A lightweight Ontology for real time semantic correlation of situation awareness data generated for first responders

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***Abstract*—In case of an emergency, the immediate action of the first responders is crucial for saving human lives. Their intervention requires specialized instrumentation, available at all times and easily accessible, which meets stringent requirements in terms of detection accuracy, quick localization, and reduction of false alarms. This work proposes a novel ontology-based methodology which integrates data from IoT devices in the frame of a Situation Awareness (SA) semantic model. The proposed model aims at providing the conceptual representation of core entities, which will be represented by concepts and will cover specific aspects of the SA domain, such as proper decision making during the course of an emergency operation, conceptual representation of critical information required for such tasks and of important information flows which potentially exist between involved actors. Finally, we set the scene towards validating the efficiency and efficacy of our proposed model directly in the field, through seven (7) use cases.**

***Index Terms*—real time emergency management, ontology, situation awareness model, EMS, first responders, semantics**

I. Introduction

Human existence has always been threatened by risks from various natural and human-caused disasters such as fires, floods, earthquakes, industrial accidents or acts of terrorism, all of which pose a significant threat to human beings. Major adverse events such as these have the potential to cause catastrophic loss of life and natural destruction [1].

In case of a crisis, immediate action is crucial and, consequently, the fast and efficient reaction of the first responders plays a pivotal role in life-saving intervention, urban search and rescue, and in overall disaster response. First responders require specialised instrumentation, available at all times, easily accessible, which meets stringent requirements in terms of detection accuracy, quick localisation and reduction of false alarms. In addition, the response requires a high and wide range of expertise, which is associated with the level of the situational awareness (SA) of the experts. The term SA refers to the ability of the experts team to respond to critical situations, to make right decisions and to communicate with the other individuals and teams who comprise the responding social system [2].

Proper and efficient SA is highly dependent on the information which is acquired and shared within the team, which ideally should be easy to understand, fast to process and clear about the cues which trigger action [3]. However, since such information may stem from different sources, such as satellite images, sensors, historical databases or social media content, it is often heterogeneous and cannot be easily integrated [4]. Therefore, there is a need for information systems to support such challenges in SA information production, sharing, support, decision-making and actions. With the advent of Semantic Web technologies and the Internet of Things (IoT), semantic models have been proposed to cover numerous SA scenarios [5], [6]. Moreover the use of ontologies may help overcome semantic heterogeneity and guarantee a consistent framework of shared information in the domain of crisis management [7]. Ontologies offer rich representations of machine-interpretable semantics for systems and databases, serving as a means to enable semantic interoperability of heterogeneous systems. [8].

This work presents an ontology which offers real time semantic correlation of situation awareness data and entities coming from various types of sensors, drones and robot monitoring systems for the purpose of supporting the management of decisions of first responders during search and rescue operations. To that end, in section 2 we present a survey of existing ontology-based methodologies for emergency management. Section 3 presents our methodology regarding the model specification (including vocabularies and ontologies incorporated into the model for additional usability and compatibility with existing widely used standards) and the model itself. Finally, the evaluation of the model and conclusions are presented in

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section 4.

II. Related Work

One of the greatest challenges which first responders and emergency teams face during a crisis is dealing with inadequate information access, semantic differences and inconsistency of heterogeneous data sources [9]. Since crisis management requires a robust and efficient response framework, facilitating quick and reliable data exchange is key for successful emergency operations and efficient SA in case of an emergency. To address the challenges of interoperability in crisis management, recent works have explored the use of ontologies for facilitating decision support during a crisis. Ontologies serve as the foundation for providing a semantically unified representation of concepts and relationships, which is shareable by different users and is processable by machines [10].

In [4], an ontology for situational awareness and events during emergency scenarios that facilitates social media conversation and real-time monitoring by enforcement agencies is proposed. This work, namely *empathi*, takes into consideration the aforementioned conceptualizations (taxonomies and vocabularies) in disaster scenarios while relying on a promoted representation. It also introduces new concepts and relations in capturing situation awareness, such as surveillance information, human sensing reports or humanitarian events. A crisis ontology model which assists with the representation of events and related information during emergency crises is presented in [11]. The model is based on the NeOn methodology [12] and focuses on providing a relatively simple model which can be easily reused and extended for specific situations. In [13], a collaborative decision-making approach in the context of crisis situations such as road accidents and which is based on ontologies and multi-agent systems, is proposed. Another work [10] proposes an ontology for climate crisis management, which merges all aspects of crisis management, such as the representation of a crisis (along with climate parameters that may cause climate crises), sensor analysis, crisis incidents, related impacts and first responder unit allocations.

