Spatial Awareness for the Deafblind in Natural Language Presentation using SPIN Rules: A Use Case in the SUITCEYES Platform

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***Abstract*— This paper presents a rule-based approach towards spatial awareness for the deafblind through natural language constructs. The approach entails two components, a novel ontology for the interoperable representation of data pertaining the domain (objects, space, etc.) and a rule set to derive the natural language constructs for spatial awareness and answer related user queries. The rule set is expressed in SPARQL Inferencing Notation (SPIN), which enables simplicity and flexibility in rule definition as opposed to other frameworks. Both are applied in a use case scenario of the SUITCEYES platform for the deafblind, extending it with the ability to answer spatial awareness queries. More specifically, the ontology component uses rules to provide the users of the platform answers to queries regarding their environment. We present those rules and show how they inform the user of their surroundings, using natural language. Furthermore, we provide a differential population solution to avoid overloading the ontology with unnecessary data.**

Keywords- ontology; rules; natural language; SPIN; deafblindness.

I. INTRODUCTION

Communication with and between users with deafblindness is constrained by the medical nature of this disability, ranging from congenital to acquired deafblindness, including worsening sight or worsening hearing or both over time, plus, ultimately, symptoms of ageing as well.

This paper presets an approach towards spatial awareness for the deafblind using an ontology and a rule set to provide the user with information about their environment expressed in natural language and to dynamically update the spatial information by only keeping the most recent and relevant information provided to the ontology. Also, we apply a use-case of our approach in the SUITCEYES platform [1], by testing it with incoming data from the SUITCEYES system. The purpose of our work is to provide a way to represent spatial context and enable spatial awareness using semantic web technologies and rules to form natural language constructs that can support the deafblind.

The rest of the paper is structured as follows: In Section II we present the most related work with our approach and ontologies regarding natural language. In Section III, we present the ontology that was developed, which extends already existing ontologies. In Section IV, we describe our method for providing spatial context in natural language and in Section V we describe our method for dynamically updating the ontology with differential population. Finally, in Section VI we offer a proof of concept, a use-case performed in the SUITCEYES platform.

II. RELATED WORK

More and more Internet of Things (IoT) applications are used for healthcare purposes due to their high interoperability and expressiveness [2][3][4]. These types of applications acquire knowledge from multiple sources and from continuous and heterogeneous data flows [5][6]. Semantic technologies provide comprehensive tools and methods for representing knowledge and producing new ones. IoT environments are increasingly found in home healthcare technologies in actions that create better living conditions for the elderly, through the use of IoT technologies, such as Active and Healthy Ageing (AHA) and Home Ambient Assisted Living (AAL).

Furthermore, in the case of deafblind people, the simple and accurate representation of their surrounding environment is one of the most basic needs for their quality of life. This can be achieved by providing the nature of their surroundings in natural language. Some of the most relevant works for language processing with ontologies are [7][8].

KnowSense [3] is an activity monitoring system for elderly with dementia, deployed in controlled and diffuse environments. Semantic Web technologies, such as OWL 2, are widely used in KnowSense to display sensor and specific application observations, as well as to implement solutions for identifying activities and identifying problems in everyday life activities with the aim of clinical evaluation in various stages of dementia. Description Logic Reasoning (DL reasoning) for activity detection and SPARQL questions are used to extract clinical problems.

ACTIVAGE [4] is a large-scale pilot project, with the purpose of developing Smart Living solutions that strengthens active and healthy aging. The ACTIVAGE IoT Ecosystem Suite (AIOTES) project, contains a set of techniques, tools, and methodologies (rule-based reasoning, interoperable ontologies, etc.) that increases semantic interoperability at different levels between heterogeneous IoT platforms. The approach uses multiple mechanisms of reasoning that can

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improve the understanding of patients' heterogeneous data and help generate new knowledge by providing services to end users.

