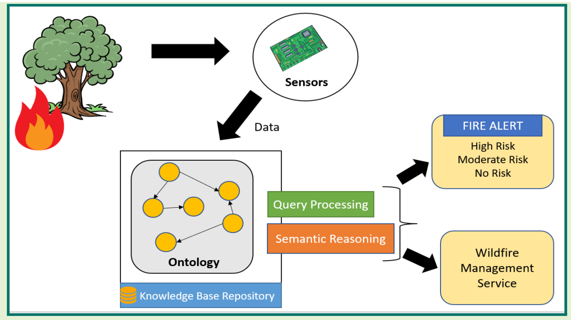
FFO: A Forest Fire Ontology and Reasoning System for Fire Alert and Management Services

Shibani Das and Abhishek Srivastava

***Abstract*— Forest fires or wildfires pose a serious threat to property, lives and the environment. Early detection and mitigation of such emergencies therefore plays an important role in reducing the severity of the impact caused by wildfire. Unfortunately, there is often an improper or delayed mechanism for forest fire detection which leads to destruction and losses. These anomalies in detection can be due to defects in sensors or lack of proper information interoperability among the sensors deployed in forests. This paper presents a lightweight ontological framework to address these challenges. Interoperability issues are caused due to heterogeneity in technologies used and heterogeneous data created by different sensors. Therefore, through the proposed Forest Fire Detection and Management Ontology (FFO), we introduce a standardised model to share and reuse knowledge and data across different sensors. The proposed ontology is validated using semantic reasoning and query processing. The reasoning and querying processes are performed on real-time data gathered from experiments conducted in a forest and stored as RDF triples based on the design of the ontology. The outcomes of queries and inferences from reasoning demonstrate that FFO is feasible for early detection of wildfire and facilitates efficient process management subsequent to detection.**



***Index Terms*— Forest Fire, Ontology, Semantic Web, Reasoning, Query Processing, Semantic Sensor Network, GeoSPARQL, Sensors, SPARQL, SWRL, RDF.**

I. Introduction

FOREST fires pose a significant threat to human life, property, and the environment. The World Wildlife Fund (WWF) estimates that fires cause the loss of 10 million hectares of forests annually. According to the US National Interagency Fire Center, 56,000 wildfires consumed more than 4.7 million acres of land in 2021. With over 130,000 fires reported, 2021 saw the highest number of fires in the Amazon rainforest in ten years. Emergency events such as wildfires can lead to major destruction if they are not detected early or not communicated quickly enough. It is seen that even a slight delay in fire detection can lead to havoc in wildlife and natural habitat of the forest. It is crucial, therefore, to detect such fires early and to make the right decisions in such emergency situations. Delays in fire detection can be due to several reasons among which difficulty in communication is quite common. Emergency Responders (ERs) use a variety of heterogeneous information obtained from various systems and distinct technologies, which causes communication issues and uncertainty [1]. Over the years, several methods have been developed to detect forest fires, ranging from traditional methods such as human observers to more advanced technologies like remote sensing and artificial intelligence. But the information about the nearby environment gathered from various observation sources has to be accessed quickly and shared with a central monitoring system. Semantic Web technologies address these interoperability issues with the help of ontologies and information retrieval using SPARQL [2]. Ontologies can facilitate the sharing and reuse of knowledge across different systems and organizations, which can help to improve the overall effectiveness of forest fire detection and mitigation efforts. Ontologies help in making the systems interoperable by standardizing the forest fire related data used in the different devices, which gather information. The fundamental RDF (Resource Description Framework) triple format ($subject - predicate - object$) is used by ontologies to store information. RDF is the data model for Semantic Web. Through the SPARQL Protocol and RDF Query Language (SPARQL), we are able to query this RDF data.

The term "ontology" was defined by T. R. Gruber in 1992 as "explicit specification of a conceptualization" [3]. Ontologies are formal representations of concepts and relationships within a particular domain of knowledge. They give a common understanding of concepts, their meanings, and the connections between them. Ontologies have grown in significance in a variety of disciplines as they allow machines to comprehend the meaning of data and support knowledge sharing and reuse.

In this paper, we present FFO, an ontology for forest fire detection and management that is designed to standardize the concepts and relationships among the concepts involved in forest fire detection and also provide efficient steps for

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managing the wildfire. Our primary research questions include displaying readings in a specific time period, identifying sensor locations, location of the detected fire, giving information about the population of a particular settlement near to the fire location, finding hospitals and fire-stations nearby and more. Overall, the objective is to eradicate the information interoperability issues, to respond to the detected anomalies in sensors' readings promptly and to properly manage the wildfire if detected.