The POLARISC Ontology [8], [14] (POLARISCO) is a modular ontology which defines the Knowledge of French emergency responders who are involved in the disaster response process. It is developed in the context of the French project POLARISC ("Plateforme OpérationnelLe d'Actualisation du Renseignement Interservices pour la Sécurité Civile"). The POLARISC project started in 2017 to propose an ontology-based crisis information management system for operational disaster response. POLARISCO extends from the Basic Formal Ontology (BFO), which serves as an upper-level ontology, as well as the Common Core Ontologies (CCO), as a mid-level ontologies, while it reuses classes from the Public Safety and Emergency Management (PS/EM) and Disease(DO) ontologies, respectively.

Taking into consideration recent works in SA models which were described above, there exist some common features that a successful SA model should pertain. For example, fast and robust performance in decision-making as well as the integration of various datasets and services in a unified and efficient way in order to harmonize heterogeneous information. Moreover, efficient representation of information is key. Since resources are most likely to have overlapping terminology and involved actors and properties, it is paramount to provide a representation which will be minimal and provide maximal coverage. Additionally, the representation should be as flexible as possible to foresee potential adaptations and extensions.

Although existing literature proves that many technologies for crisis management are reasonably available, and many others are in the pipeline, one could note that their introduction into an operational crisis management environment is far beyond a typical research matter. Moreover, existing studies do not introduce Internet of Things (IoT) devices and other state of-the-art smart monitoring systems. Of note is also the fact that, while certain existing ontologies address certain aspects of all dimensions of the general situation awareness decision support, rarely does a model endeavor to challenge all of them at once, let alone under real-life circumstances.

In light of the above, this work presents an ontology, namely the Search and Rescue model, which aims to define and represent the types of critical information required in order to support first responders in crisis management. Within this context, the proposed ontology offers real time semantic correlation of situation awareness data coming from various types of sensors, drones and robot monitoring systems for supporting management decisions.

In this work we aim to:

- define the decisions which first responders and other actors involved in crisis management make during the course of the different operations.
- represent the types of critical information required in order to support the various actors with their tasks in emergency cases.
- represent the important information flows which potentially exist between involved actors, mediated by a knowledge management system in the form of notifications, alerts and timely information supply.

III. Proposed solution

This work proposes an ontology model which includes the main concepts and relationships between actors in emergency situations, in the context of the Search and Rescue Platform. The ontology thus represents the disastrous events, the resources, the activities, the actors, the actions and the agencies which are involved in such situations, as well as the relationships and semantic correlations among them. In order to define an ontology, it is imperative to define the central entities and data comprising the model. For our needs, we build upon the state-of-the-art models/ontologies of POLARISCO [8], IMPRESS [15], foaf [16] and Geonames [17] as a basis, while we update and expand them for our needs. For compatibility purposes with widely used state-of-the-art, we map all entities and properties appearing in our model into their respective entities and properties in the state-of-the-art models we use as a basis, where applicable. This is achieved via the `owl:sameAs` property, which correlates two entities or properties representing the same piece of semantic information.

A. Entity classes

In order to supplement the understanding of our proposed ontology, the entities/classes of the model, as well as their object property relations, are presented in a grid illustrating their hierarchy (left to right indicates topmost to bottom classes) and are displayed in Figure 1. The main/core entities of the model are the following:

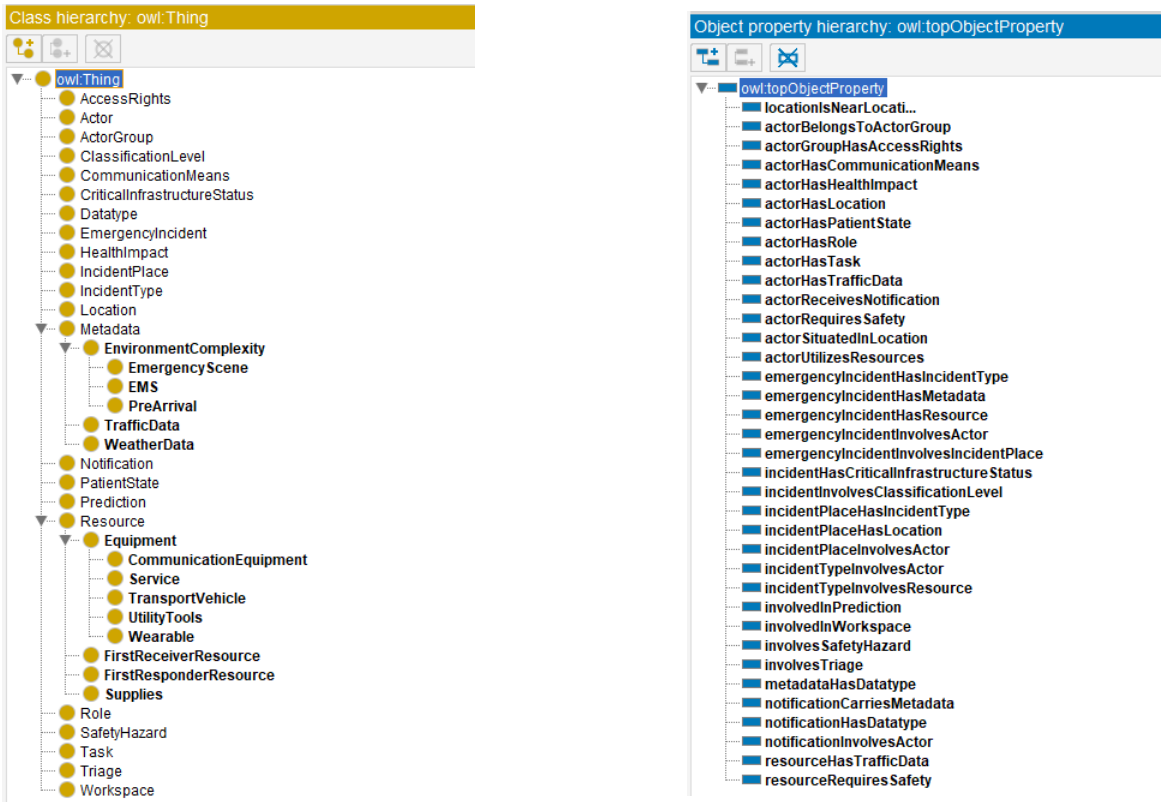
- **AccessRights**: The rights granted by a system. These are closely correlated with actor groups and roles.
- **Actor**: An agent participating in operations.
- **ActorGroup**: A conceptual group one or more actors belong to.
- **ClassificationLevel**: The classification level of the danger of the incident.
- **CommunicationMeans**: The means of communication in a Search and Rescue operation.
- **CriticalInfrastructureStatus**: The status of the critical infrastructure throughout an operation.
- **Datatype**: The datatype of data. Necessary when upholding standards in data exchange between services and components.
- **EmergencyIncident**: An emergency incident.
- **HealthImpact**: The health impact which can be caused by a specific operation.
- **IncidentPlace**: The place an incident has occurred.
- **IncidentType**: The type of incident which has occurred.
- **Location**: An entity representing a location. Correlated with entities such as resources, actors and incidents.
- **Metadata**: An entity representing metadata. Metadata is a top-level entity, which further divides into:
  - **EnvironmentComplexity**: This entity represents metadata expressing the complexity of the environment throughout an operation. It divides into:
    * **EmergencyScene**: This represents metadata about the scene of an incident.
    * **EMS**: This represents information about emergency medical services involved in an incident.
    * **PreArrival**: This represents metadata on pre-arrival to an incident.
  - **TrafficData**: This entity represents traffic metadata throughout an operation.
  - **WeatherData**: This entity represents weather metadata throughout an operation.
- **Notification**: An entity representing a notification sent from one actor to another.
- **PatientState**: An entity representing the state of a victim.
- **Prediction**: An entity representing prediction data for DSS services in the project.
- **Resource**: An entity representing resources used throughout operations. Further divided into:
  - **Equipment**: This entity represents equipment (usually for actors). It is further divided into:
    * **CommunicationEquipment**: Equipment used by actors to communicate.
    * **Service**: A service utilized in operations.
    * **TransportVehicle**: A transport vehicle involved in an operation.
    * **UtilityTools**: Utility tools and extras involved in operations.
    * **Wearable**: A wearable device such as a helmet, VR glasses etc.
  - **FirstResponderResource**: This entity represents a first responder resource.
  - **FirstReceiverResource**: This entity represents a first receiver resource.
  - **Supplies**: This entity represents general supplies.
- **Role**: An entity representing a role. Closely correlated with actor groups and actors. The role can be conceptual throughout operations, or for granting access rights to specific system functionalities.
- **SafetyHazard**: An entity representing a safety hazard.
- **Task**: This represents a task to be executed. Correlated with actors.
- **Triage**: This represents a triage entity.
- **Workspace**: This entity represents a workspace throughout operations. The workspace involves entities such as actors, locations and resources.

