Improving Health Disabled People through Smart Wheelchair based on Fuzzy Ontology

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***Abstract*—People with disabilities represent a large segment of society. They suffer from many disabilities that prevent them from carrying out normal daily activities, including monitoring their health status. To improve the health monitoring of people with disabilities, this study proposes an edge-cloud-based IoT architecture that uses the smart wheelchair as an edge for real-time health monitoring and a cloud to provide more diagnosis in complicated cases that require complex data processing. We proposed a system based on this architecture that uses the Semantic Web to overcome data heterogeneity from different sources and ensure interoperability. The system also incorporates fuzzy logic to improve diagnostic accuracy by dealing with imprecision and uncertainty in knowledge.**

***Index Terms*—smart wheelchair, health monitoring, people with disabilities, Semantic Web of Things, interoperability, fuzzy logic .**

I. INTRODUCTION

The spread of wars, the multitude of accidents, the diversification of diseases, and the increase in the number of older people globally have generated a growing number of people with disabilities(PWDs). According to the World Health Organization [1]. it is estimated that more than one billion people live with some form of disability and suffer in the performance of their daily activities; they always need the help of others. Assistive technology (AT) reduces these needs and allows them to perform tasks they could not do before, adding value to the economy and society. The wheelchair is one of those technologies that can help some people, especially those with mobility difficulties [2]. It helps them overcome the lack of movement and gives them a chance to do some activities. Health monitoring is considered a necessary activity as most of them suffer from chronic diseases and have difficulties getting the required health care. However, patients have difficulties in going to the hospital and seeing the doctor. The remote health monitoring system is proposed to avoid patients' travel, thus reducing the cost, saving effort, saving time, and ending the overcrowding of health clinics [3]. These systems use the Internet to enable the sharing of health data between clinics. However, these systems need technology to provide real-time health monitoring. With the advent of the new technology called the "Internet of Things" [4], new possibilities and capabilities are offered for different fields. It provides objects with a set of sensors, actuators, and software, allowing them to connect to the Internet and exchange information. The wheelchair can integrate this technology and benefit from its advantages. It becomes more intelligent by collecting data about its patient or its environment to allow decision making. It offers people with disabilities new services and capabilities to make their lives easier and safer. The smart wheelchair can also provide continuous health monitoring by sharing vital signs collected by sensors with doctors and hospitals. Despite this, the smart wheelchair integrates devices from different products, uses various platforms, communicates with various protocols, and employs various architectures. This creates heterogeneous data and leads to a lack of interoperability. According to the McKinsey report, areas of IoT with a lack of interoperability between different applications fail to capture 40% of the total potential value [5].

The Semantic Web integration with the IoT addresses interoperability challenges and greatly enhances data exchange, i.e., semantic interoperability [6]. The Semantic Web provides the IoT domain with standard semantic technologies and uses an explicit specification of a shared conceptualization; specifically, the ontology allows information to be represented in a machine-readable manner and facilitates sharing a common understanding of information. Nevertheless, the use of classical ontology limits the management of information imprecision, which requires improvement. Fuzzy logic is the appropriate model to manage imprecision and uncertainty. It supports the combination with ontology to solve this problem. This paper proposes an IoT architecture that facilitates real-time health data collection and processing using a smart wheelchair. The architecture also provides people with disabilities with a comprehensive diagnosis for their complicated situations by leveraging all available resources. We also propose a system that processes raw data distinguished by heterogeneity and uncertainty by integrating Semantic Web and fuzzy logic to use this architecture. The system allows us to make accurate decisions about the health status of people with disabilities and infer new knowledge.

The rest of this paper is structured as follows: after the introduction in Section 2, we present the state of the art on PWDs and their needs, the concept of the Internet of Things and its evolution to the Semantic Web of Things, a standard classical

IoT domain ontology, and related work. Section 3 describes an IoT architecture. In section 4, the conceptual architecture with its acquisition and semantic processing layers, including modules, alongside an application layer. Section 5 details the design of our fuzzy ontology, and Section 6 presents how the system provides appropriate services. In Section 7, we propose the implementation and evaluation of the proposed system. Finally, a conclusion containing future work is presented.