Dem@Care [4] is a system based on heterogenous sensors that provides support for independent living for elder people with dementia or similar health problems. This approach incorporates 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 leads to feedback and decision support, which is communicated to end users through appropriately designed user interfaces. The support includes various clinical scenarios, both short (trials in hospital settings) and long term (daily living at work), for independent living.

In [9], a system for healthcare in Smart Home environments is developed, which considers social relationship-based contexts to provide a fully personalized healthcare service.

An ontology-based sensor selection for real-world wearable activity recognition is presented in [10], in which the use of ontologies is proposed to thoroughly describe the wearable sensors available for the activity recognition process. This enables the semantic selection of sensors to support a continuity of recognition.

In [7], an extended version of a linguistic ontology is presented that works particularly with space. Language regarding space, spatial relationships and actions in space is covered and an ontological structure that relates such expressions with ontology classes is developed. Finally, examples of the ontology's results based on natural language examples are presented.

In [8], a project in which ontologies are part of the reasoning process used for information management and for the presentation of information is presented. Both accessing and presenting information are mediated via natural language and the ontologies are coupled with the lexicon used in the natural language component. This work, as well as [7], is related with the natural language aspect of our approach.

An approach to transform natural language sentences into SPARQL is proposed in [10], with the use of background knowledge from ontologies and lexicons. The results of this approach show that the diagnosis process and the data search for a broad range of users is improved.

In [11], an evaluation is made on how efficient the SPARQL query language is and the SPARQL Inferencing Notation (SPIN) when utilized to identify data quality problems in Semantic Web data automatically, and within the Semantic Web technology stack.

In the case of deafblind patients, the simple and accurate representation of their environment is one of the most important needs. In [7][8][9] even though forms of natural language processing through ontologies are proposed, they do not involve healthcare or wearable sensors. For the healthcare related work [2][3][4] and [9][12], the natural language presentation of information component is absent. In the SUITCEYES project, we combine techniques involving both semantic technologies for healthcare and representation of the environment of the deafblind patients using natural language. The SUITCEYES ontology [13] includes concepts for spaces, e.g., rooms, halls, stairways etc., and entities found in them, e.g., objects and persons. In this work, we reuse and extend this ontology with classes and properties, and use rules expressed in SPARQL and SPIN notation, to achieve spatial awareness with natural language constructs for the deafblind.

III. The Proposed Framework

A. *The Proposed Ontology*

1) *Ontology Components*

The SUITCEYES ontology [13] is extended for the purposes of this work can be found online [14]. One of its aims is to integrate heterogeneous, multimodal input from different sensors in a formal and semantically enriched basis, and thus to combine user's context-related information so as to provide enhanced situational awareness that can potentially augment users' navigation and communication capabilities. The ontology was developed to augment its semantic interoperability with other ontologies that exist in the domains of interest and to enrich its semantic representation capabilities for covering the additional concepts and functional requirements that may emerge through any system addressed to deafblind people.

In ontology engineering, it is common practice to reuse existing third-party models and vocabularies during the development of a custom ontology. This approach was also followed here, including the adoption of third-party vocabularies in order to rely on previously used and validated ontologies.

The semantic representation of objects and activities from the Dem@Care ontology [4] was adopted, which contains a set of descriptions of every-day activities and common objects used in an every-day context that are highly relevant to our goals. Moreover, the ontology is using SOSA/SSN [15] ontologies for representing sensors and the respective observations. The Friend-Of-A-Friend (FOAF) specification [16] is used for representing persons and social associations. Finally, the Smart Energy Aware Systems (SEAS) Building Ontology [17] was integrated, which is a schema for describing the core topological concepts of a building, such as buildings, building spaces and rooms. Figure 1, shows the basic classes imported from existing ontologies for interoperability.

