Detection of Health-Related Problems of People with Dementia from Lifestyle Wearables: A Rule-Based Approach

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Abstract— **In this paper, we describe a rule-based framework for the detection of health-related problems of people with dementia. The framework combines a novel ontology for lifestyle data (steps, sleep duration and heart rate measurements) and health-related problem representation and a novel set of SPARQL Inferencing Notation (SPIN) Rules to infer problems from lifestyle data. Both the ontology and the rule set are designed based on clinical expert knowledge in the field of dementia. More specifically, lifestyle data is acquired from lifestyle wearable devices in the market, making the system affordable and convenient. A model based on Semantic Web technology, Web Ontology Language (OWL), is used to formally represent and integrate sensor measurements, which promotes interoperability with other models and data exchange. SPIN rules offer the benefit of simplicity and flexibility as opposed to other rule representations in the domain. A proof-of-concept scenario is realized, showing data gathered from a real subject and the generation of expected problems by the framework.**

Keywords-*Ontology; Event Detection; Semantic Web; SPIN; Reasoning; Rule-Based Systems; Dementia.*

I. INTRODUCTION

As the world population is rapidly aging, people living with dementia globally amounted to 50 million in 2019 and are expected to triple to 150 million by 2050 [1]. Yet there is no silver bullet for dementia, such as a pharmacological solution. Only holistic and objective information about a patient's health status can drive tailored interventions to alleviate the ailments and slow down the progression of the disease. However, this imposes a huge burden on informal caregivers and healthcare professionals to manually monitor lifestyle, and health-related problems such as movement, sleep and stress.

Lifestyle sensors are a promising and affordable solution to objectively, continuously and affordably monitor patients, but a framework to map and extract clinical health-related problems is needed. The acquisition of knowledge from continuous and heterogeneous data flows is a prerequisite for IoT applications [2]-[4]. Semantic technologies provide integrated tools and methods for representing data and producing new Knowledge from them. Smart environments are increasingly encountered in healthcare technologies at home in actions that create better living conditions for older people by using Internet of Things (IoT) technologies, such as Active and healthy Ageing (AHA) and Ambient Assisted Living (AAL). In this context, human activity recognition plays a main role [5], because it could be considered as a starting point to facilitate assistance and care for the people with dementia. Due to the nature of human behavior, it is necessary to manage the time and adhere to the spatial restrictions. In doing so, semantic technologies enable expressive reasoning over health data, allowing clinical decision support to be realized. Ontologies are used to describe the context elements of interest (e.g., persons, events, activities, location, time), their pertinent logical associations [6], as well as the background knowledge required to infer additional context information.

In this paper, we propose a Semantic framework for Health-related Problem detection that combines ontologies and SPARQL Inferencing Notation (SPIN) Rules [7]. Ontologies are used to provide the common vocabulary for representing activity related contextual information, whereas SPIN rules derive high-level activity interpretations. SPIN is used as standardized declarative language able to address the limitations of the standard OWL Semantic Web technologies mentioned previously. More specifically, the temporal relations among activities are handled by SPARQL functions, whereas the derivation of new composite activities exploits the native capabilities of SPARQL to update the underlying activity model.

The SPIN language was chosen to implement this system because it combines concepts from object-oriented languages, query languages, and rule-based systems to describe the behavior of objects on the web of data and the Internet of Things [8]. In addition, it makes the rules accessible and easy to maintain, extend and share. A suitable Reasoner tool, such as the SPIN API, can extract the extra information generated by the rules and reuse it, for example, in executing a SPARQL query, thus generating new knowledge. These rules apply using SPARQL CONSTRUCT or SPARQL UPDATE requests (INSERT and DELETE). SPIN standards also make it possible to define such rules in higher level domain specific languages, so that rule designers do not have to work directly with SPARQL.

The rest of the paper is organized as follows. Section II presents related work in the domain of ontology-based reasoning architectures in Healthcare field. Section III describes the proposed System architecture that combines OWL ontologies and SPARQL rules in order to derive high-

 ISBN: 978-1-61208-763-4

level activity interpretations. Section IV presents the use case scenario that evaluates the proposed architecture. Finally, Section V concludes our work.