II. STATE OF THE ART

A. The need to monitor the health of people with disabilities

Health surveillance is a critical area related to diagnosing and protecting people's lives from the disease. It can provide important assistance to people with disabilities by addressing their health needs. It can also meet their basic needs, such as determining the appropriate foods, medications, and activities that best suit their health status. This health surveillance is based on measuring data that diagnose and report on the health status of patients. A vital sign is an essential piece of data about the health of patients. It can be collected using medical devices. Systems use it to analyze a patient's health status, detect disease and quickly predict health risks. Vital signs are used by a scoring system called The Modified Early Warning Scoring (MEWS) to rank patients according to health risks. The system used to calculate its score is used to help in hospitals. It is based on five vital signs: heart rate, respiratory rate, systolic blood pressure, body temperature, and oxygen saturation. This health monitoring could be improved and provided in real-time with new IoT technologies integrated with assistive devices for people with disabilities such as wheelchairs.

B. Smart wheelchair

The wheelchair presents an essential means for people with disabilities to overcome their mobility difficulties. The intelligent wheelchair is the result of its integration with the Internet of Things. It facilitates and reduces the effort of control, ensures safety throughout the movement, and provides new services that were previously considered impossible. One such service is the ability to measure the vital signs of the user's body. The smart wheelchair (SW) allows contact, data sharing with doctors and hospitals for better diagnosis and provides continuous monitoring of the health of people with disabilities [7]. The smart wheelchair is based on the Internet of things domains that deal with heterogeneous data and interoperability challenges. To address these challenges, researchers suggest using the semantic web.

C. Semantic web of things

The Semantic Web of things is a recent research field aiming to integrate the Internet of things with the Semantic Web to solve heterogeneity and interoperability problems [8]. The Semantic Web uses an ontology that allows a machine to represent domain knowledge formally. However, the numerous definitions of ontologies limit their flexibility for sharing and reuse. The need to define standard ontologies motivated the World Wide Web Consortium (W3C) community to define the Semantic Sensor Network (SSN) ontology. This ontology describes sensors, sensing methods, observations, and measurement processes [9]. OneM2M proposes another standard architecture based on an ontology of common services such as entity, application, and normal service functions [10]. The Smart Appliance REFerence ontology (SAREF) proposed for the smart appliance domain became a standard ontology [11]. It has structure-based blocks (modules) that allow the reuse of some of its parts. The SAREF ontology has been extended to other domains such as energy, environment, and transportation. It also allows alignment with other ontologies, such as mapping to the oneM2M core ontology. However, these ontologies have a limitation in representing vague and imprecise data.

D. Fuzzy Logic

In 1965, Zadeh introduced a new logic called "fuzzy logic", an extension of Boolean logic based on fuzzy set theory [12]. A fuzzy set T is defined by a membership function μ_T that expresses each element x of the universe of discourse X by a membership value interval [0, 1]. The fuzzy set T can be represented by flow: T = (x, μ_T(x)) ; x$\in$X, $\mu_T(x) \in [0, 1]$. Fuzzy logic simulates human reasoning in dealing with uncertain and imprecise data to make decisions. For example, a diagnostic doctor takes on the task of measuring blood pressure using terms such as "high", "moderate", or "low" to decide the patient's condition.