2) *Ontology Concepts*

Some of the basic classes of the ontology represent objects, spaces and people that can be detected as raw data form sensors, such as cameras, or processed data, through a visual analysis component. For example, some of the objects that can be found in the ontology are computer, laptop, alarm clock, mug, table, chair and other everyday objects and some of the spaces include bedroom, bathroom, living room and other spaces that can usually be found in a home environment. We extend these concepts by adding further objects, spaces and rooms that could be useful to any deafblind user. In Figure 2, the main object entities of the combined ontologies are presented, while in Figure 3, the main spaces, such as rooms, are presented.

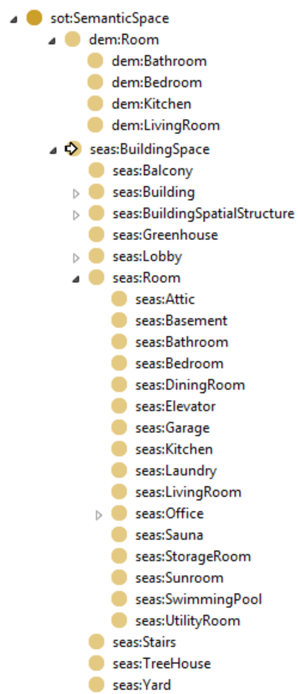

Figure 1. Classes imported from the Dem@Care and SEAS ontology for interoperability

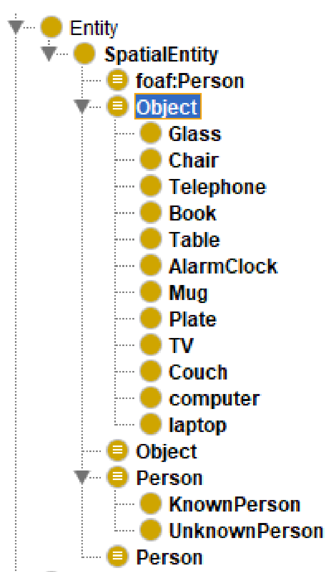

Figure 2.Object Class of the ontology

3) *Spatial Relations*

Topological relations of geometric objects have been widely described in literature and are generally utilized for navigation-, location- and context-based services. More specifically, the Egenhofer relations [18] or the DE-9IM topological model [19] can be used to specify how an object is located in space in relation to some reference object. For any two spatial objects, which can be points, lines and/or polygonal areas (represented by the definition of a bounding box), there are 9 relations derived from the model, which are:

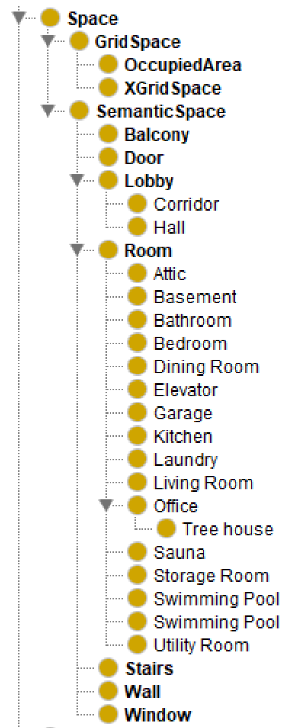

Figure 3. Space Class of the ontology

equals, disjoint, intersects, touches, contains, convers, covered by, and within. Distinct specializations of topological relations also exist, such as the so called alignment relations (horizontally aligned or vertically aligned) and orientation relations (left of, right of, top of and bottom of); these are considered in literature as mereology and parthood relations, as described in detail in [20] and visualized in Figure 4, from different perspectives (object-centered vs observer-centered).