II. RELATED WORK

In previous related studies, Semantic Web technologies have been used to represent knowledge from home healthcare systems. Some examples of projects are Knowsense [9], COSAR [10], ACTIVAGE [11], Dem@Care [12], Faber [5], and FallRisk [13]. Table I summarizes their aim and semantic web methods used.

TABLE I. RELATED WORK.

Project	**Year**	**Aim**	**Methodology**
KnowSense	2015	Activity Recognition in Healthcare system	Description Logic Reasoning, (DL) for activity detection and SPARQL queries to extract clinical problems
COSAR	2011	Activity Recognition in in context-aware environments	Ontological reasoning is also combined with statistics
ACTIVAGE	2017	Development of Smart Living solutions for active and healthy aging	Interoperable Ontologies, rule-based reasoning
Dem@Care	2015	Supporting independent life for elderly people with dementia	Interoperable Ontologies, Rules, Reasoning
FABER	2015	Detect abnormal behaviors for medical applications	Simple reasoning on an ontology
FallRisk	2015	Detect falls of elderly in smart homes.	Semantic Reasoning techniques

KnowSense is designed to support monitoring of the activities of elderly people with dementia in controlled and ubiquitous environments. Semantic Web technologies, such as OWL 2, are extensively used in KnowSense to display observations from sensors and specific applications, and to implement solutions to identify activities and problems in everyday life activities (IADLs) with the aim of clinical evaluation in different stages of dementia. The Description (Logic Reasoning, DL) reasoning for activity detection and SPARQL questions are used to extract clinical problems. However, the semantic techniques used by KnowSense cannot be easily extended and reused.

COSAR offers a solution based on the use of ontologies and ontological reasoning combined with statistical inference. Simple patient activities are identified by statistical methods, such as selecting the most likely method compared to others. The ontological reasoning is also combined with statistics to identify complicated activities that are not only detectable by statistical methods.

ACTIVAGE is a large-scale pilot project, aimed at developing Smart Living solutions that have a positive impact on active and healthy ageing. The ACTIVAGE IoT Ecosystem Suite (AIOTES) project, provides a set of techniques, tools and methodologies (rule-based reasoning, interoperable ontologies, etc.) that enhance semantic interoperability at different levels between heterogeneous IoT platforms. The approach uses different reasoning mechanisms that can improve the understanding of heterogeneous patient's data and help to generate new knowledge by providing services to end users.

Dem@care offers a complete system, consisting of heterogeneous sensors, to support the independent life of elderly people with dementia or similar health problems. This approach includes a heterogeneous set of detection methods and technologies, including video, audio, in addition to normal, environmental and other measurements. Semantic technologies (e.g., rule-based reasoning) are used to process and analyze sensor data according to user requirements. This results in feedback and decision support, that is delivered to end users through appropriately designed user interfaces. A variety of clinical scenarios and environments are supported, from short-term experiments in a hospital environment to long-term monitoring and support of daily life at home, for independent living.

FABER is is an ubiquitous system developed to detect abnormal behavior for medical applications. It first calculates events and actions from the available context data by using simple reasoning on ontology. Computed boundaries, actions and events are sent to the knowledge-based inference engine.

The main goal of FallRisk is to detect falls of elderly people in smart homes. It is based on a platform that uses several learning-based fall detection systems. The results of these systems are filtered and entered into an ontology that contains the contextual knowledge. The knowledge, including contextual information about the user, is then used to refine fall detection. The strength of this approach, in addition to the combination of both techniques, is the compatibility with any fall detection technique. However, it deals exclusively with fall detection.

The above systems use semantic rule-based mechanisms and provide solutions for activity and event recognition based on the use of ontologies and ontological reasoning. However, most methods are quite sophisticated and complex to express and to maintain due to rich logic support. For this reason, the SPIN language was chosen by us to create semantic rules. SPIN offers a lot of advantages [6][7]. SPIN rules offer the benefit of simplicity and flexibility as opposed to other rule representations It is based on SPARQL, a well-established query language and protocol, which is well supported by numerous engines and databases. This means that SPIN rules can be directly executed on the databases and no intermediate engines with communication overhead need to be introduced. Moreover, it has an object-oriented model that leads to better

ISBN: 978-1-61208-763-4

maintainable models. Specifically, the SPIN rule engine does not have to check all rules at all times, but instead rules are checked incrementally when new instances of a certain class are inserted (or modified) in the ontology. This leads to better rule execution performance. Furthermore, SPIN is a more promising de-facto industrial standard for the future of combining ontologies and rules, because it builds upon the widespread use of SPARQL.

