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Context-aware Modeling for Spatio-temporal Data Transmitted from a Wireless Body Sensor Network

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Abstract

Context information such as environmental and physiological data is considered as a type of knowledge whose attributes can be defined in the form of ontology. Therefore, reasoning and inferring may be carried out on the context knowledge. In this research work, we introduce a model that takes the dynamic nature of a context-aware system into consideration. This model is constructed according to the 4D-objects approach and 3D-events for the data collected from a WBAN. In order to support mobility and reasoning on the temporal data transmitted from WBAN, an ontology-based hierarchical model is presented. It supports the relationship between heterogeneous environments and reasoning on the context data for extracting a higher-level knowledge. Location is considered as a temporal attribute. In order to support temporal entity, the reification method and Allen's algebra relations are used. Using reification, new classes of the time_slice and time_interval, and new attributes of ts_time_slice and ts_time_intervalare defined in the context-aware ontology. Then thirteen logic relations of Allen such as Equal, After, and Before are added by the OWL-Time ontology to the properties. Integration and consistency of the context-aware ontology are checked by the Pellet reasoner. This hybrid context-aware ontology is evaluated by three experts using the FOCA method based on the Goal-Question-Metrics (GQM) approach. This evaluation methodology diagnoses the ontology numerically, and decreases the subjectivity and dependency on the evaluator's experience. In terms of completeness, adaptability, conciseness, consistency, computational efficiency, and clarity metrics, the overall performance quality is 0.9137.

Keywords: *Hybrid Context-aware Modeling, Ontology Model, Reification, 4D-fluent, N-ary, Protégé, Chronos, Spatio-temporal Data.*

1. Introduction

Context modeling defines all the entities involved in a context and the relationships among them. These entities can be location, time, persons, and activities. In this modeling, indeed, the relationship between context and human life is defined. Context serves as a critical input to a ubiquitous system. Therefore, context modeling must consider the heterogeneous environments and the interoperability among them. In the present work, our proposed context-aware model aimed to tackle this problem using ontology.

Software applications that are sensitive to environmental changes and adapt their functionality are called the context-aware applications. Environmental changes, user's states and attributes, and device functionality are constantly retrieved, updated, and processed by such applications to provide appropriate recommendations to the user [29].

A body area network (BAN) [6], consists of a collection of heterogeneous sensors. In this research work, BAN is assumed to collect the cardiac patient's heart beat, ECG signal, body temperature, body pressure, and activity state such as walking, running, and sleeping. In addition, ambient sensors are located in a smart environment serving the patient by collecting data such as environmental temperature and humidity.

Our proposed context-aware model combines the continuous monitoring of a cardiac patient. Good modeling can considerably reduce the complexity and inaccuracy of a healthcare application but increase its recommendation capability, adaptability, reuse, and consistency. Moreover, a context-aware model should adapt heterogeneous environments, support mobility, and timeliness. Three main models including *ontological model*, *spatial model*, and *object-role model (CML)* are intended for context-aware systems. An ontological model is a hierarchical model that supports the relationship between heterogeneous environments and reasoning on the context data to extract a higher-level knowledge. An object-role model does not support mobility and context data reasoning. Therefore, for a context-aware model, the ontological and spatial models have been integrated.

The raw data directly acquired from the sensors are changed continuously. This leads to limitation of human interaction modeling, context reasoning, and interpretation. Therefore, instead of using a low-level data, the perception and situation concepts from the sensor are used. The notion of situation is used as a higher-level concept for a state representation [5]. Initially, in 1980, the term “situation” was used in linguistics and natural language semantics [5].Situations are the “semantic abstraction”[5] of low-level data, ricksen et al. [7] are working to update their model to be a hierarchical model to encompass the heterogeneity of a context-aware system.

In a context-aware location-based application, space (i.e. location) is considered as one of the most important factors [5, 10].*Spatial models* are fact-based models that organize environmental entities to derive the user's location. The location data relate either to the location of entities in the physical world or to non-physical entities such as virtual notes left on Google maps [5]. The location information is measured using the global positioning system and triangulation methods [5]. It indicates the longitude and latitude of a mobile object by an error of only a few meters. Location can also be measured or predicted imprecisely using inertial sensors, device cell ID or Wi-Fi access point ID [5].

Heterogeneous context information such as environmental and user's physiological data is considered as a form of knowledge whose attributes can be defined in ontology. Therefore, reasoning and inferring can be carried out on context knowledge [5]. *Ontology-based models* have the advantages of describing heterogeneous environments and their relationships based on a BAN and ambient sensors’ data to assist human knowledge, and interpretation integrated in one model, and they are labeled using human definitions. Situations based on the WBAN’s data in this research work are *Activity, Blood-pressure, Body-temperature, SPO2, Location*, and *ECG*. Another challenge of raw sensor data is temporal attributes. In this research work, we have modeled the temporal and continuous data transmitted from a wireless body sensor network. In chapter 2, three main context-aware models are introduced. Chapter 3 explains the representation of spatial and temporal date in ontology. In chapter 4, the design and implementation tools are introduced. Chapter 5 presents an evaluation of the hybrid spatio-temporal ontology using a numerical method called FOCA.

2. Content-aware models

According to Bettini*et al.* [5], there are three main content-aware models including object role-based, spatial, and ontology-based models, as described below:

Object role-based model is one of the main modality approaches to databases using Context Model Language (CML) [7] introduced by Henricksen [5,7]. It describes an atomic context using a flat information model but it ignores the importance and priority of context atoms such as location [7]. Hen hierarchical model of a domain of knowledge using graphical software programs such as “protégé [8]” through the OWL-DL language. However, the ontology model does not support the timelines and mobility attributes that correspond to the any time anywhere availability of a context-aware system [4, 5].