B. Object properties

Leveraging subtyping relations among the ontology's entities, the defined object properties are as flexible as possible with respect to the entity type of their semantic domain and range. This means that each object property tries to link higher-level classes as much as possible, since this implies that lower-level classes having the same parents can also utilize these properties themselves. The object properties of the model described in Figure 1b.

C. Data properties

Regarding data properties, the vast majority have an intuitive data type. However, some have a more complex datatype, such as `xsd:XMLLiteral`. The reason for this is to keep structured information in a serialized format, in order to better assist services consuming such information from the system. For example, services might need to store into the model a structured `JSON` message indicating a plan of action to be taken by first responders and then, another service will get this information from the system in order to forward it to the first responders directly. If the two services have already agreed upon the message's representation, then they can just deserialize this information and use it directly, instead of being forced to reconstruct it manually by parsing each field individually. In other words, at certain parts of the ontology we compromise the details/expressivity of the model in favor of assisting services in utilizing important information. Naturally,



(a) Classes.

(b) Object properties.

Fig. 1: Class and object properties of the SA model ontology.

throughout Search and Rescue's development, this design is subject to change, in order to better facilitate the needs of the components and the end users and as the model gets tested in real-time.

It should also be noted that we will take into consideration the EDXL standards [16], when representing messages. EDXL is a suite of XML-based messaging standards which facilitate emergency information sharing between government entities and the full range of emergency-related organizations. EDXL standardizes messaging formats for communications between these parties. It was developed as a royalty-free standard by the OASIS International Open Standards Consortium, while it was designed to enable information about life-saving resources to be shared across local, state, tribal, national and non-governmental organizations. Implementation of EDXL standards aims to improve the speed and quality of coordinated response activities by allowing the exchange of information in real time.

D. Interlinking with state-of-the-art ontologies

In this section, we present the semantic linking to other ontologies which are considered state-of-the-art and which have been already presented in this document. It should be noted that some central ontologies like skos, Geonames and foaf are already included in bigger ontologies such as IMPRESS [15]. For the sake of simplicity, we will discuss the links towards bigger ontologies which might have already incorporated smaller ones and we will provide this information explicitly, where applicable.

1) *POLARISCO:*

- Classes:
  - **http://www.ontologylibrary.mil/CommonCore/Mid/AgentOntology#**
    Agent: This entity corresponds to the Actor class represented in our ontology.
  - **http://purl.obolibrary.org/obo/BFO_0000023**:
    This entity corresponds to the Role class represented in our ontology. More specifically, it is part of POLARISCO's BFO (Basic Formal Ontology).
  - **http://purl.obolibrary.org/obo/BFO_0000011**:
    This entity corresponds to the IncidentPlace class represented in our ontology. More specifically, it is part of POLARISCO's BFO (Basic Formal Ontology).
- Object Properties:
  - **http://www.ontologylibrary.mil/Common Core/Mid/AgentOntology#**
    uses: This property corresponds to the actorUtilizes-Resources object property of our ontology. Part of POLARISCO's CCO (Common Core Ontology).
  - **http://wwww.obofoundry.org/ro/ro.owl#**
    located_in: This property corresponds to the inci-

dentPlaceHasLocation object property of our ontology.

  - **http://www.ontologylibrary.mil/CommonCore/Domain/SpaceObjectOntology#has_payload**: This property corresponds to the notificationCarriesMetadata object property of our ontology. Part of POLARISCO's CCO (Common Core Ontology) and, more specifically, of the Space Object Ontology.

