapy: Describes information on physical therapy services provided in the clinical setting, referring Medicals, attending Medicals, and patients receiving the service.

Preference: Describes the preferences of the actors (Medicals and patients) involved in the process.

Profile: Describes the profile of the actors (Medicals and patients) involved in the process.

Surgical Services: Describes the information on the types of surgical services provided.

Time: Describes the notion of time in the context of the clinical setting.

Ontology in Protégé

For ontology modeling, the Protégé application (https://protege.stanford.edu/), developed at Stanford University, has been used. The version used was 5.6.1, downloaded from the site https://protege.stanford.edu/products.phpthe. After the application configuration process, the

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classes were created, as well as the object properties, data properties and individual by classes.

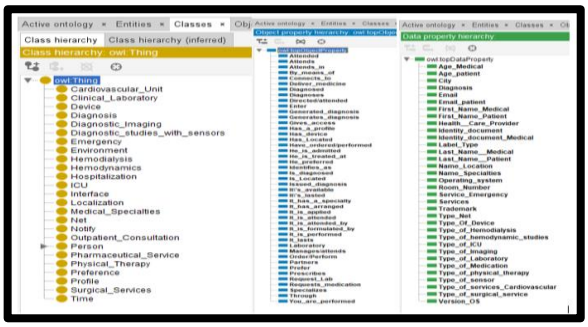

Figure 5. Class, Object Property and Data Property. Obtained from Protégé software.

Figure 5 shows the classes, Object Property and Data Property of the designed model.

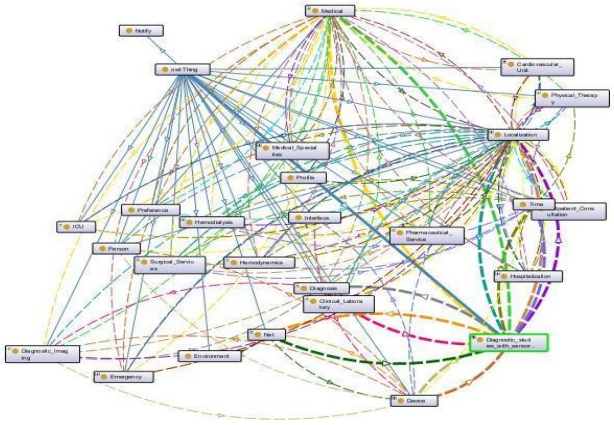

Figure 6. Ontology in Protégé. Obtained from Protégé software.

Using the Ontograf tab, Figure 6 shows the ontology with its respective relationships; each of the dotted lines of different colors represents the relationships between the concepts of the ontology.

Situations or Behaviors for a Clinical Setting Supported by Contextual Awareness

The situations or behaviors are as follows:

1. A patient A is seen by a Medical X.
2. A Medical sees different patient.
3. The system issues alarms to patients on the results of their studies to their devices.
4. A Medical with a specialty diagnoses patients based on laboratory tests.
5. A doctor with a specialty diagnoses patients based on diagnostic imaging results.
6. A Medical with a specialty diagnoses patients based on sensor test results.
7. A Medical manages an ICU.
8. A patient requires medication.
9. A Medical prescribes medications to his patients.
10. A patient requires monitoring of vital signs with sensors.

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11. A doctor orders different tests for his patients and notifies them of the results.
12. A patient is hospitalized.
13. A patient is admitted to ICU.
14. A Medical sees patient on an outpatient basis.
15. A patient attended by a Medical is admitted to the hemodynamics room.
16. A patient seen by a Medical requires admission to a cardiovascular unit.
17. The system helps patients to select their Medicals.
18. A patient has a device that allows him to measure his vital signs.
19. A Medical treat a patient who requires hemodialysis.
20. A patient prefers to be seen by a doctor.
21. A person (doctor or patient) has a location.
22. A Medical sees a patient who requires surgical service.
23. A patient who has undergone different diagnostic studies uses his device to view his results by scanning QR code and/or NFC tags.