E. Related Work

The idea of the smart wheelchair has been researched since 1980 to enable people with disabilities to be independent in their lives [13]. Internet of Things technologies have motivated and directed many works to propose and realize this idea. In the most of these works, the researchers focus on the use of the internet of things to propose approaches for controlling the movement of the smart wheelchair via the internet [14]. They added other features such as voice gestures [15], and touch screen control via the internet. In other works, such as the healthcare field is concerned by saving lives, especially those with illnesses or disabilities. Researchers use smart wheelchairs to collect health data, which can contribute to continuous health monitoring [16]. The authors in [17] proposed a system architecture that enables health care monitoring for disabled and older people based on wheelchairs, wireless body sensor networks (WBSN), and home mobile. To detect any cardiovascular abnormality of a patient, the researchers proposed a smart wheelchair that sends the vital signs to the cloud and informs the concerned person through a message [7]. However, the latency limitations of the cloud can decrease the efficiency of the system. Thus, providing an architecture that ensures real-time diagnosis is essential. The use of smart wheelchairs based on various patient health monitoring devices generates heterogeneous data that needs to be processed. To deal with the problem of heterogeneous health data, researchers have used the Semantic

Web, particularly its backbone, the ontology. However, classical ontology limits the representation of imprecision and data inaccuracy, a fundamental problem in real-world health care. Fuzzy ontology incorporates the concept of fuzzy logic in ontology development to overcome this limitation [18]. The authors in [19] used the fuzzy ontology to propose a system that recommends appropriate food and medication for chronic (diabetic) patients. However, the system is based on an ontology specified for the diabetic disease, which cannot be applied to other diseases. The authors in [20]. proposed a fuzzy ontology system that integrates semantic interoperability in distributed electronic health records (EHRs). The system creates for each input source a standard ontology and merges these ontologies to create a unified ontology. The processing of the proposed system is oriented via complex data. It requires a cloud level which is due to the inability to provide a real-time diagnosis. To perform health monitoring for people with disabilities, we need an IoT architecture that provides real-time health and diagnostic services and allows for full diagnosis if needed. We also need a system that can handle heterogeneous data using a standard ontology to facilitate data reuse and sharing. The system can represent fuzzy and imprecise data to make accurate decisions.

III. Proposed architecture

Real-time health monitoring is considered vital for protecting the lives of people with disabilities. Exchanging health data via the Internet increases latency due to network traffic congestion. Using the smart wheelchair as a device brings the processing task closer to the data sources and provides a real-time result. Although the smart wheelchair offers many cost and time advantages, its storage and processing capabilities are limited, resulting in poor decision accuracy due to a lack of available data. On the other hand, the diagnostic process requires a more detailed medical profile, patient history, lab results, and disease information in complicated health cases. Cloud computing is a new technology that provides servers, storage, platforms, and software to users through the Internet. However, this technology has lost its advantages for many devices that generate and exchange a large amount of data using a cloud. The architecture described in ”Fig. 1” combines the cloud with a smart wheelchair. It overcomes the limitations of both technologies and benefits from their advantages by ensuring the collection, exchange, and processing of health data at the smart wheelchair and using the cloud to provide more accurate diagnosis in case of health complications.

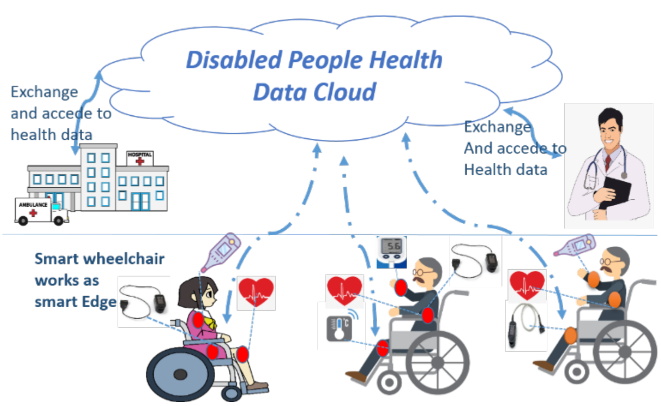

Fig. 1. Proposed architecture

IV. Proposed System

The proposed system shown in ”Fig. 2” consists of the sensing layer, the semantic processing layer, and the application layer. Each of these layers is loaded by a set of modules, its tasks being necessary for the others.