On the basis of the above-mentioned points, it appears necessary to provide a hybrid version of the spatial and ontology models. Once ontology and spatial data are combined, advantages such as mobility and timeliness are added to the other advantages of an ontology-based model [30].

The purpose of this research work was to model a context for at-home health monitoring systems that are based upon a wireless body sensor network. This work provides a hybrid of spatial and ontology models for grounding a context-aware model. Our proposed model is illustrated in figure 1.

The following advantages can be extracted from the proposed model:

- Clearly shown data
- Hierarchical structure
- Reliable reasoning

- Celerity, quick coordination, and compliance with the environment
- Timeliness
- Mobility
- Separating the knowledge processing from knowledge, and, hence, easier development

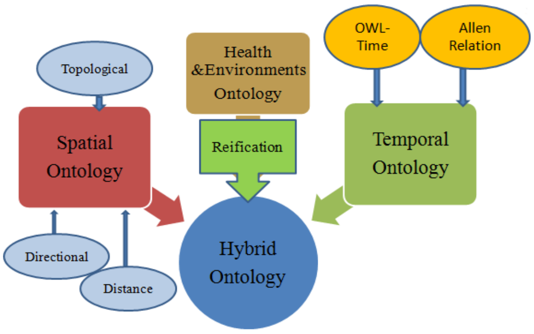

Figure 1.Proposed hybrid model.

In this research work, according to the 4D-objects approach and 3D-events, a model was made of the data transmitted from a wireless body sensor network. Here, a wireless body sensor network is a network that consists of physiological sensors (for ECGs or electro-cardiograms, blood pressure, body temperature, and SpO2), environmental sensors (for environment temperature, amount of oxygen, and environment humidity), location sensors (such as GPS), and motion detectors (such as a WBAN-based accelerometer) [27]. The low-level sensor data is transmitted to a base station (a cell phone with an android operating system is used in this project). The initial processing is performed on the base station, and the data is transmitted to the server for storage. In fact, data modeling is utilized on the server for a better context description, and context reasoning is performed for the activities of an individual and for being used in context-aware applications in the base station. For more details, refer to [21] and [30] . The proposed conceptual model in a WBAN-based pervasive computing environment is illustrated in figure 2. In this research work, two main ontologies were definable as 1) person ontology and 2) health ontology.

Person ontology: It consists of two parts. The first part relates to the environmental conditions in which a person is located (e.g. home, outdoors, hospital). The system responses are different through each of these places. In each place, features such as environment temperature, amount of CO, and amount of O_2 are measured by environmental sensors. The other part determines the user's activity, which is performed through an accelerometer sensor.

Health ontology: Through this ontology, physiological conditions of the user such as ECG, blood pressure, pulse, body temperature, and blood oxygen are measured and transmitted [35, 38].

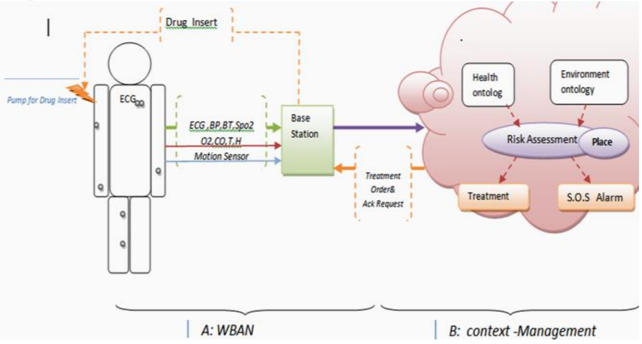

Figure 2.A conceptual model of a defined pervasive computing environment.

In summary, the context atoms for this work were considered to be activity, environment, SpO2, blood pressure, and body temperature (HR, P, Q, R, S, P-R, QRS, S-T, and QT).

3. Showing spatial and temporal data in ontology

The context atoms for this research work were dynamic, and they changed through time. Time and place are the two most important aspects of the real world. Moreover, the concepts of time and place are the most significant issues in context-aware planes. Time can be fixed or protracted, linear or rotary, absolute or relative, and qualitative or quantitative. In addition, time might be shown as a time period. The concept of "temporal" in the daily life of a human is shown in the semantic web using the OWL-T ontology. OWL-Time[9] makes it possible to define time distance, time interval, and concepts such as days, weeks, months, years, time area, and course period. The OWL-time is an ontology of time concepts; however, it cannot be applied to show variable feature changes of an object through time, and quality relation concepts as well as temporal intervals are not clear. Although the World Wide Web Consortium (W3C) suggests OWL-Time, there are temporal ontologies such as semantic web rule language (SWRL)[10], which are in compliance with the definition of time concepts, cover change, and dynamic concepts. “The primary philosophy in the mentioned change is perdurantist and endurantist [39, p. 17, and 34]”. The difference between these two relates to the condition, for example, of identifying objects subjected to time, and objects remaining in place, while time passes and their features might be changed. This explanation can be a good example of the primary difference between an object and an event. Variable features related to time and place are, in fact, the results of an event. According to the 4D periodic approach, each object is, in fact, developed by a time and place event. Although objects are fixed during time such as the solar system or sun, they are subjected to temporal changes [15]. A basis for defining temporal reasoning and relations is the Allen's interval algebra. This algebra is a calculus for temporal reasoning introduced by James F. Allen in 1983, in which it is possible to define relations between time intervals using a hybrid table. This table is used as a basis for reasoning the temporal descriptions of events [29].