Ontology Evaluation by Means of SWRL Rules

The ontology is evaluated by means of established rules, which are described in natural language and SWRL, which allows expressing OWL concepts in combination with RuleML [16], [17].

For this evaluation, five (5) of the situations described above are considered.

Situation 1: 1. A patient A is seen by a Medical X.

Rule 1: Patient 0003 is seen by a doctor.

Patients(?pac), Attended(pac0003, ?med), Medical(?med) -> Notify(?med)

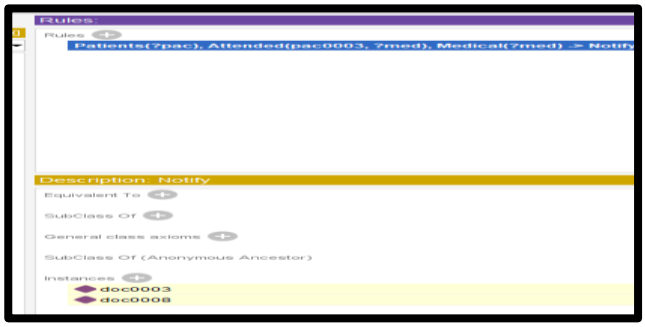

Figure 7. Diagram sutuation 1. Obtained from Protégé software.

Figure 7 shows that patient 0003 is seen by Medicals doc0003 and doc0006.

Situation 2: A Medical sees different patient.

Rule 2: A doctor doc0003 sees different patients.

Medical (?med), Patients(?pac), Attends(doc0003, ?pac) ->Notify(?pac)

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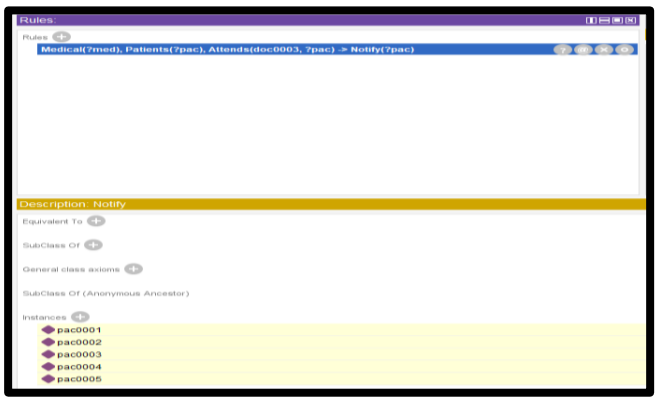

Figure 8. Diagram situation 2. Obtained from Protégé software.

Doctor doc0003 sees patients pac0001, pac0002, pac0003, pac0004 and pac0005.

Si***tuation 3***: A doctor orders different tests for his patients and notifies them of the results.

Rule 3: Dr. doc0003 orders different tests for his patients and notifies them of their results.

Medical (?med), Diagnostic_studies_with_sensors(?sensor) Have_ordered/performed(doc0003, ?sensor) -> Notify(?sensor)

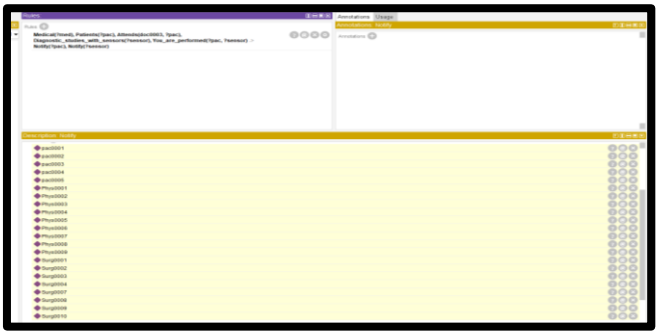

Figure 9. Diagram situation 3. Obtained from Protégé software.

The figure shows the different studies that Dr. doc0003 ordered for his patients.

Situation 4: A doctor with a specialty attends to a patient who is hospitalized and undergoes different studies.

Rule 4: Doctor doc0002 with a specialty attends to a patient who is hospitalized and undergoes different studies.