The rest of the paper is organised as follows. Section II includes the relevant work on ontologies related to crisis, wildfire, hydrological or any natural disaster and proper management and decision systems. Section III discusses about the proposed ontology with the framework and competency questions (CQs). Section IV shows the results and discusses the evaluation of the ontology. Section V concludes the proposed work and presents the future scope of the work.

II. Related Work

Ontologies have been the subject of in-depth study in the realm of natural disasters [4]. This section discusses published research focused on developing ontologies that define concepts within specific domains, such as hydrology or wildfire management, as well as generalised domains, along with reasoning rules that allow for the inference of new knowledge from existing data.

Masa et al. [5] describe the ONTO-SAFE framework, which aims to improve the effectiveness of detecting forest fires and offers a decision-support system for managing in the context of wildfire hazards. Based on the SSN vocabulary [6], SoKNOS ontology [7] and also beAWARE ontology [8], the ONTO-SAFE framework uses SHACL-compliant rules [9] as the reasoning scheme. Chandra et al. [10] developed rules using SWRL(Semantic Web Rule Language) [11] for calculating fire weather indices like FFMC, DMC, DC ISI, BUI and FWI [12], which are used to measure fire danger with respect to the prevailing weather conditions. Kalabokidis et al. [13] presented OntoFire, in which they attempted to extract meaningful information in geo-portal environments by employing hyperlinks rather than browsing with keyword-based queries and for that reason, they had to maintain a meta-data catalogue. In our ontology, we extended the base SSN ontology to our forest-fire domain by including the GeoSPARQL ontology for location, and the Settlement Ontology and also created the classes for different temperature-humidity and gas sensors. For reasoning, we used the W3C recommendation SWRL. The ontologies SoKNOS and beAWARE are more general and less geared at forest fires. Our methodology was to get the information from sensors like smoke sensors and CO2 level sensors and propose rules for forest fire detection at a location and management after detection. OntoFire ontology was not preferred because we have to maintain a metadata catalogue about the wildfire resources in the area of our interest, which is complex and tedious work.

Wang et al. [14] proposed a hydrological sensor web ontology based on W3C SSN ontology by including the W3C Time Ontology [15] and OGC GeoSPARQL [16]. The BeAWARE [8] ontology is a knowledge representation of concepts relevant to the managemenet of climate-related crises. The ONTOEMERGE (2010-2013) [17], an ontology developed by UFRJ and University of Valencia, contains some generic potential concepts like climatic condition, incident, emergency, organisation, resource, event, among others. The EmergencyFire ontology [18] facilitates standardization and sharing of response protocols for fire in buildings. It facilitates interoperability between people and systems and reduction in occurrences of false compliances. BeAWARE, ONTOEMERGE and EmergencyFire ontologies are too generic and contain the generalised concepts related to natural disasters. FFO is more lightweight and specific to forest fire detection and management. For the purpose of management, it incorporates logical rules to notify nearby fire stations in case of fire detection, as well as the ability to locate hospitals within a specified distance through semantic querying, among other management features. This ensures that our ontological model not only detects fires but also facilitates efficient management afterward.

Competency Questions (CQs) play a vital role in ontology evaluation. The efficiency of an ontology depends on the answerability of the ontology to the CQs. The QuestionChecker module, which considers CQs expressed as interrogative phrases that work over classes and their relations, is presented by Bezerra et al. along with a discussion of its significance [19]. References [20], [21], [22] have also suggested utilizing CQs.

III. Proposed Ontology

The proposed FFO ontology is designed by extending the standard W3C SSN ontology [6] and OGC GeoSPARQL [16]. The main ontological components involved are the Sensor Ontology (extension of SSN ontology) in which concepts or classes related to sensors and their observations are defined, the Settlement ontology defining the concepts related to settlements, the GeoSPARQL ontology having the concepts related to the location of a point or area of interest like location of the point where fire is detected or location of a hospital nearby, etc. The namespaces and the prefixes used in the ontology are listed in Table I.

The proposed ontology was constructed with five main objectives :

1) to define the main concepts and properties (relationships) between the concepts in the Forest Fire Detection and Management domain.
2) to link the ontologies involved like the sensor ontology, the settlement ontology and GeoSPARQL.
3) to overall monitor efficiently and enable fast response by improving the semantic interoperability among the sensor nodes.
4) to infer new knowledge from the existing data stored and better reasoning process by establishing inference rules and query processing.
5) to perform some emergency management tasks like alerting the authorities of fire stations nearby about the detected fire, find hospitals nearby, etc.