Thirteen pairs of Allen relations, which make it possible to define the relations between two time intervals, are "before, meets, overlaps, starts, during, finishes, equals," along with their inverse relations including "after, metBy, overlappedBy, startedBy, contains, and finishedBy" [29]. For example, Before (i, j) means i takes place before j. A time interval can be shown via starting and end points such as (s, e), through which point 1 is the starting point and point 2 is the end point of the time interval. "*i1 before i2 _ e1 < s2"* [29].

3.1. Modeling spatial data

Place is an important aspect of knowledge representation, and can be 2D or 3D (x,y,z). However, in this research work, place was considered as a 2D concept. In most programs, a 2D approach is sufficient; however, it is not appropriate in certain global scale programs as it has defects. In a 2D approach, each spatial point is shown through a pair of numbers that are variable based on the scale and system used [34].

Area is defined by a set of points. The least number of points for a triangular area are three points. Spatial information can be shown in three ways: distance, direction, and topology.

In the direction approach, the linear relations are determined based on the environmental axis areas. Through this method, eight relations can be identified as follow: "North (N), Northeast (NE), East (E), South (S), Southeast (SE), West (W), Northwest (NW), and Southwest (SW)" [38].

In the distance method, a project environment identifies a point or an area. It determines the distance to that point or area based on the two dimensions of length and width. The distance method is used in the spatio-temporal OWL (SOWL) as well. The SOWL framework is for handling spatio-temporal information in OWL [11]. However, it should be noted that distance states quantity, and does not signify quality distance, which is defined as 'far or near'. For example, 3 Km to Tehran refers to the distance method. Such data can be stored in ontology as an N-ary relation [39].

In the topological method, the relations are determined based on their location in an area. The biggest formulation in this method is called region connection calculus (RCC). There are eight modes that can be shown between two areas, known as RCC8. Topologic relations are as follow: "tangential proper part inverse (TPPI), partially overlapping (PO), tangential proper part (TTP), NTPPI, non-tangential proper part (NTPP), equal (EQ), externally connected (EC), and disconnected (DC)". SOWL is used in this model as well [39].

3.2. Reasoning in spatial data

Reasoning ability is, in fact, the ability to infer information and lack of integration. This mechanism does not apply in the case of quality representations because spatial and temporal relations are extracted from multi-session time. For example, comparing the data types in temporal relations and geographical algorithms in quality relations, one finds out that reasoning of relations between temporal and spatial identities is limited. If it is stated that point A is north of point B, the location of these two points in the area can be determined. In another place, if it is stated that point A is south of point B, lack of integration can be inferred. To conclude on quality spatial or temporal data, these relations can be turned into an "NP-hard problem" [34]. Reasoning over spatio-temporal relations is known as an "NP-hard problem", and identifying tractable cases of this problem has been in the focus of many research efforts over the last few years [28,34]. It is essential to note that, in large knowledge bases in which the number of asserted relations and identities are high, there is often a lack of integration. Rene *et al.* have proposed some usable solutions to the problem [34]. Using exponential algorithms is more appropriate than averaging. Also using approximate system patterns, which are closer to the original algorithm, creates much complexity in multi-session data. Multi-session algorithms can be used to create restrictions on relations and traceable sets. Reasoning in relations depends on the relations existing in their semantic knowledge base. In directional relations, using a cone-shaped or projection-based method will result in a different conclusion. Although their relations are similar, a different meaning is inferred. In quality relations, the meaning variable in time might be inferred. For example, if there are two time points P1 and P2, P1 can be before or after P2 in terms of time. In a temporal spatial show, using the Allen relations, the following condition might be found to exist:

"P1 is before or equal to P2, P1 is after or equal to P2 or P1 is equal to P2."

Then the integrity should be controlled to check whether the asserted data is in compliance with the data. In the recent studies, the "NP-hard problem" has been considered as one of the known methods for traceable instances, which has been the basis for most studies [29, p. 22]. Through this method, identifying constant K is of great importance, as explained in reference [32].

3.3. Temporal data reasoning in ontology

OWL-time describes the temporal contents of web pages and web service features. It consists of a temporal structure for showing the time in ontology that cannot yet support concepts (events) change through time. This problem is similar to the problem of showing the temporal data in a database. One of the common ways to solve this problem is entering time in an existence-relation (ER) table, which is entered into the relation as a time interval or as a time representation for performing an action. However, there are differences between OWL and a database [22]:

Owl semantics are not equal to an ER semantic figure because OWL is based upon "Open world" assumptions, while a database is based on "Closed world" assumptions [22].

Order relations in Owl are limited to the basis relations. Time showing in a semantic web can be performed through each of the following methods: concrete domain, logics temporal description (TDL), reification, labeling of, versioning, named graph, and 4D-fluents [22].

There are different methods of time representation in a semantic web. Temporal Description Logics (TDLS) is the advanced version of standard DLs. It is the base standard of a semantic web in which structures such as "always", "sometimes in the future", and "in the past" are added. TSLS provides some additional statements that make it possible to activate or deactivate and to analyze descriptive temporal statements. It also supports information representation at a certain temporal point for a concrete domain.

Concrete domain describes the data types and the necessary domain functions (such as decimal numbers). In this approach, additional data types and functions are required in OWL. It is, in fact, one of the proposed plans of combining TOWL with 4D-fluent that does not support quality relations. Moreover, OWL editors, likewise, do not support it (such as SPARQL, Protégé, and pellet).

Temporal RDF is a developed RDF version using features resulting from time intervals. In this method, temporal RDF should be clearly asserted; otherwise, quality relations are adopted instead. Temporal RDF is suitable for combining with fuzzy methods to support temporal assertions.

Versioning proposes different ontologies through different times. When some changes take place in ontology, a new version of that is created. This method has different disadvantages. For example, 1) in the case of changes in features or identities, a new ontology is created, which causes redundancy; 2) searching for events in a single time or time interval is unendurable; and 3) relations between classes and their changes are not clear enough. In addition, the OWL language is an adherence language, and changes in time is not taken into consideration.