III. SEMANTIC REASONING APPROACH FOR HEALTH-RELATED PROBLEMS DETECTION

This section presents the proposed Semantic System for Health-related problem detection with the aim of recognizing the activities of the people with dementia through different sensors and producing new knowledge by offering new services to end users of the system such as doctors, health professionals and patients. As shown in the Figure 2, the raw data are collected by users (i.e., the patient with dementia) using various wearable sensors and smart home sensors. Afterwards, raw data are modeled on RDF ontologies and stored in the Knowledge Database (GraphDB) for the purpose of creating the System Knowledge Base of the system. Then, the semantic analysis, which will be presented in the next section (Spin Rule Engine, Ontology and Rule reasoner, etc.), processes and interprets the data, enriching the Knowledge Base of the system.

A. *Ontology and Knowledge Base*

The proposed approach is built on top of emerging Semantic Web technologies. We started with the definition of system ontology for representing different elements of a healthcare system. The goal of ontology is to semantically visualize all concepts related to activity recognition in healthcare system and acts as a semantic information integration model derived from the system's sensors. A common practice in the development of ontologies is the reuse of existing models, so we're relying on already developed and valid ontologies for developing a part of the supporting ontology. The following are an overview of the existing entities used:

Dem@Care [12]: An ontology to represent experimental protocols of diagnostic support and dementia diagnosis in a controlled environment.

Semantic Sensor Network (SSN) [14]**:** Contains the ontology SOSA (Sensor. Observation, Sampler and Actuator). These ontologies describe semantic sensors, actuators, sampling and their actions. It is a W3C recommendation and OGC application.

SmartHome [15]**:** This ontology is an extension of SSN ontology and focuses on the representation of spatial and time aspects of entities included in spaces with devices belonging to the smart home category.

The system's ontology is expressed in OWL 2 (W3C, 2012), which is a representation language commonly used in the semantic issue community for entity development. Figure 1 shows the hierarchy of entity classes and the hierarchy of its properties. Object attributes are relationships that link classes together, and data attributes link classes to simple values (such as integers, alphanumeric, dates, etc.).

The main classes of ontology are Device, Event, HealthProblem, Person, and Profile. The Device represents the devices of the system. Event is a parent class for different Event-related classes. It has two subclasses Activity and Measurement. Activity contains the information of activities. Measurement includes instances, which represent information of measurements (Calories, Distance, Floor, HeartRate, Movement, Sleep, Steps). The HealthProblem is a parent class for different Health Proplem-related classes. It consists of subclasses HeartProblem, MovementProblem, MultiProblem and SleepProblem. The class Person includes instances, which represents the type of Person of the system (Doctor, Patient). Finally, the class Profile includes information from users' profile (Age, Gender, etc.).

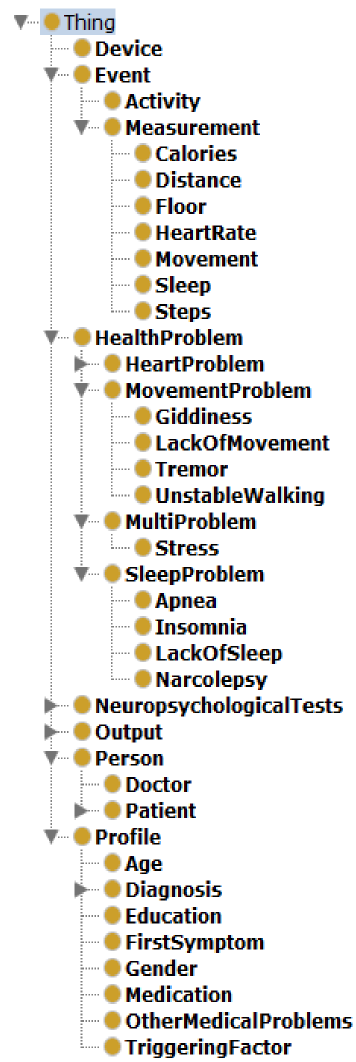

Figure 1. Classes of the proposed ontology.