TABLE I: Prefixes and namespaces used in the proposed ontology

Prefix	Namespace URI	Description
sosa	http://www.w3.org/ns/sosa/	The lightweight Sensor, Observation, Sample, and Actuator (SOSA) ontology, which forms the basis of SSN, aims to broaden the audience for Semantic Web ontologies as well as the scope of applications that can use them.
ssn	http://www.w3.org/ns/ssn/	The Semantic Sensor Network (SSN) ontology is an ontology for describing actuators and sensors, as well as their observations, related processes, interesting topics for research, samples utilized in that research, and observed attributes.
geosparql	http://www.opengis.net/ont/geosparql#	The Open Geospatial Consortium (OGC) has developed GeoSPARQL, a standard, for representing and querying geospatial linked data for the Semantic Web.
geof	http://www.opengis.net/def/function/geosparql/	A collection of GeoSPARQL-compatible, domain-specific spatial filter functions for use in SPARQL queries.
rdf	http://www.w3.org/1999/02/22-rdf-syntax-ns#	An information representation system for the Web is called Resource Description Framework (RDF). In RDF graphs, which are collections of *subject-predicate-object* triples, IRIs, blank nodes, and datatyped literals can all be used as elements. They are used to give descriptions of resources.
rdfs	http://www.w3.org/2000/01/rdf-schema#	For RDF data, RDF Schema offers a vocabulary for data modeling. An expansion of the fundamental RDF vocabulary is RDF Schema.
xsd	http://www.w3.org/2001/XMLSchema#	The structure of an XML document is described by an XML Schema. XML Schema Definition (XSD) is another name for the XML Schema language.
swrlb	http://www.w3.org/2003/11/swrlb	The logic operation formulae for boolean operations, string operations, mathematical computations, etc. are included in built-ins, which are modular SWRL components.
	http://www.semanticweb.org/hp/ontologies/2023/1/ffo	The proposed ontology. No prefix is used for the ontology.

A. The Framework of the Proposed Ontology

Simplicity was the key principle while constructing our ontology and we wanted the ontology to be forest fire detection and management specific. Therefore, we covered all of the aspects for forest fire detection and management system with minimum number of classes and properties. FFO is designed using the Protégé software [23]. The core classes and properties are shown in Figure 1. As we can see in the figure, the properties are defined to connect a subject to an object in a RDF triple structure. There are two types of properties - 1) Object properties and 2) Data Properties. The object properties are those in which the object is a class whereas data properties are the properties in which the object is a literal or value. In figure 1, we have shown the main object properties.

Below we discuss the main classes and properties in the proposed ontology. $prefix : class\_name$ or $prefix : property\_name$ notation is used to introduce them. No prefix is used for our ontology.

1) Classes

- *sosa:Sensor*: The class 'Sensor' is taken from SOSA ontology. It represents all the sensors that we deployed and has four subclasses in our ontology : 1) *TemperatureandHumiditySensor* (to measure temperature and humidity), 2) *SmokeSensor* (to detect smoke), 3) *AirQualitySensor* (to get the carbon dioxide level), and 4) *InfraredSensor* (to detect movement). DHT11 has been used as temperature and humidity sensor. For smoke sensor, we have used MQ2 gas sensor. MQ135 is used as air quality gas sensor to measure the level of carbon dioxide (CO2) in atmosphere. Finally, IR sensor as an infrared sensor. Altogether, there are 20 sensors (five of each category) under the class *Sensor*. These 20 sensors are the individuals or instances of the class.
- *sosa:Observation*: Class Observation has five subclasses in our ontology - *TempValue*, *HumidityValue*, *SmokeValue*, *InfraredValue*, and *CO2level*.
- *geosparql:Feature*: Every entity is a Feature if it has a geographical location or area. We have created many subclasses in Feature, viz. *Deployment*, *Forest*, *FireStation*, *Hospital*, and *Settlement*.
- *ssn:Deployment*: There are five deployments that have been deployed in the forest of IIT Indore. Each deployment has a set of four sensors DHT11, MQ2, MQ135 and IR sensor. The location of the detected fire can be traced from the location of a Deployment whose sensors detect the fire. The location has been recorded by GPS (Global Positioning System) sensor.
- *geosparql:Geometry*: In [24], the OGC GeoSPARQL class *Geometry* is described as a coherent collection of direct positions in space. A spatial reference system (SRS) is used to hold the positions. It has two subclasses : *Point* for one single location of interest, and *Polygon* for an area of interest. These define the coordinates of a location.

The class hierarchy is shown in Figure 2.

2) Properties

In this section, the main properties (object properties and data properties) are discussed and also, $Subject \rightarrow Object$ notation is used to denote the domain and range of each property. The main object properties are shown in figure 1.

- *ssn:deployedOnPlatform*: It is an object property showing the relation between Deployment and Platform.