Named graph represents temporal context data in a three-sentence manner of features, and is called 'named graph'. Each sub-graph is determined in a certain graph of ontologies with a separate name. The default graph is named according to the starting and end points of the interval. This method is not a subset of OWL. Thus its orders are not transmittable to the naming graph. Moreover, OWL reasoning is not applied.

Reification is a general technique for showing multiple relations (n-ary) using OWL language, which is limited to adherence relations. This multiple relation (n-ary) with a new object consists of all arguments of a multiple relation (n-ary) as an object-property [18]. For example, if there is the relation R between two objects, let's say A and B, at the time of t, it is explained as R (A, B, t). In addition, using reification depends on elements R, t, B, and A in OWL. Figure 3 shows the relation between a patient and a hospital in a given time interval. The use of reification requires an additional reified relation class for each property in the object-properties relation.

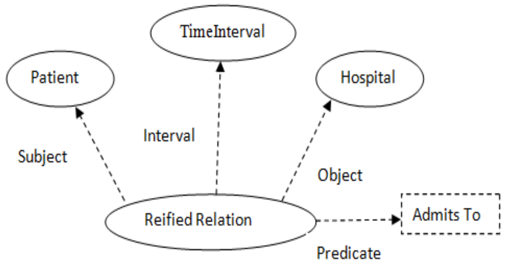

Figure 3.Utilizing reification to show patient relations to a hospital.

However, there are two disadvantages attributed to reification: (1) A new object should be created to show temporal relations. It is common in all methods with the use of OWL.(2) There is some limitation in using OWL reasoning. When R is shown as an object-property relation, semantic OWL is not applicable to properties. Reified temporal relations are called events or activities. In an improved version of reification, for both properties of a new object, an n-ary relation is taken into consideration. In this method, just one object is created for each temporal relation; however, it causes redundancy in inverse and symmetric relations.

Through this method, a temporal relation is well-shown. In addition, property domains and areas should be determined by considering object classes as a representative of associated relation [31]. There is a plug-in, named Chronos [12] for the prosthesis, which has been created for multiple temporal relations (n-ray). To develop a protégé library for n-ray and 4D-fluent relations, a specific instrument has been generated [17, 41]. In 4D-fluent, temporal information and its changes can be shown via OWL. Temporal concepts are also displayed as the fourth dimension of objects through the use of a time slice. Time constant and time interval are presented as examples of the "Time Interval" class, which consists of different values in time (Figure. 4).

In the case of an event, we experience changes in properties; however, identities remain fixed and unchanged. One disadvantage of the 4D-fluent method is the increase in the number of objects. This is because for each temporal relation, two objects should be added. Different methods have used a combination of developed RDF and OWL-Time [24-26].

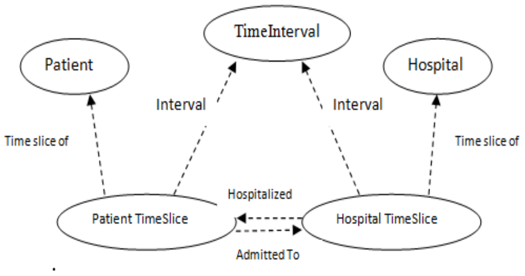

Figure 4.Utilizing 4D-fluent to represent a patient's relations to a hospital.

In an improved version of reification, for every two related properties of a new object, an n-ary relation could be derived. In this method, just one object is created for each temporal relation; however, it causes redundancy in inverse and symmetric relations. In the n-ary relation, an object is added to show temporal properties. This object belongs to the events class, and the contract is acceptable in conventions such as ontology. Figure 5 indicates an example of an n-ary relation, which is comparable to 4D-fluent. In this method, temporal relations are shown well. In addition, the domain and the area of the properties should be determined considering the object class as a relation representative. There is a plug-in (named FONTE) for the prosthesis, which has been created for editing multiple temporal relations [17,41].

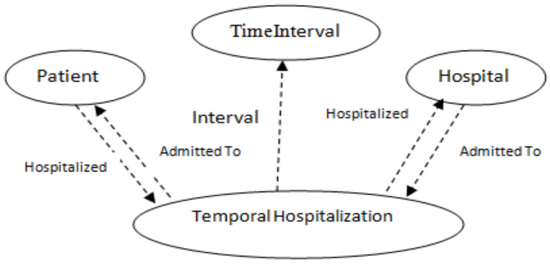

Figure 5. Example of "n-ary relations".

For a spatial representation, the 4D-fluent mechanism should be improved with the spatial quality relations, as applicable in topological and directional representations. In this method, a general ontology serves to show spatial information. The location class consists of Name property. Moreover, the location object can optionally be connected to the footprint class, which includes subclasses of point, line, polyline, and Minimum Bounded Rectangular (MBR). The class of point consists of two numerical properties of X and Y (Z can be also considered as the third dimension). The line class includes properties of point 1 and point 2, as the starting and the end points. The polyline class indicates distances around an object (area) as a set of successive lines. An object or area can be shown using four numerical properties $(y_{min}, x_{min}, x_{max}, y_{max},)$. This type of representation is called MBR. Both of these point-based methods and MBR are usable in ontology.

The spatial relations between areas are easily extractable from MBR relations. For example, in MBR and point-based relations, quality relations can be extracted and transmitted to ontology from quantity activities using SWRL rules. In ontology, each spatial relation that connects two spatial points is known as topological or directional relation. In a topological relation, concepts such as NTTO, EQ, EC, DC, and NTTPI in SOWL can also be defined [36].