A. Sensing layer

It provides the system with patient health data from various devices embedded in the smart wheelchair or through the Internet.

B. Semantic processing

This layer is the core of the proposed system. It is responsible for interpreting and understanding the data collected by the detection layer to provide accurate results. The layer is also composed of a set of modules that are detailed in the following.

1) Semantic knowledge base: Includes a set of modules to represent fuzzy knowledge and to enrich it to deduce new knowledge.

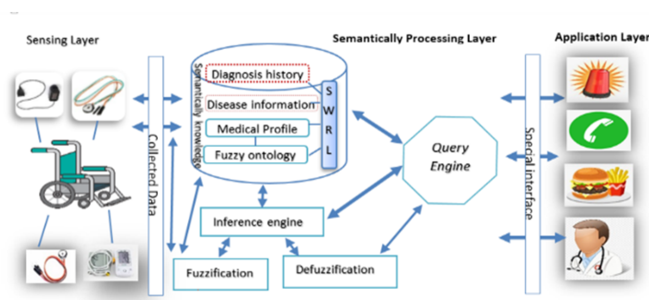

Fig. 2. The proposed IoT-based health monitoring system for people with disabilities.

a) Fuzzy ontology: Fuzzy ontology is an extension of classical ontology that overcomes its limitations to represent fuzzy and uncertain knowledge.

b) Medical profile: It is a file containing information about a patient that helps the system make the right decision and diagnose diseases that require certain features related to parents, age, blood, etc.

c) SWRL: It uses the knowledge base, including ontology, to derive new knowledge that helps a system make appropriate health decisions.

2) Fuzzification: This process converts sensor data values into fuzzy variables by applying a membership function to any variable in the set.

3) Inference engine: It uses explicit knowledge representing and rules to infer implicit knowledge about the patient's health status and make accurate decisions accordingly. The system's core applies a set of "if-then" rules that convert fuzzy input variables into fuzzy output variables.

4) Defuzzification : This is the term used for the reverse process of fuzzification, which turns a fuzzy output into a crisp value.

5) Query engine: It uses SPARQL queries, and the system can retrieve results and responses to user requests.

C. Applications layer

The layer provides the user with a user-friendly interface adapted to his type of disability and allows him to control or access the different services provided by the software. The applications layer allows the user to interact with the SW by displaying health recommendations or contacting other actors interested in the patient's health. The system must have an ontology that represents all data types and improves knowledge sharing for good decision accuracy.

V. ONTOLOGY OF HEALTH MONITORING FOR PEOPLE WITH DISABILITY

The objective of developing an ontology for HMD is to provide a formal representation of imprecise and vague knowledge of the healthcare and ease reasoning over it. The ontology will be a fuzzy ontology that supports classical ontology for its design and development.

A. Design classical health monitoring ontology for people with disability

Designing a classical ontology from scratch requires time and cost for its development process, and reusing existing ontologies can add quality to these ontologies through continuous improvement. For the IoT domain, there are many ontologies, some standard and some specific. Reusing existing standard ontologies, defined by an institute concerned with ontology development, can contribute to knowledge sharing between different domains, even if they are limited to representing a specific domain. To design our classical ontology that represents the health monitoring of people with disabilities through the support of the IoT domain, we choose to reuse a standard ontology defined by the ETSI (European Telecommunications Standards Institute) called SAREF ontology (Smart Appliance REFerence ontology). This ontology allows representing the IoT concept. It has a property that characterizes it uniquely, such as modularity that facilitates the reuse of its parts and extensibility that allows its extension to other IoT domains. For the design of our classical ontology, we take some concepts from the selected ontology that represent devices, measurements, and properties with their instances and relationships. As the representation of vital signs in the concept of this ontology is important, we define new concepts such as body temperature, heart rate, blood pressure, and SPO2 as a "property" concept. We also enrich the ontology with a new concept representing the condition of disabled people, such as type of disability, communication methods, and medical profile, which could include information about medication, age, height. To represent the fuzzy knowledge, the ontology must be converted into a fuzzy ontology.