2) IMPRESS:

- Classes:
  - **http://fp7-impress.eu/EOPHC/Incidents**: This property corresponds to the EmergencyIncident class of our ontology.
  - **http://xmlns.com/foaf/0.1/Agent**: This property corresponds to the Actor class of our ontology. Part of foaf ontology.
  - **http://fp7-impress.eu/Activity/Communication**: This property corresponds to the CommunicationMeans class of our ontology.
  - **http://fp7-impress.eu/Person/HealthStatus**: This property corresponds to the PatientState class of our ontology.
  - **http://fp7-impress.eu/Resource/Equipment**: This property corresponds to the Equipment class of our ontology.
  - **http://fp7-impress.eu/Resource/Vehicles**: This property corresponds to the TransportVehicle class of our ontology.
  - **https://www.auto.tuwien.ac.at/downloads/thinkhome/ontology/WeatherOntology.owl#WeatherPhenomenon**: This property corresponds to the WeatherData class of our ontology.
  - **http://www.w3.org/2003/01/geo/wgs84_pos#SpatialThing**: This property corresponds to the Location class of our ontology. Part of Geonames ontology.
- Object Properties:
  - **http://www.purl.org/wai#plays**: This property corresponds to the actorHasRole object property of our ontology.
  - **http://www.xmlns.com/foaf/0.1/based_near**: This property corresponds to the locationIsNearLocation object property of our ontology. Part of foaf ontology.
- Data Properties:
  - **http://www.w3.org/2003/01/geo/wgs84_pos#alt**: This property corresponds to the hasAltitude data property of our ontology. Part of Geonames ontology.

IV. Evaluation and Conclusions

This work proposes an ontology for crisis management which represents data such as disastrous events, resources, activities, actors, actions and agencies which are involved in such situations, as well as the semantic correlations of relationships among them. A highlight of the proposed approach is reaching a good compromise between expressivity of semantic concepts and a representation which greatly accommodates efficient and timely real-time information flow. A number of exciting applications of the proposed semantic ontology are opened based on the results of this work. More specifically, the proposed ontology is going to be utilized in seven (7) use cases in the context of the Search and Rescue project. The use cases are as follows:

- Use case 1: Victims trapped under rubble in Italy. This use case is going to test a real-life crisis scenario in which victims are trapped under rubble. Our model will to be utilized as a central portal of information management and semantic representation of information flow for decision support of the command center.
- Use case 2: Plane crash, mountain rescue, non-urban in Greece. In this use case, a forced airplane landing will be simulated in a mountainous area which is isolated without road access. Our model is going to be utilized as a central information hub with the aim of maintaining state status during timely intervals throughout the operation. Decision support systems of the Search and Rescue project are going to take into consideration feeds of live data from sensors, robots and sophisticated devices, as well as the information provided by our model in order to efficiently guide first responders during the pilot.
- Use case 3: Earthquake and heavy storms between Vienna Rail Station and Kufstein railway station in the cross-border between Austria and Germany. The simulation involves collapsed structures such as damaged buildings and communication break downs because of lack of power supplies. In the context of this scenario, our model is going to represent proper geospatial information and correlations of positions, equipment and teams of first responders, in order to monitor the situation in real-time as fast as possible to properly guide first responders.
- Use case 4: Two-pronged threat between a forest fire which expands rapidly and a threat in a nearby industrial zone in the Attica region of Greece. In this scenario, our model is going to be responsible for proper semantic correlation of geospatial information, locations, actors, triage teams, equipment of first responders and will contribute towards the timely communication of messages among actors.
- Use case 5: Victims trapped under rubbles in France. In this use case, our model's utilization is going to be largely equivalent to Use case 1.
- Use case 6: Resilience Support for Critical Infrastructures through Standardised Training on CBRNE (chemical, biological, radiological/nuclear, explosive) in Romania. In this scenario, specialized staff will undergo standardized training against CBRNE hazards management. Our model will contribute proper communication messages among the relevant actors, as well as properly representing the

situation of the scenario in a timely fashion.

- Use case 7: Chemical substance spill in Spain, after an accident in a factory that derives in chemical spill in a building, threatening the health of the workers of the factory. The Use case involves real life simulation of S&R of victims in chemical risk emergency situation. In the context of this scenario, our model will represent critical environmental hazards of chemical substances and proper information flows among communicating actors. In addition, the model will forward relevant information with the proper actions first responders should take according to the decision support analysis and the instructions of the command center.

The merit of our model is going to be thoroughly tested against the harsh conditions of each use case of the project, which are going to serve as pilots simulating real-time crisis situations. We are looking forward towards reporting our observations, the strengths and potential limitations of our model in future work.

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