Directional relations are defined in cone-based zones. According to Batsakis [14], eight directional relations can be shown through concepts of "North (N), Northeast (NE), East (E), South (S), Southeast (SE), West (W), Northwest (NW), and Southwest (SW)"[14]. Cone-based relations are suitable for showing objects or points. They are, in fact, complementary to topological relations. The projection-based method is also complementary to the topological relations [17].

Adding the projection-based method to the topological method makes it possible to use algebra on a vertical axis (X,Y). In this method, instead of each temporal example, it is possible to use an axis. Moreover, if the Allen relations are used, instead of each dimension, it is possible to use an axis [17].

Spatial and temporal representations could be combined. In mobile objects, location is a property of a time slice, which is kept for a certain time interval. However, in a static object, location is a property of the object [17]. Note that even if the location of an object is static, its other properties may change in time and need a time slice. In the n-ary method, location [13],[19]of a mobile object is a property of the object-event relation. In a static object, location is one of the properties of the object. In 4D-fluent, an object can have temporal properties, known as events [17].

4. Design and implementation

Researchers have suggested different methods for designing ontologies. For example, Uschold (2000) has categorized ontology design methodology into four types including basis, existence, information resources, and combination. In accordance with this categorization,1) the ontology is designed from the basis without using the existing ontologies, 2) the ontology is designed based on the existing ontologies of global or local Types, 3) the ontology is designed based on a set of information resources, and 4)the ontology is designed based on a combination of the previous two approaches (i.e. existing ontologies and information resources) [37].

Shamsfard and Abdollahzadeh Barforoosh (2002) have divided the ontology design methods into three types including 1) manual construction, 2) engineering tool, and 3) semi-automatic construction, based on the use of technology[38]; thus an automation system is compared with a manual system. In the manual construction method, the conceptual knowledge is coded in the machine by the individuals, and it is based upon development of large general or specialized knowledge bases. "CYC"[40] was one of the ontology designs created with the aim of developing a large knowledge base including a reservoir of basic knowledge for reasoning and problem-solving functions in various fields. In the recent years, some ontology engineering tools have been developed for supporting ontology construction. Protégé [8], Ontolingua [41], and WebOnto [42] have prepared the environment to acquire conceptual knowledge and define concepts, features, relations, and conceptual limitations by providing a proper user interface. Another group such as Doddle II [43] have extracted the necessary data and structures for ontology construction from input resources, and have provided them for an ontology constructor (human or machine).For semi-automatic construction and using knowledge acquisition procedures in this research work, the manual method was used. The proposed five-step method for designing ontologies through a manual process is as follows:

- determining the goal and range of ontology
- designing ontology in a three-step process including:
    i. ontology assembly (determining concepts and main relationships and developing definitions for these concepts and relationships)
    ii. coding ontologies (using key terms for ontology (category, entity, relationship) selecting a language for representation, code writing
    iii. integrating the existing ontologies
- ontology evaluation
- documentation
- providing guidelines for each of the previous steps

Moreover, Noy and McGuinness (2001) [39] have suggested a seven-step method for designing ontologies as follows: determining the domain of ontology, considering the possibility of re-using the existing ontologies, preparing a list of important terms in the ontology, defining classes and class hierarchies, defining the relationships between classes, defining abstracts related to the relationships in the ontology, and setting the samples. In this research work, extraction of relationships among concepts and identification of definitions and samples were carried out manually. The ontology's subject is healthcare, and the domain analysis approach is adopted in this work. The ontology design was done using Protégé 3.4.4 software.

There are two main implementation tools for the ontology. Protégé 3.4.4 software [8] is a free tool for editing the ontology. This tool allows constructing the ontology, adding classes, data characteristics, object characteristics, and samples to ontology, and inferring from it. In fact, Protégé is a framework for constructing knowledge-based systems. This framework allows knowledge-based systems as OWL, RDF, and frame-based forms. The newest version of Protégé is the Protégé Beta version, which is not discussed here as it has not been finalized yet. The previous version is version 4, which supports only OWL. Protégé version 4 allows us to provide knowledge-based systems in a frame-based form. OWL 1 support and RDFS have been added to this version. However, ultimately, the Protégé design team decided to provide a new version of Protégé (Protégé 4) for the OWL2 version and the later ones. The other version of Protégé has also been provided in a web-based form. Its purpose is providing a real knowledge-based system, which is beyond the expertise of an expert. Thus this ontology is implemented using OWL2.0 and Chronos plug-in [28] in Protégé version 4.3, defining events and spatio-temporal data [23]. Protégé can be used in two ways for constructing ontology:

- Installing Protégé software on the system and using it to build the ontology
- Using "Protégé API" and adding it to the Java project

The second implementation method is incorporating the Chronos Plug-in. Ontologies provide a way for representing high-level concepts, their properties, and relationships. Dynamic or temporal ontology allows the representation of variable time information. In order to represent the dynamic features, identical representation mechanisms should be used for temporal concepts in the ontology OWL-Time [44]. OWL-Time provides a vocabulary set for expressing time-related facts. In addition to linguistic structures for time representation used in the ontology, there is a mechanism for representing the change of concepts in time (i.e. events). Some features of this mechanism include concrete domains, property labeling, versioning, temporal description logics, named graphs, and reification with two approaches of n-ary [45] relations and 4D-fluents, which are described in the research method section.

Representation of temporal information in ontology takes place through the OWL language [25]. However, the OWL language has structural limitations for describing temporal features. Every object has three subsets including (i) object, (ii) subject, and (iii) time interval or time instance. Though implementation of temporal concepts is possible with OWL, it is very complicated. Reasoning on temporal data has similar complexities; thus the SOWL language is used [17]. Ontology editors such as Protégé 4 edition are suitable for static ontology's development, with a binary relation. However, they are not suitable for working with temporal entities and temporal relations (triples) [28]. Thus in all the recognized methods of representing common dynamic concepts (such as n-ary relations or 4D-fluent), triple relations are divided into a set of binary relations.