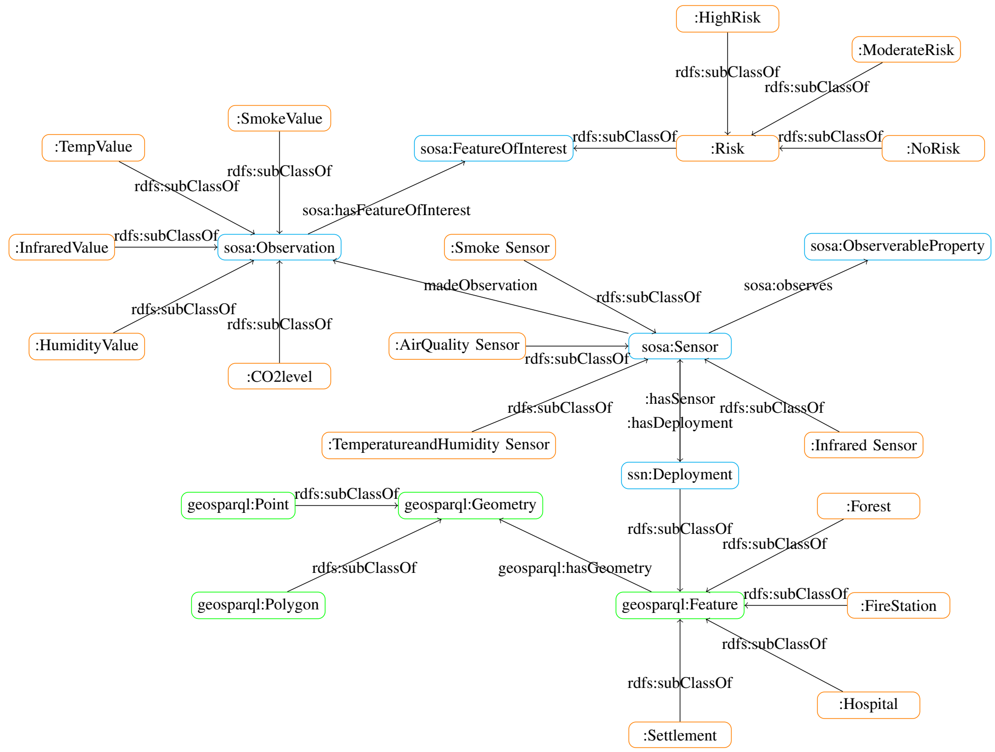


Fig. 1: The core classes and properties in FFO based on SSN and GeoSPARQL. The classes from the SSN ontology are outlined with 'blue' colour, those from the GeoSPARQL ontology are outlined with 'green' colour and the classes from our proposed ontology are outlined with 'orange' colour. $prefix : name$ notation is also used.

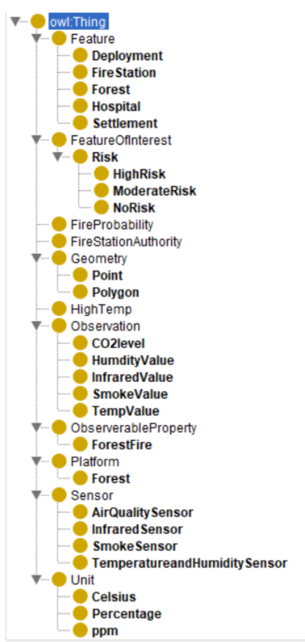


Fig. 2: Class hierarchy of FFO.

$Deployment \rightarrow Platform$

- *:hasCO2Level*: An object property created by us to show the relation between AirQualitySensor and CO2level.
$AirQualitySensor \rightarrow CO2level$
- *:hasDeployment*: showing on which deployment the sensor is placed on.
$Sensor \rightarrow Deployment$
- *:hasSensor*: Inverse property of the property 'hasDeployment'.
$Deployment \rightarrow Sensor$
- *geosparql:hasGeometry*: This object property from GeoSPARQL defines the spatial representation of a Feature (class from GeoSPARQL).
$Feature \rightarrow Geometry$
- *:hasLocation*: We created this object property to directly connect a Feature with a location (geosparql:Point) or an area (geosparql:Polygon).
$Feature \rightarrow Point$
$Feature \rightarrow Polygon$
- *sosa:madeObservation*: Showing the relation between Sensor and Observation.
$Sensor \rightarrow Observation$
- *geosparql:asWKT*: This a data property from GeoSPARQL which links class Geometry with the datatype wktLiteral from GeoSPARQL. The datatype geosparql:wktLiteral is used to contain the Well-Known Text (WKT) serialization of a Geometry [24].
$Geometry \rightarrow wktLiteral$
- *sosa:hasSimpleResult*: It links HumidityValue or TempValue or CO2level or SmokeValue to xsd:float to get the output value of each observation from a sensor.
$HumidityValue \rightarrow float$
$TempValue \rightarrow float$
$SmokeValue \rightarrow float$
$CO2level \rightarrow float$