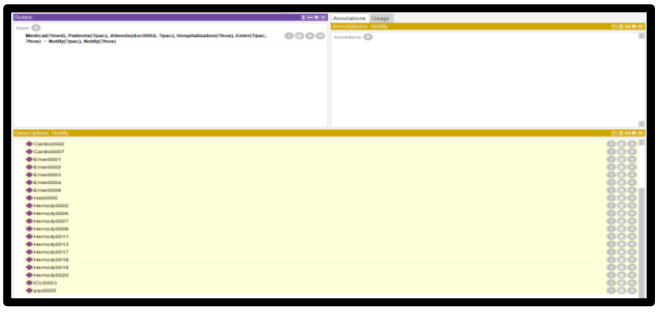

Figure 10. Diagram situation 4. Obtained from Protégé software.

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As shown in figure 10, doctor doc0002 attends patient pac0005, who is hospitalized in room hab0005, and performs different medical studies and refers him to the adult ICU.

Situation 5: A patient who has undergone different diagnostic studies uses his device to view his results by scanning QR code and/or NFC tags.

Rule 5: A patient pac0003 who has had different diagnostic studies performed on him uses his device to view his results by scanning QR code and/or NFC tags.

Diagnostic_studies_with_sensors(?sensornfc_QRcode), Patients(?pac), You_are_performed(?sensornfc_QRcode, ?pac0003), Device(?devnfc_QRcode), By_means_of(?devnfc_QRcode, ?pac0003) -> Notify(?sensornfc_QRcode)

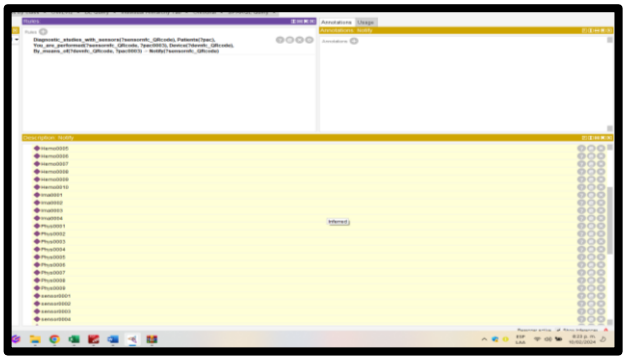

Figure 11. Diagram situation 5. Obtained from Protégé software.

Figure 11 shows all the studies that were performed on patient pac0003 and that can be read by the patient using QR codes and NFC tags.

In the frontend layer, the alerts generated by the contextual awareness can be visualized, where the necessary configurations for the patient's location in the clinical environment, the medical history record and the real-time visualization of vital signs are recorded.

The following figure shows the alerts and vital signs.

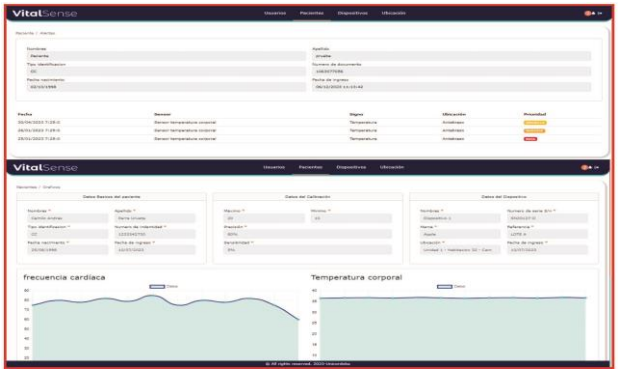

Figure 12. Display of alerts and vital signs

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7. Conclusions

This paper presents a designed ontological model that will be consumed by a designed architecture capable of extracting data from the model and generating alerts. These alerts play a key role in clinical decision making in the context of patient care.

Similarly, a system is designed that collects and processes critical data from the medical environment and, through semantic intelligence and contextual awareness, provides relevant information that enriches and supports informed clinical decision making. This innovation has the potential to significantly improve the quality of medical care and the efficiency of decision making.

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