In order to implement ontologies in Protégé software, first, a diagram of RDF-Schema concepts should be designed for the ontology and its classes. When the ontology file is developed in the Protégé, it is possible to select the file type (Protégé file, Protégé database, trial XML file, OWL/RDF database, etc.). After the selection of the file type and set-up, data entry of the metadata section, class section, relationship section, and sample section for different parts of the context-aware ontology are entered manually. In metadata, the general information related to the ontology such as version number, ontology developer specifications, construction history, and ontology web address (in order to publish it in the web) is provided. In this stage, it is possible to enter the data from other ontologies as well. Due to the lack of related ontologies, no other ontology has been used in the construction of a context-aware ontology. In order to prevent repetition of temporal concepts such as year, month, day, hour, minute, and second, the OWL-Time ontology is used in context-aware ontology. Then the classes (i.e. context atoms) are stated in the hierarchical structure of classes (super-class, sub-class), and the relationships related to each concept are developed. The context atoms include the user activity (sleeping, running, sitting, being anesthetized), environment (temperature, location, o2), and physiological context atoms such as blood oxygen (spo2), blood pressure, body temperature, ECG signals components' HR, P, Q, R, S, P-R, QRS, S-T, and QT. In this stage, the classes are entered into the ontology structure based on the data available in the ontology schema in the form of concept structure. The concept with its particular characteristics and relationships will be shown in a special format. In Figure6, the implemented classes are illustrated.

Considering this figure, first, the context-atom class is developed in the super-class *OWL: thing*. Then the primary sub-classes *health, activity*, and *location* of *OWL: thing* are constructed. Time slice and time interval sub-classes are also defined to be connected with the class *temporal entity*.

The proposed model benefits from the instance-based method. Temporary entities such as interval instance are defined in the ontology using OWL-Time. Every interval is related to two temporary instances, and has starting and ending points. In fact, every instance can be related to a specific date using the Date Time data type. The time slice class is the class domain for objects in the temporal section, and the time interval class is the class domain for the time interval. A time interval stores the temporal data of time slice. Figure 6 indicates an example of the relationship between classes, time slices, and time intervals. The properties *ts_time_slices*, *ts_time_interval*, *time slice*, and *time interval* are used to represent the temporal data.

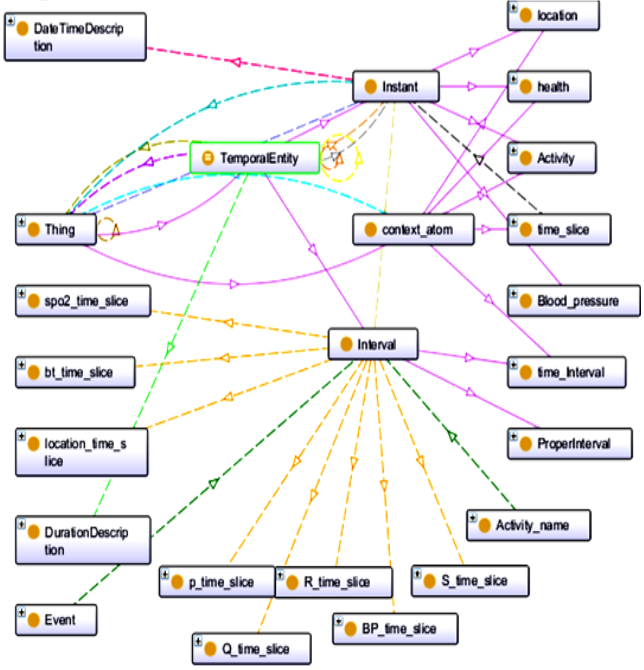

Figure 6.Relationship between classes, Time Slice and Time Interval.

A schematic view of the ontology can be studied on the WIZ and Graph tabs. These tools are also used in the ontology evaluation. The property *ts_time_interval* connects instances of *Time Slice* class to instances of *Time Interval* class. Such properties possess a temporal dimension. Thus they are called fluent properties, and are connected to *Time Slice* class instances.

The relations in ontology are divided into two classes:

- Relation between classes, defined by the Object Property tab
- Relation between classes and their values, defined by the Data Type Property Figures 7 and 9 indicate relations in the context-aware ontology. Figure 7 indicates the *Allen 13-relation*. In the Protégé software, this relation is defined using the *OWL-TIME* ontology concepts. *Before*, *After*, and *Equal* relations can be established only between two temporary instances. However, the *Before* relation is inverse to the *After* relation, and *Equal* can be shown by the *Same* command in *OWL*.

Class individuals can be defined using the Individual tab. In Figure7, some individual samples are indicated.

In our project, activity samples include seated, lying, unconscious, standing, and walking. Theweekday samples are *Saturday*, *Sunday*, *Monday*, *Tuesday*, *Wednesday*, *Thursday*, *Friday*, and others.

An overall view of the context-aware ontology through the Chronos tab is presented in Figure 7.