B. Fuzzy health monitoring ontology for people with disability

The designed ontology is classical and has one main limitation: dealing with uncertainty and vague knowledge can lead to incorrect results and inappropriate decisions, which is unacceptable in the health domain. It is important to make the ontology more representative of reality and summarize human reasoning to describe detailed knowledge to overcome these drawbacks. We use fuzzy set theory and follow the most widely used IKARUS-Onto (Imprecise Knowledge Acquisition Representation and Use) methodology to develop fuzzy ontologies from classical ontologies. We study our classical ontology and determine the degree of fuzziness needed to define the fuzzy element. The fuzzy concepts that compose an instance represent the fuzzy set and the form's relations, data types, and axioms. In our classical ontology, vital sign concepts with a vague value need to be made fuzzy, and by using the ranges of each element, we can define new fuzzy concepts. The MEWS (Modified Early Warning Score) defines the value of this range. The "property" class allows defining the concepts of vital signs such as blood pressure, heart rate, oxygen saturation and others as its instances. To define these fuzzy variables, we transfer their range value to linguistic terms called fuzzy sets. For example, the vital sign heart rate has many ranges classified by MEWS. The range [95-110] is classified by a score of "1", which the fuzzy term *highHeartRate* can express. Using the same method, we define the fuzzy variables "heart rate" by a fuzzy set (*lowHeartRate, MediumHeartRate, highHeartRate*). Similarly, for each concept of blood pressure, body temperature, oxygen saturation, and according to MEWS classifications, we follow the same strategy to define its fuzzy sets.

The concept of the medical profile of people with disabilities includes various instances such as age, gender, disease, etc. It also requires the definition of new fuzzy sets related to its instances. It also requires the definition of new fuzzy sets related to its instances. For example, the fuzzy variable age may include a new fuzzy set such as "Kid" for age below 18 years, "Young" for age between 18 and 40 years, "Old" for age between [18, 40], and Very-Old for age above 60 years. Another important concept is *HealthStatus*, which refers to the health status of the patient after diagnosis. It should also be fuzzy by defining its fuzzy sets (*Normal, Abnormal, Risky*). In the formulation and validation of the fuzzy ontology steps, we use the protected-with owl plugin to create our fuzzy ontology described in "Fig. 3" in OWL format and check their consistency and completeness.

VI. PROVIDING HEALTH SERVICES TO PEOPLE WITH DISABILITY USING THE PROPOSED SYSTEM

Based on the data collected on a patient through smart wheelchair detection to provide correct health services, the