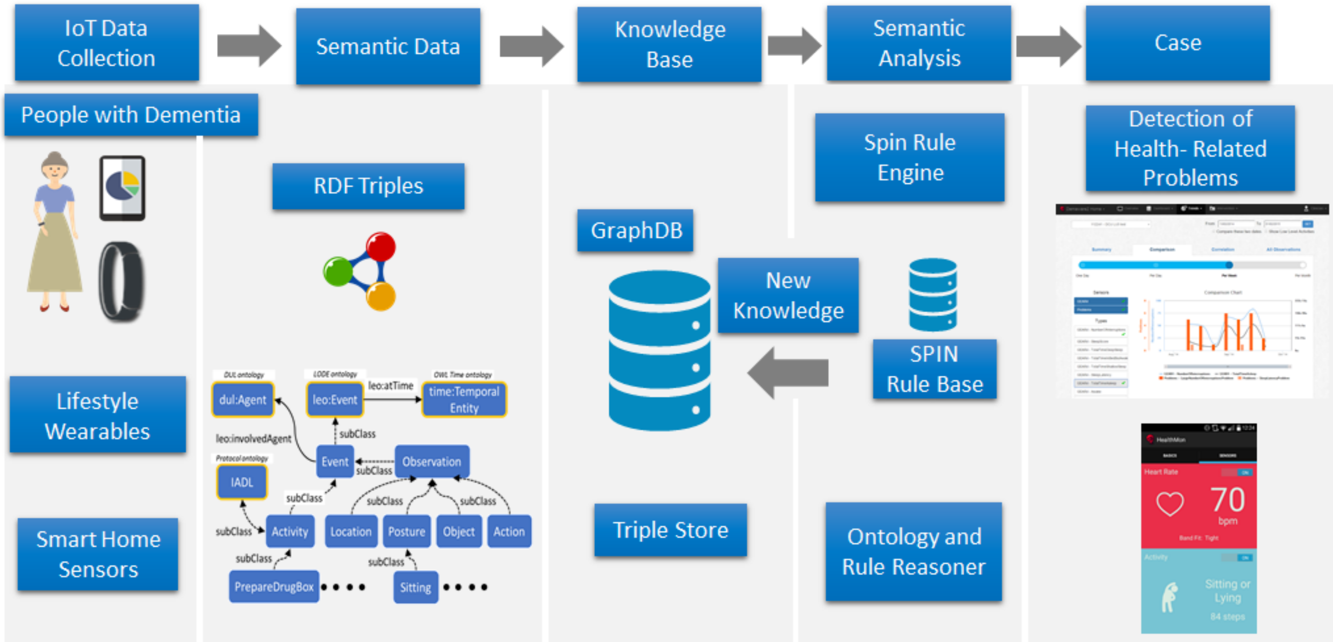

Figure 2. Architecture of the proposed system.

After adding Semantic Web technologies to the raw data and modeling them based on the system ontology, "Semantic Data" are stored in a semantic Graph Database, which constitutes the Knowledge Base of our system. For this purpose, we have chosen GraphDB, an enterprise ready Semantic Graph Database, compliant with W3C Standards. Semantic Graph Databases (also called RDF triplestores) provide the core infrastructure for solutions where modelling agility, data integration, relationship exploration and cross-enterprise data publishing and consumption are important. Querying and reasoning are performed over stored RDF graphs with SPARQL language.

B. *Rule Base*

Table II presents a sample of the semantic rules created after the collaboration of scientists, doctors, psychologists and patients. The rules contained in this section are a subset of the rule base of the proposed system. In every rule, there are upper and lower limits that control whether a condition is satisfied or not. The numerical values of the limits were decided after consultation of the clinicians and the patient users. Thus, for example, in the first rule, the limit for drawing a conclusion of a user's insomnia problem was set at 1800 minutes. In addition, to conclude that the patient needs to exercise more, his steps are limited to less than 80 in one day.