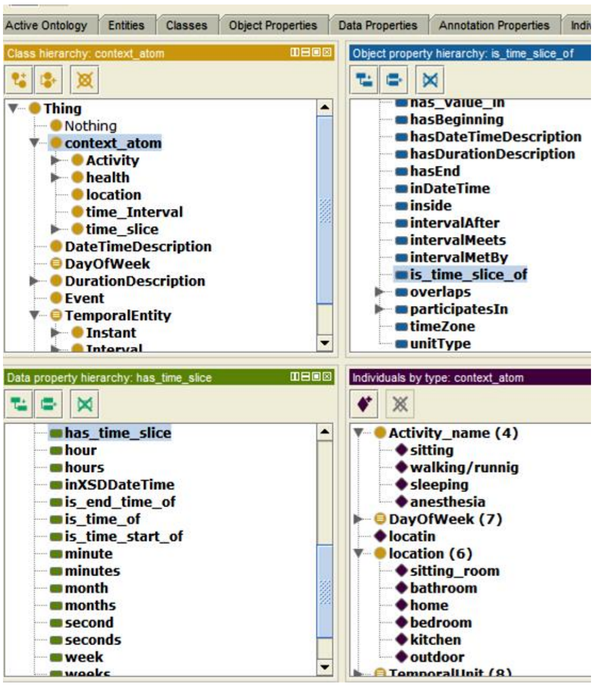

Figure7. Classes and relations in Chronos tab.

Additionally, a graphic display of the context-aware ontology is given in Figure 8.

5. Evaluation FOCA evaluation using GQM Approach:

The “FOCA” evaluation method was introduced by Bandeira2016 [39] based on the expert evaluation. It is carried out manually based on thirteen questions and step-by-step guidelines. Expert evaluations are considered subjective; however, the *Goal-Question-Metric (GQM)* approach decreases the effect of the evaluation experience on the overall quality of the evaluation. L_{Exp} is the evaluator's experience variable, which is considered in the evaluation formula 2. If the evaluators' experience in ontology is vast, the value of $\mathrm{L}_{\mathrm{Exp}}$ is 1, if not, 0 is assigned. The main metrics that is introduced by [47] are according to the goals or roles defined for the ontology. These goals are:

1. "Substitute" [47], i.e. how close is the proposed model to the real world?
2. "Ontological commitment" [47], i.e. how much are the real world relationships presented in the proposed model?
3. "Intelligent reasoning" [47], i.e. how close is knowledge reasoning on the proposed model to the real world?
4. "Efficient computation" [47], i.e. how accurate and fast is the model reasoning?
5. "Human expression" [47], i.e. how easily is the model understandable by the human?

In the next step, to investigate the main goals, thirteen questions are posed to the evaluators. *Goal 1:* Questions 1 to 3 correspond to the "substitute" role, with "completeness" and "adaptability" metrics, justifying the competency and coherence of the documentation with the ontology and reusing the concepts. *Goal 2*: Questions 4 to 6 correspond to the "ontological commitments" role, with "conciseness" and "consistency" metrics, justifying the similarity of the ontology to the domain and the real world. *Goal 3*: Questions 7 and 8 correspond to the "intelligent reasoning" role, with "conciseness" and "consistency" metrics, justifying the ontology reasoning as free from errors. *Goal 4:* Questions 9 and 10 correspond to the "efficient computation" role, with "computational efficiency" metrics, justifying the success and speed of the computational performance of the ontology. *Goal 5:* Questions 11 to 13 correspond to the "human expression" role with "clarity" metrics, justifying the comprehension of the model as not difficult [47].

According to the "FOCA" [47] methodology, there are two types of ontology: (i) "task or domain ontology" and (ii) "application ontology". Context-aware ontology is the domain ontology of body area networks and ambient sensors. Variable $\mathrm{L}_{\mathrm{Exp}}$ is selected from [0, 1] by evaluators according to their experience.

Score "1" is assigned to fully expert ontology evaluators, while "0" is considered for no experience in the ontology research field. The evaluators have a choice to assign "0, 25, 50, 75, and 100" to assess each question. Finally, the performance quality (μi) of the ontology is calculated from formula (2) [47]:

$$\mu_i = \frac{\exp\left\{-0.44 + 0.03\left(Cov_s \times Sb\right)_i + 0.02(Cov_c \times Co)_i + 0.01(Cov_R \times \mathrm{Re})_i + 0.02(Cov_{cp} \times C_p)_i - 0.66LExp_i - 25(0.1 \times NL)_i\right\}}{1 + \exp\left\{-0.44 + 0.03(Cov_s \times Sb)_i + 0.02(Cov_c \times Co)_i + 0.01(Cov_R \times \mathrm{Re})_i + 0.02(Cov_{cp} \times CP)_i - 0.66LExp_i - 25(0.1 \times NL)_i\right\}} \qquad (1)$$