- *:hasTimestamp*: It links HumidityValue or TempValue or CO2level or SmokeValue or InfraredValue to xsd:dateTime to get the timestamp of observation.
  $TempValue \rightarrow dateTime$
  $HumidityValue \rightarrow dateTime$
  $SmokeValue \rightarrow dateTime$
  $InfraredValue \rightarrow dateTime$
  $CO2level \rightarrow dateTime$
- *:hasPopulation*: It links between Settlement and xsd:integer. It defines the population of a settlement. This is important to know to get an idea of the impact that will be caused by the fire.
  $Settlement \rightarrow integer$

3) Individuals

Individuals are the concrete entities or instances that exist within a domain and are represented within the ontology. A class may or may not have individual(s). In our ontology, *Deployment1*, *Deployment2*, *Deployment3*, *Deployment4*, *Deployment5* are the five instances of the class Deployment as we have five systems deployed at five locations in the IIT Indore forest. In each deployment, there are four sensors. For example, *Deployment1* has *DHT_1*, *MQ135_1*, *MQ2_1* and *IR_1* sensors. *DHT_1*, *DHT_2*, *DHT_3*, *DHT_4* and *DHT_5* as the instances of the DHT sensors. Every deployment has a location which is of class 'Point'. For example, *D1PointGeom* is the location of Deployment1.

B. Competency Questions

The competency questions are the set of questions which an ontology is expected to answer correctly to be efficient. Therefore, they play a crucial role in the development of an ontology. There are total eight CQs on the basis of which our ontology is evaluated. These are as follows.

1) Show the values of sensors from time t1 to time t2.
2) Find the location of the sensor which recorded values greater than the threshold value.
3) What are the hospitals that are nearby with respect to a location?
4) Which are the nearest fire stations?
5) State whether there is a settlement located near a detected fire location. If yes, what is the distance of the settlement from fire location and what is its population?
6) If there is a probability of fire, state which sensor sensed the probable fire and what is the risk level?
7) Whether there is a high risk of fire, a medium risk, or no risk at all?
8) Notify the fire station authorities about the location where there is high probability of fire.

IV. Results and Evaluation

A series of semantic querying and reasoning was developed to assess the proposed FFO ontology. For reasoning, we devised 14 rules and for semantic querying, we used the RDF query language, SPARQL [2] which we have implemented in GraphDB [25]. The reasoner deduce new inferences based on the existing data or knowledge and the rules defined. The query-answering and reasoning processes will be discussed in this section.

A. Experimental Data

We have collected real-time data by experimenting in the IIT Indore forest. We placed one deployment in each of five locations and initiated a controlled fire in the forest area near Deployment 3 and collected the readings for different sensors. Figure 3 shows the recorded readings and figure 4 shows the placement of deployment 3 in the forest and the fire.

MQ2 smoke sensor exhibited 0.15 ppm (parts per million) when no smoke is detected and a value range from 1200 ppm to 400000 ppm when smoke is detected. MQ135 (CO2 level) gas sensor recorded values in a range 0.3 - 138 ppm. However, DHT11 temperature and humidity sensor showed a gradual increase in temperature and humidity. The temperature range was recorded to be from 43.1 °C to 59.2 °C in the presence of fire whereas the normal temperature was 38 °C.

We have defined certain thresholds for the DHT11 temperature value, MQ2 smoke level, and MQ135 ppm value for the "Fire Alert" based on the findings of our experiment in the IIT Indore forest. The thresholds will be discussed in the subsection IV-C.