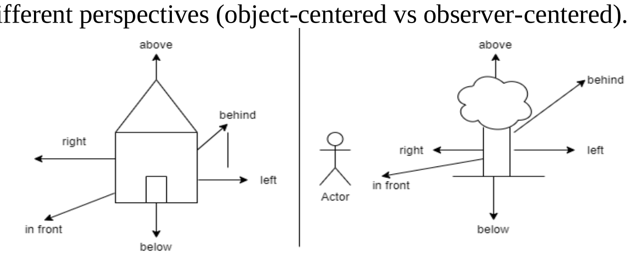

Figure 4. Object centered (left) and observer-centered (right) frames of reference

We focus on specific spatial relations that have to do with the orientation (left/right), existence (in a room) and the distance (far/close/immediate). Thus, in the ontology, an entity that occupies space (e.g., persons, objects) is considered as a SpatialEntity and the occupied space (e.g., a room or a location) belongs to the SemanticSpace representation. These two aspects formulate the respective entity's Spatial Context, which provides information regarding the entity's relationship to the semantic space it is located in. Examples include: in, on, left, right, far, close, etc. The aforementioned concepts are depicted in Figure 7.

B. *Spatial Information Presented in Natural Language*

In Table 1, we present a list of indicative queries that are used in the ontology to provide the user with a natural

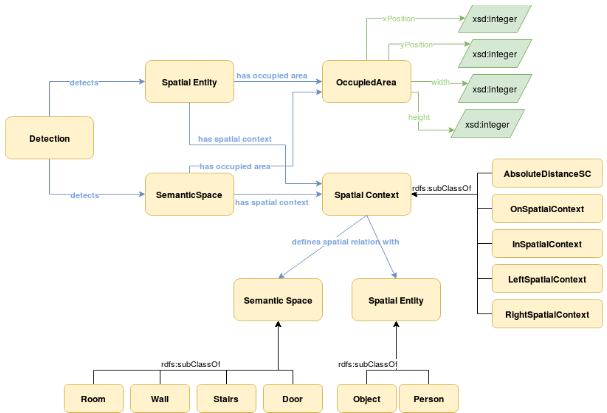

Figure 7. Extended Semantic Spaces and Spatial Contexts of the SUITCEYES ontology

language output regarding spatial information of their surroundings. In these queries, variables are used to cover a broad number of objects and spatial contexts. This kind of inference is achieved by using a set of ontological rules, written in SPARQL/SPIN notation, that run on top of the ontology, whenever a specific query is triggered by the user. Within the context of this scenario, a list of indicative queries have been created that can dynamically change on specific aspects, i.e., to cover different entities of interest, different spatial relations (with respect to the distance of position left/right), etc.

TABLE 1. LIST OF RULES

#	Query	Nat. Lang. Output
1	Where is my <object >?	Your <object > is on your <right/left spatial context> side, <close/far spatial context> to/from you.
2	How many <objects> are on my <right/left spatial context> side?	<# counted> objects, an <object1> and an <object 2> are on your <right/left spatial context> side.
3	Which <objects> are <spatial context> to/from me?	An <object1>, <object2> and object3> are located <spatial context> to/from you.

The variables in the above queries are given a specific value, depending on what the user wants to ask. For example, the first query can be transformed in natural language to: “Where is my laptop” and its output can be: “Your laptop is on your right side, close to you”. The implementation of this query is presented as an ontological rule written in SPARQL/SPIN syntax in Figure 5, using synthetic data that we created that include various objects and spatial contexts. Most of our ontological rules use SPARQL CONSTRUCT and DELETE/INSERT commands, in order to create new triples in the ontology and thus enrich the knowledge stored in the schema.