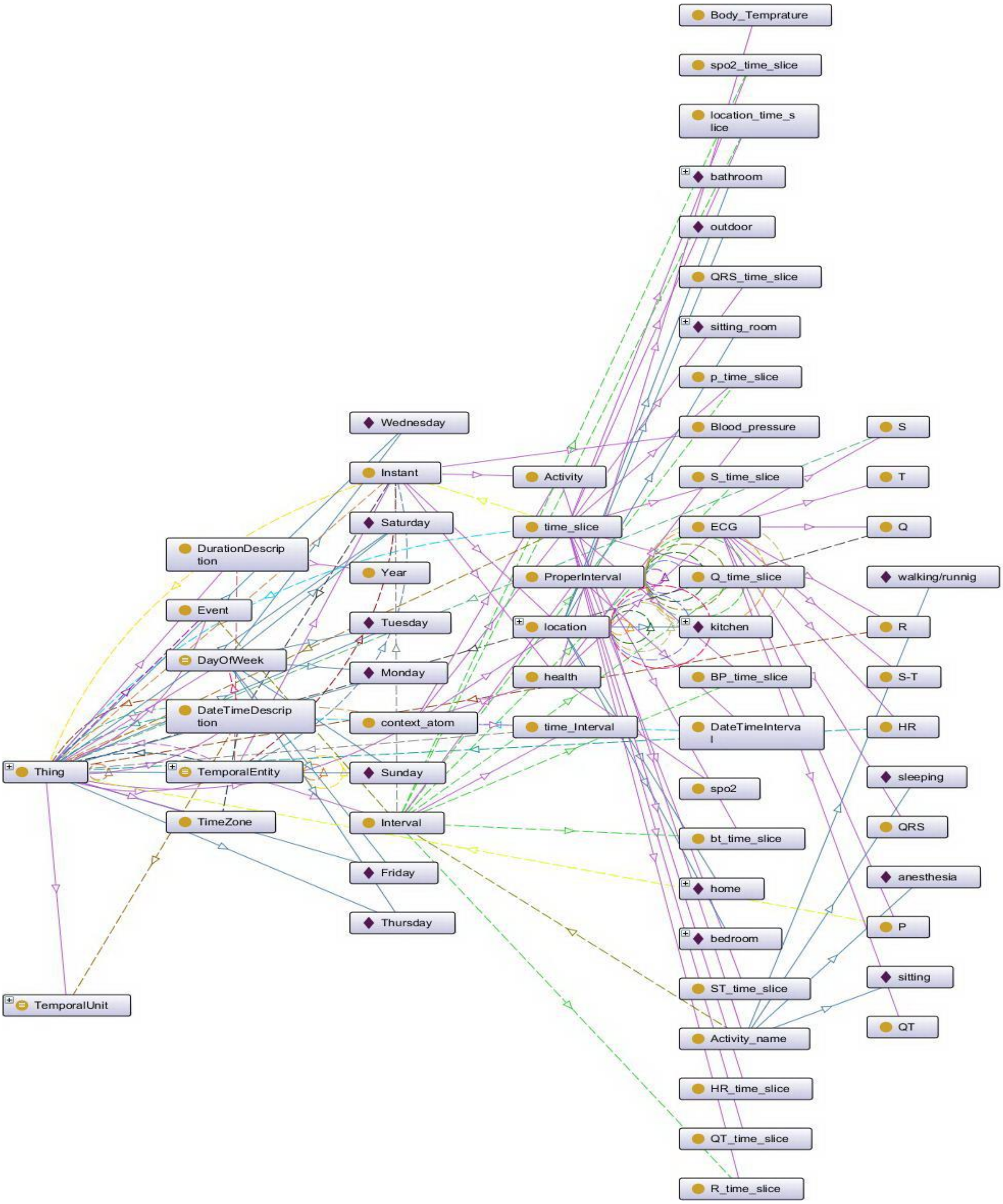

Figure 8.Graphic display of the context-aware ontology

Cov_s, Cov_c, Cov_R, Cov_{cp} are the means from goal 1, goal 2, goal 3, and goal 4, respectively. *Lexp* is the evaluators' experience. *Nl*, is one if the evaluators cannot answer some questions. Sb, Co, Re, and C_p are considered one for calculating the total quality [47]. The proposed context-aware ontology is evaluated by three evaluators, r1 to r3; the scores of every question and variable L_{Exp} are shown in Table1. Question 4 is null because it is only answered if the ontology is type 2 [47].

Table 1.The scores assigned to 13 questions and variable LExp by 3 evaluators.

		Evaluator1	Evaluator2	Evaluator3
Q1		75	50	75
Q2	**Goal(1)**	75	100	75
Q3		100	100	75
Q4		Null	Null	Null
Q5	**Goal(2)**	75	75	75
Q6		100	100	75
Q7	**Goal(3)**	100	100	100
Q8		100	100	100
Q9	**Goal(4)**	100	75	75
Q10		50	75	50
Q11		75	75	75
Q12	**Goal(5)**	100	100	75
Q13		100	100	100
Exp		0.99	0.9	0.88
Mi		0.958	0.91	0.88

Total quality (μ) is calculated for each evaluator in Table 1. At the end, the mean *performance quality* is calculated according to the following formula:

$$\mu = \frac{\sum_{i=1}^{n} \mu_i \times LE\,\mathrm{xp}_i}{\sum_{i=1}^{n} LE\,\mathrm{xp}_i} \qquad (2)$$

$$\mu = \frac{\left(0.99 \times 0.958 + 0.9 \times 0.91 + 0.9 \times 0.88\right)}{(0.99 + 0.91 + 0.88)} = 0.9137$$

6. Conclusion

In our context-aware model, the situations are the external semantic interpretations of low-level contexts. The situations inject meaning into the applications, and are more stable and easier to define and maintain than low level data. The design and implementation of the applications become much easier with the situations because the designer/programmer can operate at a high level of abstraction (situation) not on all the context cues that create the situation.

Furthermore, the temporal attributes of a body area network have been added to the domain ontology using the Allen algebra relations and *OWL-Time* ontology. The temporal reasoning and temporal relationships are defined by Allen's relations logic. It was used as a basis for reasoning when the events occur. Spatial information was incorporated in topological, directional, and distance-based manners. The hybrid context-aware ontology was evaluated by three experts using" the FOCA method based on the GQM approach". This evaluation methodology diagnoses the ontology numerically and decreases the subjectivity and dependency on the evaluator's experience.

The hybrid model supports the temporal and continuous data transmitted from a wireless body sensor network. Our ontological model promotes mobility, reduces the complexity of context and facilitates designing and programming of context-aware applications using world concepts (situations). The OWL language supports automatic reasoning using a reasoner such as a pellet [3]. Therefore, the present model contributes to management and reasoning in pervasive computing systems. However, the OWL language limitations make the implementation and programming of the temporal ontology complex and difficult. The present work will combine the human activity ontology such as [48] to further enrich the hybrid ontology.

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