Time	Date	Temperature	Humidity	LPG (ppm)	CO (ppm)	Smoke (ppm)	CO2 (ppm)	Obstacle
14:25:00	6/4/2023	nan	nan	0.02	0.05	0.15	nan	0
14:25:03	6/4/2023	43.9	15	0.02	0.05	0.15	0.3	0
14:25:05	6/4/2023	43.7	15	0.02	0.05	0.15	1.79	0
14:25:07	6/4/2023	43.7	15	0.02	0.05	0.15	6.51	0
14:25:09	6/4/2023	43.8	15	0.02	0.05	0.15	13.92	0
14:25:11	6/4/2023	43.9	15	3875.44	409769.5	28855.07	23.68	0
14:25:14	6/4/2023	43.9	15	6226.54	785008.06	44262.81	27.77	0
14:25:17	6/4/2023	43.9	15	6749.25	802429.75	44262.81	26.71	0
14:25:20	6/4/2023	43.9	15	6537.94	785008.06	44262.81	24.66	0
14:25:22	6/4/2023	43.7	15	6028.84	640666.12	37176.72	21.84	0
14:25:25	6/4/2023	43.9	15	4533.26	496380.62	29388.66	18.35	0
14:25:28	6/4/2023	43.8	15	3610.07	345407	22146.59	16.04	0
14:25:31	6/4/2023	43.8	15	3545	336830.62	23470.85	16.04	0
14:25:34	6/4/2023	43.8	15	3610.07	345407	23470.85	15.31	0
14:25:36	6/4/2023	43.8	15	3298.44	320399.59	23019.25	14.61	0
14:25:39	6/4/2023	43.7	15	3610.07	345407	23470.85	15.33	0
14:25:42	6/4/2023	43.8	15	3610.07	345407	23470.85	15.31	0
14:25:45	6/4/2023	43.9	15	3610.07	345407	23019.2	14.59	0
14:25:48	6/4/2023	44	16	3238	282454.4	19322.78	13.16	0
14:25:50	6/4/2023	44.1	16	2741.02	236045.78	17489.21	12.52	0
14:25:53	6/4/2023	44.2	16	2741.02	236045.78	17489.21	11.89	0
14:25:56	6/4/2023	44.3	16	2741.02	229882.84	17135.29	11.88	0
14:25:59	6/4/2023	44.4	16	2492.73	207010.12	15802.32	11.28	0
14:26:02	6/4/2023	44.6	16	2492.73	207010.12	15802.32	11.26	0
14:26:04	6/4/2023	44.7	16	2492.73	196177.81	15476.92	10.68	0
14:26:07	6/4/2023	44.8	16	2175.3	171481.28	12831	10.12	0
14:26:10	6/4/2023	44.8	16	2051.11	158098.06	12831	9.59	0
14:26:13	6/4/2023	45.1	16	1855.6	137653.39	11528.96	9.56	0

Fig. 3: The date and time and the values from the experiment recorded by Deployment 3. The sudden increase in the values implies detected fire.

B. Query Processing

Queries are processed in GraphDB. SPARQL is used to query and validate ontologies. By query processing, we test

Fig. 4: Deployment3 in the forest of IIT Indore, taking readings in the presence of fire.

```
PREFIX xsd:<http://www.w3.org/2001/XMLSchema#>
PREFIX geof:<http://www.opengis.net/def/function/geosparql/>
PREFIX ssn:<http://www.w3.org/ns/ssn#>
PREFIX : <http://www.semanticweb.org/hp/ontologies/2023/1/final#>
PREFIX geosparql: <http://www.opengis.net/ont/geosparql#>
PREFIX sosa: <http://www.w3.org/ns/sosa#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

select ?datetime ?temperature ?sensor ?deployment
where {
        ?sensor :hasDeployment ?deployment .
        ?sensor :hasTemperature ?t .
        ?t :hasTimestamp ?datetime .
        ?t sosa:hasSimpleResult ?temperature .
        Filter(?datetime >= "2023-04-06T14:27:00"^^xsd:dateTime && ?datetime <= "2023-04-
06T14:28:00"^^xsd:dateTime) .
}
```

(a)

	datetime	temperature	sensor	deployment
1	"2023-04-06T14:27:00"^^xsd:dateTime	"41.8"^^xsd:float	:DHT_2	:Deployment2
2	"2023-04-06T14:27:02"^^xsd:dateTime	"40.0"^^xsd:float	:DHT_1	:Deployment1
3	"2023-04-06T14:27:03"^^xsd:dateTime	"39.0"^^xsd:float	:DHT_2	:Deployment2
4	"2023-04-06T14:27:03"^^xsd:dateTime	"47.6"^^xsd:float	:DHT_3	:Deployment3
5	"2023-04-06T14:27:09"^^xsd:dateTime	"39.6"^^xsd:float	:DHT_4	:Deployment4

(b)

Fig. 5: Frame view of GraphDB showing (a) SPARQL query to display the temperature values in DHT sensors of all the deployments in the specified time period. (b) showing initial five results to the query.

the functionality of an ontology by testing its capability to answer as expected to the competency questions.

- **Query 1**: Query to show the temperature values of DHT sensors from all the deployments within the specified time period. This query corresponds to competency question 1. Figure 5 shows the query and the results.
- **Query 2**: Query(table II) to display all the hospitals that are within the range of 20 km from the MQ2 sensor which detected smoke level greater than 1200 ppm. This is related to competency question 3. Figure 6 shows the result to query 2.