TABLE II. A PRIORI RULE BASE OF THE DIFFERENT SEMANTIC RULES THAT DESCRIBE THE MODELED ACTIVITIES.

Variables (number)	Rule	Problem
Duration in minutes	**Time to fall asleep in a day > 1800**	**Insomnia**
Count of sleep interruptions	**Number of interruptions in a day > 10**	**Restlessness**
Duration in minutes	**Sleep total duration in a day> 480**	**Too much sleep**
Duration in minutes	**Sleep total duration in a day < 300**	**Lack of sleep**
Duration of "Nap" state in minutes	**Asleep in Naps > 100 in a day**	**Increased Napping**
Occurrence of "Nap" State, Occurance of "Night Sleep" state	**Asleep in Naps end time < 2 hours from Sleep start time**	**Nap close to bedtime**
Time Alseep / Time in bed	**Sleep Efficiency < 85**	**Bad Quality Sleep**
Step count, Heart Rate measure, Duration in minutes	**Steps < 50 & Heart Rate > 90 (Fat Burn Zone) for duration > 300**	**Stress or Pain**
Heart Rate measure	**HR < 60**	**Low Heart Rate**
Step count, Heart Rate measure, Duration in minutes	**Steps <1000 & Heart Rate < 80 for duration > 300**	**Inactivity**
Step count, Heart Rate measure, Duration in minutes	**Steps < 500 & Heart Rate < 100 for duration > 800**	**Lack of Movement**
Step count	**Steps < 80**	**Lack of Exercise**

 ISBN: 978-1-61208-763-4

C. Implementation of the rules with SPIN

We used the TopBraid composer [16], a tool for modeling and developing semantic data applications, to present the SPIN rules. Topbraid allows us to easily develop spin rules in the form of SPARQL queries, which is more readable than regular spin syntax. In practice, the following three code blocks present in SPIN three simple semantic rules that were applied to the system ontology.

The following code block shows the implementation of SPIN rule for Sleep problem “Lack of Sleep”. Applying this rule produces the addition of a new property that represents the type of sleep problem “Lack of Sleep” in the objects of the ontology (users of a support system). If the patient's sleep duration is less than 300 minutes, then it is considered that there is a sleep problem (lack of sleep).

SPIN rule for sleep problem “Lack of Sleep”.

```
CONSTRUCT {
?p owl:hasSleepProblem "Lack of Sleep "}
WHERE {
   ?p a :Person .
          ?p :duration ?d.
          FILTER (?d <300 )}
```

The following rule in SPARQL and SPIN adds new knowledge to the system Ontology. If the sleep duration of the patient with dementia is greater than 480 then we conclude that there is a sleep problem (too much sleep).

SPIN rule for sleep problem “Too much Sleep”.

```
CONSTRUCT {
?p owl:hasSleepProblem "Too much sleep "}
WHERE {
   ?p a :Person .
          ?p :duration ?d.
          FILTER (?d >480 )}
```

The following code block shows the implementation of the simple semantic rule “lack of exercise”. If the steps of the patient with dementia are less than 80 and we conclude that there is a lack of exercise.

SPIN rule for problem “Lack of Exercise”.

```
CONSTRUCT {
?p owl:hasProblem "lackOfExersice" }
WHERE {
?p a :Person .
          ?p :steps ?st1.
          FILTER (?st11<80)}
```

IV. USE CASE

For the evaluation of the proposed architecture we consider the following use case scenario. A wearable sensor was given to a patient with dementia in order to monitor his activities. The duration of the measurement is 11 days (20-30 November 2019). The initial sensor data was modeled by using the system ontology and stored in the Knowledge Base. Then, the proposed semantic techniques were applied and in particular the semantic rules of the system were checked. Figure 3 shows the measurement of sleep minutes of the patient. Figure 4 presents the measurements of steps per day of the user. This data is processed, and the results, showing the problems that the patient experiences during this time, are produced.