In Figure 6, the implementation of the #3 query is presented, which in natural language translates to “Which objects are close to me?”, which using our synthetic data produces the output: “A laptop, a TV and a chair are located close to you”. For this query, we have skipped the construct rule, which is the same as the #1 query.

```
CONSTRUCT{
        ?detection sot:producesOutput ?output.
        ?output sot:refersToDetection ?detection.
        ?output a sot:Output.
        ?output sot:hasTextualDescription ?description
}
WHERE{
BIND(sospin:Function_SelectLatestObjectDetection() AS ?detection).
?detection a sot:Detection.
?detection sot:detectsObject ?object.
?object a ?objectType.
FILTER(?objectType = sot:Laptop).
?object rdfs:label ?objectName.
?object sot:hasSpatialContext ?spatialContext.
?spatialContext a ?spatialContextType.
?spatialContextType rdfs:subClassOf sot:spatialContext.
FILTER((?spatialContextType = sot:RightSpatialContext) ||
(?spatialContextType = sot:LeftSpatialContext)).
BIND(sospin:Function_leftRightContext(?spatialContext) AS
?leftright_annotation).
FILTER((?spatialContextType = sot:CloseSpatialContext) ||
(?spatialContextType = sot:FarSpatialContext).
BIND(sospin:Function_CloseFarContext(?spatialContext) AS
?closefar_annotation).
BIND (BNODE() AS ?output).
BIND(CONCAT(?objectName, "is on your", ?leftright_annotation, "
side", ?closefar_annotation, " to you") AS ?description).
}
```

Figure 5. SPARQL/SPIN rule for query #1

```
WHERE{
        BIND(sospin:Function_SelectLatestObjectDetection() AS
?detection).
        ?detection a sot:Detection.
        ?detection sot:detectsObject ?object.
        ?detection sot:detectsObject ?object2.
        ?detection sot:detectsObject ?object3.
        ?object a ?objectType.
        ?object2 a ?objectType.
        ?object3 a ?objectType.
        ?object sot:hasSpatialContext ?spatialContext1.
        ?object2 sot:hasSpatialContext ?spatialContext2.
        ?object3 sot:hasSpatialContext ?spatialContext3.
        ?spatialContext a ?spatialContextType.
        ?spatialContext2 a ?spatialContextType2.
        ?spatialContext3 a ?spatialContextType3.
        ?spatialContextType rdfs:subClassOf sot:SpatialContext.
        ?spatialContextType2 rdfs:subClassOf sot:SpatialContext.
        ?spatialContextType3 rdfs:subClassOf sot:SpatialContext.
        FILTER((?SpatialContextType = sot:closeSpatialContext)
        && (?SpatialContextType2 = sot:closeSpatialContext) &&
        (?SpatialContextType3 = sot:closeSpatialContext)).
        BIND(sospin:Function_CloseFarContext(?spatialContext)
                AS ?closefar_annotation).
        BIND (BNODE() AS ?output).
        BIND(CONCAT(“A “, ?objectName, “ , a “,
                ?objectName2, “ and a “, ?objectName3, “, are
                “. ?closefar_annotation, “ to you.” AS
                ?description).
}
```

Figure 6. SPARQL/SPIN rule for query #3

C. *Dynamic Update of the ontology with Differential Population Procedure*

In our proposed method, we use an efficient approach to store the incoming data to the ontology. We call this approach "differential population" of the ontology, which means that instead of populating the ontology with every Detection type data coming from every message in the message bus, a method is applied that checks if the incoming detection data is already included in the ontology. If it is, then we change only the timestamp of the existing Detection instance, otherwise we add the new Detection to the ontology. This method is implemented in java code and the pseudocode is presented in Figure 8.

```
Procedure: Differential Population
Data: D (Detection type object obtained from message bus)

for each D_i stored in ontology do
    if D.detects_object == D_i.detects_object and
    D.spatialContext == D_i.spatialContext then
        D_i.timestamp = D.timestamp;
    end
end
```

Figure 8. Pseudocode for the Differential Population procedure

By using this technique, we limit the volume of data that are inserted in the ontology by only applying a simple check each time a message arrives from the message bus. This increases efficiency, considering that in a home environment the same objects could be detected in the same place multiple times (e.g., a TV almost never changes place in a home) and that many sensor systems continuously send data via their sensors.