TABLE II: Query 2

```
PREFIX xsd:<http://www.w3.org/2001/XMLSchema#>
PREFIX geof:<http://www.opengis.net/def/function/geosparql/>
PREFIX ssn:<http://www.w3.org/ns/ssn#>
PREFIX : <http://www.semanticweb.org/hp/ontologies/2023/1/final#>
PREFIX geosparql: <http://www.opengis.net/ont/geosparql#>
PREFIX sosa: <http://www.w3.org/ns/sosa#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

select ?deployment ?sensor ?smoke_value ?Hospital ?distance where
{
?deployment a ssn:Deployment .
?deployment :hasSensor ?sensor .
?sensor :hasSmokeValue ?tvalue.
?tvalue sosa:hasSimpleResult ?smoke_value .
:Deployment3 :hasLocation ?d1 .
?d1 geosparql:asWKT ?l1 .
?Hospital a :Hospital .
?Hospital :hasLocation ?h .
?h geosparql:asWKT ?l2 .
BIND(geof:distance(?l1,?l2) as ?distance) .
FILTER(?smoke_value >1200 && ?distance <= 20000 ) .
}
```

By processing queries in this manner, we were able to test the ontology for the aforementioned competency questions 2, 4, and 5. The results were as we had anticipated.

	deployment	sensor	smoke_value	Hospital	distance
1	:Deployment3	:MQ2_3	"2371.4"^^xsd:float	:IITIHealthCentre	"432.5770665987057"^^xsd:double
2	:Deployment3	:MQ2_3	"2371.4"^^xsd:float	:MhowRailwayHospital	"16568.84776703363"^^xsd:double

Fig. 6: Result to query 2.

C. Rule-based Reasoning

Based on the competency questions mentioned above, we set up rules with the purpose of making inferences and acquire new knowledge based on the existing classes and relationships, to check whether our ontology can answer the competency questions. This is also a process of evaluating the ontology in addition to query processing.

To create the rules, we used the SWRL language [11] and for reasoning, we used the Pellet Reasoner [26]. The rules were implemented in Protégé software. Protégé has a Plugin for SWRL, named $SWRLTab$. We have created 14 Rules for reasoning. The main rules are shown as follows.

1) $swrlb: greaterThanOrEqual(?t, 45) \land hasDeployment(?s, ?d) \land hasLocation(?d, ?p) \land geosparql: asWKT(?p, ?loc) \land hasTemperature(?s, ?temp) \land sosa: hasSimpleResult(?temp, ?t) \rightarrow ProbabilityofFirefromTemp(?p, High)$
2) $hasSmokeValue(?s, ?sv) \land hasDeployment(?s, ?d) \land sosa: hasSimpleResult(?sv, ?ss) \land hasLocation(?d, ?p) \land geosparql: asWKT(?p, ?loc) \land swrlb: greaterThanOrEqual(?ss, 30000) \rightarrow ProbabilityofFirefromMQ2(?p, High)$
3) $swrlb: greaterThanOrEqual(?v, 20) \land hasDeployment(?s, ?d) \land sosa: hasSimpleResult(?c, ?v) \land hasLocation(?d, ?p) \land geosparql: asWKT(?p, ?loc) \land hasCO2level(?s, ?c) \rightarrow$

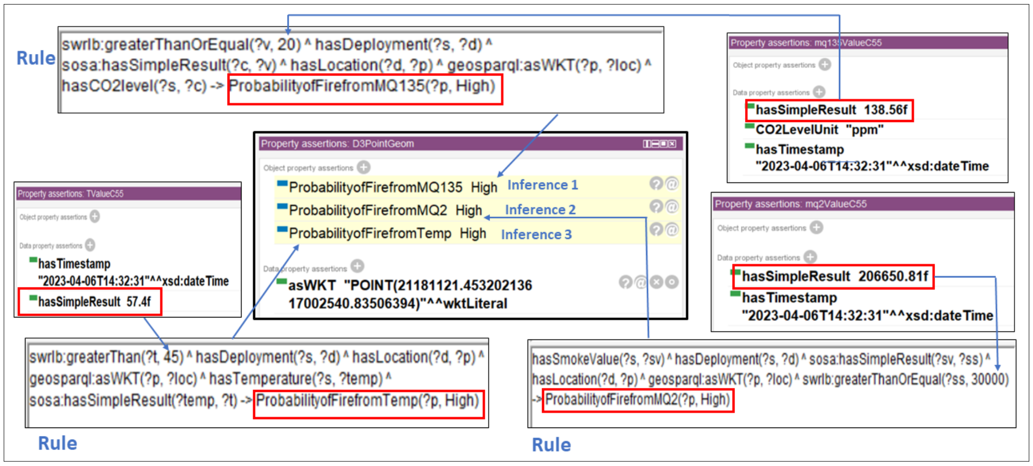
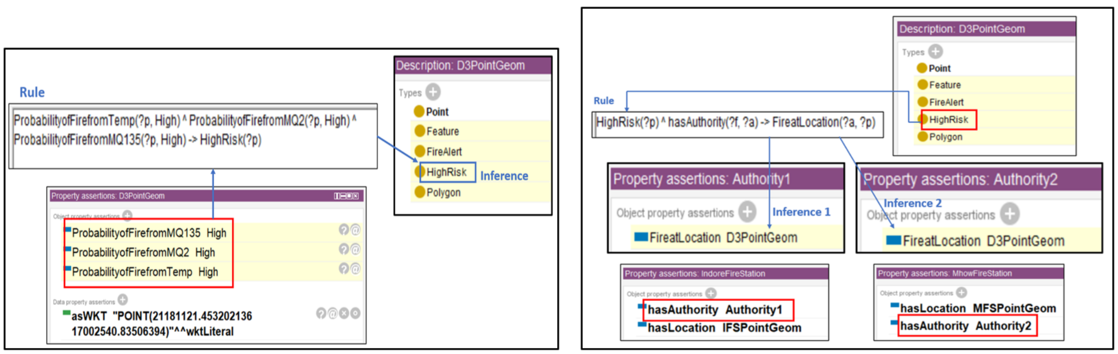