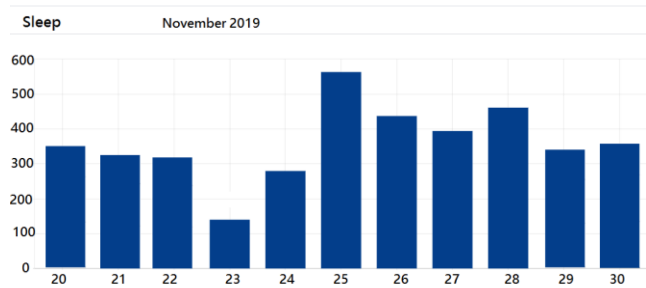

Figure 3. Sleep Minutes of a single patient with dementia whose activity was monitored.

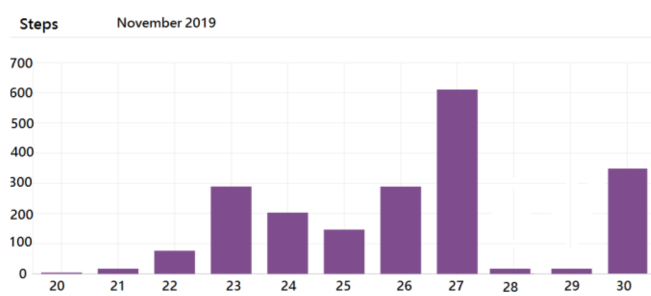

Figure 4. Sleep Minutes of a single patient with dementia whose activity was monitored.

Specifically, as shown in Figure 3, the patient with dementia slept below the limit of 300 minutes (rule 1) on November 23 and 24. The results of these measurements are shown in Figure 5 with the creation and visualization of the "Lack of sleep" problem. In addition, the patient slept above the limit set by rule 2 (480 minutes) on November 25, and this resulted in the creation of the problem “too much sleep”. Finally, in Figure 4 it is observed that on November 20, 21, 28, and 29 the patient took a few steps. The result of this measurement is shown in Figure 5, by creating the problem (rule 3) “Lack of exercise”. This also shows how the user can easily observe the days with a lot and different problems e.g., the 25th, and the days with a few problems e.g. 20th, 21th, 28th, and 29th, at a glance, without going through the raw data each time.

 ISBN: 978-1-61208-763-4

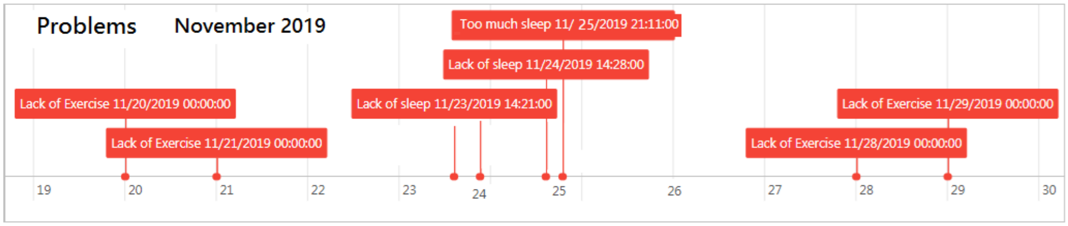

Figure 5. Health-related Problem Detection of a single patient with dementia whose activity was monitored.

V. CONCLUSION AND FUTURE WORK

In this paper, we presented our approach towards the definition of a semantic system for Health-related Problem detection that combines ontologies and SPIN Rules. Architectures related to the proposed framework are listed, and the advantages of using the SPIN language to create semantic rules are presented. The main purpose of the proposed architecture is to generate new knowledge from the original raw data, especially recognition of healthcare problems in the users with dementia. The system is validated through a proof-of-concept use case scenario where a wearable sensor gathers data from a real subject and the framework extracts the expected health-related problems.

As future work, we plan to evaluate the framework in a formal clinical trial with real subjects. Subjects will be recruited in the spectrum of dementia, as well as healthy controls and use the wearables for several months. The framework will be used to extract problems and clinical experts will evaluate its accuracy, usability and usefulness for the disease. In the long run, it will support decision making of the clinicians adjusting their non-pharmaceutical interventions, e.g., a clinician can "prescribe" exercise for lack of activity or relaxation exercises for stress, insomnia and lack of sleep problems.

ACKNOWLEDGMENT

This work was co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH-CREATE-INNOVATE, project code: T1EDK-02668 (https://www.ypostirizo-project.gr/).

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