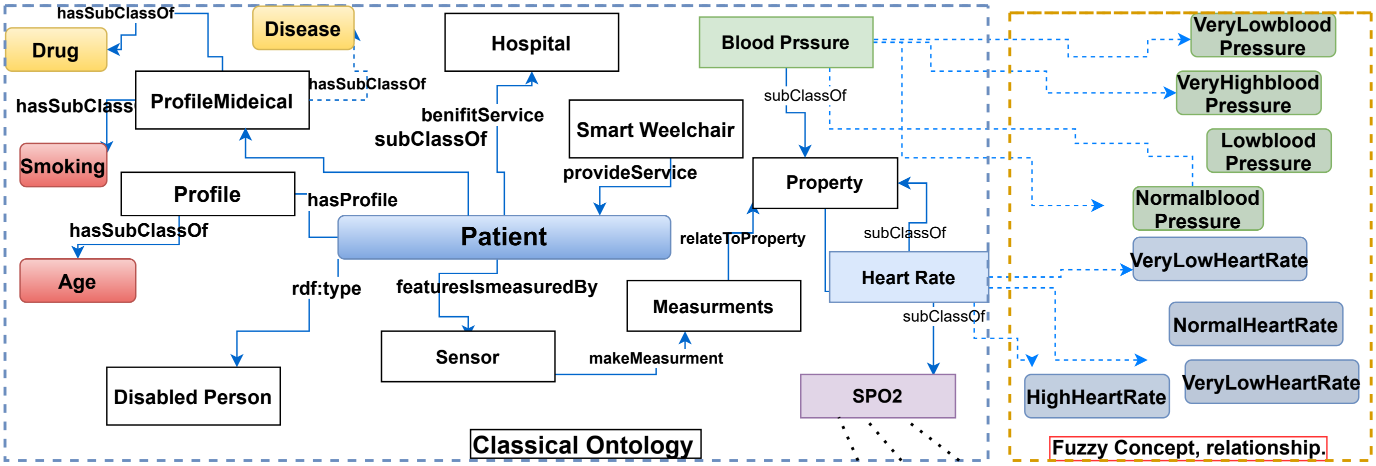

Fig. 3. Fuzzy Health Monitoring Ontology for People with Disability.

system performed various operations to process and exchange knowledge among its components to reach an accurate decision. Using a membership function that expresses the degree of fuzziness, the fuzzification module allows the system to convert the collected crisp values into fuzzy values. The fuzzification process results are transferred to semantic knowledge modules that consist of a fuzzy ontology that allows it to be represented with medical profile data and other formal data to enrich, share, and reuse this knowledge in the health domain. For example, the following SWRL rule calls the inference engine, which uses Mamdani's approach to determine the fuzzy output and infer the implicit knowledge that considers health services or recommendations.

Rule 1: Measuring vital signs collected on the patient's health using a smart wheelchair composed of sensors allowed the system to deduce that the patient's health condition is normal.

Patient(?p),SmartWheelChair(?SWC),HasSmartWheelChair (?P,?SWS),Sensor(?S),consistOf(?SWS,?S),featuresIsMeasure dBy(?P,?S),Measurement(?M),makeMeasurement(?S,?M), relatesToPropertyBloodPr(?M,?NormaBloodPr),greaterThan (?NormaBloodPr,95),lessThan(?NormalBloodPr,199), relatesToPropertyHeartRt(?M,NormalHeartR),greaterThan (?NormalHeartR,53) ,lessThan(?NormalHeartR,100), relatesToPropertySPO2(?M,NormalSPO2),greaterThan (?NormalSPO2,93),relatesToPropertyTempB(?M,NormalTe mpB),greaterThan(?NormalTempB,36),lessThan(?Normal TempB, 38) → hasHealthStatus(?p,Normal), displayMessage(?SWS,?p),Message (?your health is good).

Rule 2: The smart wheelchair provides a set of services to patients with an abnormal health condition. It allows him to contact the doctor and his family, drink his medicine, and send his data to the cloud for further verification.

Patient(?p),Measurement(?M),SmartWheelChair(?SWC) , relatesToPropertyBloodPr(?M,LowBlooodPr),lessThan(?LowBloodPr,100),greaterThan(?LowBlooodPr,80), relatesToPropertyHeartR(?M,LowHeaR),greaterThan (?LowHeaR,45),lessThan(?LowHeaR,60)relatesToPropertySPO2), (?M,LowSPO2),greaterThan(?LowSPO2,87),greaterThan (?LowSPO2,95),relatesToPropertyTempB(?M,NormalTemp), greaterThan(?NormalTemp,36),lessThan(?NormalTemp,38)→ hasHealthStatus(?p,Abnormal),Contact(?SWC,doctor), transferData(?SWC, ?DHPcloud).

Rule 3: The system deduces that the patient's condition is risky and needs to be rushed to the hospital by providing an ambulance. Further, the system transfers these data and results to the cloud for further diagnosis.