IV. PROOF OF CONCEPT – THE SUITCEYES USE CASE

The SUITCEYES system tries to enrich the spatial awareness of the deafblind by implementing a solution involving a vest with a processing unit that receives raw information from sensors and actuators (mainly cameras and haptograms), and advanced information through a visual analysis component and a semantic component. An important aspect of the platform is the integration of information coming from the environment (via sensors) and from the system's analysis components (camera feed and visual analysis). The most important sensors of the system are static cameras placed in rooms and cameras integrated a vest that the deafblind user wears (dynamic). In this sense, the ontology is primarily focused on semantically representing aspects relevant to the users' context, in order to provide them with enhanced situational awareness and augment their navigation and communication capabilities. More importantly, the ontology also serves as the connection between environmental cues and content communicated to the user via haptograms. The deafblind user receives the output of the ontology via haptic sensors. i.e., a vest that vibrates in specific patterns on the user's back and a special tablet that has haptic capabilities so the user can form patterns to ask questions regarding their environment. These mechanics and translation patterns from text to haptics are outside of the scope of this paper, which focuses on the information models and rules to form the natural language constructs to be translated. To test the correctness of those constructs formed using the rules, we have used synthetic data received by the SUITCEYES system.

We present the output of the SPARQL/SPIN rule presented in Figure 5 by using the Protégé [21] software. In Figure 9, we present the object and description returned by the query. The description will be used as the output to the user.

object	description
Laptop	"Your Laptop is on your right side, close to you."^^<http://www.w3.org/2001/XMLSchema#

Figure 9. Query output of "Where is mylaptop"

In Figure 10 and Figure 11, we present the objects returned from the query "Which objects are close to me" with their spatial context, and the output that the user will get as textualDescription.

obj	spatialContext	obj2	spatialContext2	obj3	spatialContext3
Laptop	Close	Chair	Close	TV	Close

Figure 10. Objects and their Spatial Context from query #3

queryOutput	textualDescription
QueryOutput	"A Laptop, a Chair and a TV are close to you"^^<http://www.w3.org/2001/XMLSchema#string>

Figure 11. Query output of "Which objects are close to me"

By receiving the expected results regarding our synthetic data, we validated the correctness of our queries.

We also used the same synthetic data to test the differential population procedure. In the example below, we assume that a detection of a laptop in the living room exists in our ontology and that a same new detection arrives from the SUITCEYES system with a more recent timestamp. In Figure 12, we present what the outcome would be without using our differential population method, i.e., the storing of 2 similar detections.

detection	obj_detected	where	timestamp
Detection_1	Laptop	Living_Room	"2020-08-25T13:18:30Z"^^<http://www.w3.org/2001/XMLSchema#dateTimeStamp>
Detection_2	Laptop	Living_Room	"2020-08-25T13:20:00Z"^^<http://www.w3.org/2001/XMLSchema#dateTimeStamp>

Figure 12. Detections saved without the differential population procedure

In Figure 13, the outcome of the same incoming detection is presented, but with using the differential population procedure. Here, only the first detection is stored, with its timestamp field changed to match that of the second, incoming detection.

detection	obj_detected	where	timestamp
Detection_1	Laptop	Living_Room	"2020-08-25T13:20:00Z"^^<http://www.w3.org/2001/XMLSchema#dateTimeStamp>

Figure 13. Detections saved with the differential population procedure

This absence of almost identical detections could save a lot of space in real applications that continuously receive and store data.

V. CONCLUSION AND FUTURE WORK

In this paper, our method for providing spatial awareness to people with deafblindness, using natural language and semantic reasoning with SPIN/SPARQL notation was presented. Also, the differential population technique used for updating the data in the ontology was proposed. Finally, we tested our methods using synthetic data coming from the SUITCEYES platform.

With today's technology, people with deafblindness can be provided with advanced tools that enhance their spatial awareness. For our future work, we aim for the integration of our methods with the SUITCEYES project in two phases. The first phase includes the use of real data provided by sensors, such as cameras and the visual analysis component, and the second phase includes deafblind users' interaction with the system.

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