Fig. 7: Protégé frame view showing inferences deduced by the reasoner with respect to the experiment data values of Deployment 3 and the rules 1,2,3 given in IV-C.



(a) (b)

Fig. 8: Protégé frame view showing (a) Reasoning 2 which infers that D3PointGeom is at $HighRisk$, (b) the authorities of the corresponding fire stations and these authorities are being notified about D3PointGeom, the location of Deployment 3 through inferences 1 and 2.

$ProbabilityofFirefromMQ135(?p, High)$

4) $ProbabilityofFirefromTemp(?p, High) \wedge ProbabilityofFirefromMQ2(?p, High) \wedge ProbabilityofFirefromMQ135(?p, High) \rightarrow HighRisk(?p)$
5) $HighRisk(?p) \wedge hasAuthority(?f, ?a) \rightarrow FireatLocation(?a, ?p)$

We have used the Pellet reasoner to deduce inferences from our existing classes and properties, and our designed SWRL rules. Our ontology deduced three distinct inferences when the reasoner was started. These are discussed as below.

- **Reasoning 1:** DHT_3 of Deployment 3 recorded 57.4 °C which is greater than 45 °C. According to Rule 1 of the rules discussed above, if the temperature is greater than 45 °C, then the object property called *Probabilityof-FirefromTemp* connects the "location of the Deployment which has the DHT11 sensor" to $High$. In our case, it connects $D3PointGeom$, which is the location of Deployment 3 to Risk level, $High$. This is the Inference 3 in the figure 7. Similarly, inferences 1 and 2 are drawn from the Rules 3 and 2 mentioned above.
- **Reasoning 2:** If the probability of Fire from DHT11, MQ2 and MQ135 sensors are high, then the location of the corresponding deployment is marked as 'HighRisk'. Rule 4 states this deduction. Figure 8(a) shows how the reasoner marks D3PointGeom as 'HighRisk' as it deduced the inferences discussed in Reasoning 1 section.
- **Reasoning 3:** If a location is marked as 'HighRisk' then the authorities of all the fire stations should be notified about that location. Rule 5 is designed for this deduction. Figure 8(b) shows the two fire stations in our ontology which are *IndoreFireStation* and *MhowFireStation*, and *Authority1* and *Authority2* are their authorities respectively. The object properties *FireatLocation* connects
  $Authority1 \rightarrow D3PointGeom$
  $Authority2 \rightarrow D3PointGeom$
  These are the inferences 1 and 2 respectively in Figure 8(b).

V. Conclusion

In this paper, we have presented the ontology-based model for Forest Fire Detection and Management with the purpose of (a) representing the main concepts and properties of the Forest Fire domain and also instantiating the concepts designed according to the requirements of our experiment, (b) standardising the data created by sensors deployed in forest and enhancing efficiency in data sharing and reusing among the sensors, thereby improving information interoperability to a great extent, (c) detecting the Risk Level or Fire Probability at the proper time, and, (d) taking actions for systematic management subsequent to fire detection. This paper also discusses how our ontology satisfies the feasibility test against the competency questions using semantic reasoning and query processing on the real-time data collected through experiments and stored in RDF triple format according to the design of FFO.

This is a minimal ontological prototype in this domain and will be extended based on the requirements further as future scope. More rules will be added for extensive reasoning and therefore, management steps will be increased further.

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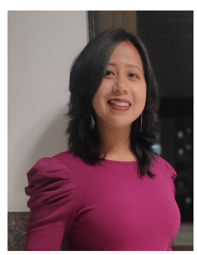

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