Patient(?p), Measurement(?M), SmartWheelChair(?SWC), relatesToBloodPr(?M,HighBloodPr), greaterThan(?HighBloodPr,185), relatesToHeartR(?M,VeryHighHeaR), greaterThan(?VeryHighHeaR,105), lessThan(?VeryHighHeaR,130), relatesToTempB(?M,HighTemp), greaterThan(?HighTemp,38), HealthStatus(?Risky), startAlarm(?SWC,?urgent), Contact(?SWC,?Hospital), transferData(?SWC, ?DHPcloud).

Using the query engine module to process SPARQL queries, the system responds to requests from the application layer that presents a patient request for a service or information of interest about his/her health. Here is example of SPARQL queries:

Q: determine the services provide to patient has a disease: *SELECT ?patient ?disease ?healthStatut ?services-Name WHERE {?patient HMD:hasdisease ?disease. ?disease HMD:HasName ?disease. ?patient HMD:hashealthstatus ?healthStatut. ?SW HMD:provideServices ?Services. ?services HMD:HasName ?servicesName}.*

To evaluate and assess the system's effectiveness, its development and implementation with real data is necessary.

VII. Implementation and Evaluation of the System

To develop the proposed fuzzy ontology, we used Protégé OWL4.3. The software integrates the pellet reasoner and FuzzyOwl2 to define classes, subclasses, and the relationships that connect them, which allows us to define a fuzzy data type that can determine each fuzzy value. We implemented the proposed system depicted ”Fig. 4” using two modules provided by the java language. The first module, called “jfuzzylogic”, receives uncertain input data from various sensors to determine the value of a patient’s vital signs. The second module is the “Jena” framework. We use it with the developed fuzzy ontology and SWRL rules. We transfer the results of the first module to derive knowledge represented by recommendations on the health of people with disabilities. The proposed system answers different queries using SPARQL.

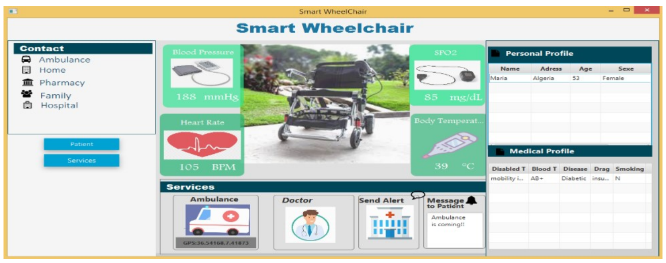

Fig. 4. system interface.

An experiment using the health data of 30 patients [21] was conducted to evaluate the performance of the developed system. The proposed system’s results using fuzzy and crisp ontology are compared with the recommendations of a doctor. The results show that the accuracy of the proposed system reaches more than 90% of the doctor’s results, while the system using classical ontology reaches 70%. The proposed system proves the similarity with the doctor’s diagnosis and makes a good decision to recommend specific health. The system allows specifying a particular disease or monitoring the activity of patients, such as food and medication.

VIII. CONCLUSION

To provide people with disabilities with continuous health monitoring, improve their health and prevent diseases and risk situations, we proposed an edge and cloud-based IoT architecture to collect data and process it through a smart wheelchair that works as an “edge” or with a cloud for complicated cases. To make an accurate decision about the patient’s health, we proposed a system that processes heterogeneous data and vague information by integrating Semantic Web and fuzzy logic. The proposed approach is used to represent the vagueness and uncertainty data with fuzzy ontology. It was designed after studying several standard IoT ontologies, which led us to select the SAREF ontology to reuse and reformulate it with the steps of the IKARUS-Onto methodology. Based on the raw data collected to answer the patients’ queries with a precise decision, a set of compound modules of this system, such as fuzzification, inference engine, semantic knowledge, and query engine, have precise tasks and play a crucial role in improving the diagnosis. For future work, we plan to use the system with infected diseases such as coronavirus, combine this work with other domains such as transportation, and use other machine learning algorithms to improve the results and provide other services.

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