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Wildfire monitoring using satellite images, ontologies and linked geospatial data☆

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ABSTRACT

Advances in remote sensing technologies have allowed us to send an ever-increasing number of satellites in orbit around Earth. As a result, Earth Observation data archives have been constantly increasing in size in the last few years, and have become a valuable source of data for many scientific and application domains. When Earth Observation data is coupled with other data sources many pioneering applications can be developed. In this paper we show how Earth Observation data, ontologies, and linked geospatial data can be combined for the development of a wildfire monitoring service that goes beyond applications currently deployed in various Earth Observation data centers. The service has been developed in the context of European project TELEIOS that faces the challenges of extracting knowledge from Earth Observation data head-on, capturing this knowledge by semantic annotation encoded using Earth Observation ontologies, and combining these annotations with linked geospatial data to allow the development of interesting applications.

1. Introduction

The issue of fire monitoring and management in Europe in general and Greece in particular is considered to be of paramount importance. Almost every summer, massive forest wildfires break out in several areas, leaving behind severe destruction in forested and agricultural land, infrastructure and private property, and losses of human lives. Thus, European initiatives in the area of Earth Observation (EO) like the Global Monitoring for Environment and Security initiative (GMES) have undertaken an active role in the area of fire monitoring and management in Europe, and supported the development of relevant European operational infrastructures through projects such as linkER (supporting the implementation of an operational GMES service in the field of emergency management) and SAFER (Services and Applications For Emergency Response).

In the framework of SAFER, the National Observatory of Athens (NOA) has been developing a real-time fire detection service for monitoring a fire-front. The service depends on the real-time processing of satellite images and outputs validated fire-related products (e.g., hotspot and burnt area maps) for Southern Europe (Spain, France, Italy, Portugal, and Greece).

In this work, we discuss how NOA has redeveloped its real-time fire monitoring service using linked geospatial data and semantic web technologies developed in the research projects TELEIOS and SWeFS. TELEIOS[1] is a European research project that addresses the need for scalable access to petabytes of EO data and the effective discovery of knowledge hidden in them. SWeFS (Sensor Web Fire Shield) is a recent Greek research project that investigates the use of sensor networks in fire monitoring. TELEIOS and SWeFS pioneer the use of the following state-of-the-art technologies upon which the wildfire monitoring service has been built:

- Publicly available *linked geospatial data*[2] for use in emergency response situations, such as OpenStreetMap[3] and GeoNames.[4]
- The data model stRDF, an extension of the W3C standard RDF that allows the representation of geospatial data that changes over time [1,2]. stRDF is accompanied by stSPARQL, an

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[1] http://www.earthobservatory.eu/.
[2] http://linkedopendata.gr/.
[3] http://linkedgeodata.org/.
[4] http://www.geonames.org/ontology.

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extension of the query language SPARQL 1.1 for querying and updating stRDF data. stRDF and stSPARQL use OGC standards (Well-Known Text and Geography Markup Language) for the representation of geospatial data and are implemented in the open source spatiotemporal RDF store Strabon.[5]

The presented wildfire monitoring service improves significantly the wildfire monitoring service used until now by NOA. The service is available on the web[6] and is operational and used by decision makers and emergency services in Greece since the fire season of 2012. This wildfire monitoring service, as described in [3], has participated in the Open Track of the 10th Semantic Web Challenge[7] that was co-located with the 11th International Semantic Web Conference and was awarded the third place.

The contributions of this work are the following:

- We present a wildfire monitoring service that has been developed using the semantic web technologies presented above. The service is currently operational at NOA and has been used on a daily basis in the fire season of 2012 by the emergency managers monitoring wildfires in Greece, such as the Greek Civil Protection Agency, the Fire Brigade, and the Army, for strategy planning and assessment.
- In contrast to similar wildfire monitoring services available at various EO agencies, the NOA service is exclusively built using state-of-the-art scientific database, semantic web and linked data technologies. Here, we discuss how semantic web technologies and linked open data have allowed NOA to build easily from scratch a new version of its service that is much easier to modify and reuse in other GMES environmental monitoring applications.
- We present a preliminary evaluation of the implemented service concentrating on the performance of the main component of the service, namely the RDF store Strabon, and demonstrating the technologies discussed in this work: the refinement operations that use linked geospatial data and which are expressed in stSPARQL.

The rest of the paper is organized as follows. Section 2 discusses related work. Section 3 describes in detail the workflow of the wildfire monitoring service and presents the architecture of the system that delivers the wildfire monitoring service describing its main components. Section 4 introduces the data model stRDF and the accompanying query language stSPARQL which play a crucial role in this application. Section 5 presents the datasets and the ontologies that are used in the fire monitoring service and Section 6 describes how these datasets and ontologies are utilized by stSPARQL updates to increase the accuracy of primary fire monitoring results. Finally, Section 7 presents the evaluation of the developed fire monitoring service and Section 8 concludes the paper.

2. Related work

Recently, Linked Open Data Cloud has started being enriched with geospatial data. Two representative examples are [4,5]. In [4] OpenStreetMap data are made available as RDF and queried using the declarative query language SPARQL. Using similar technologies, [5] makes available as linked data various heterogeneous Spanish public datasets. With the recent emphasis on open government data, some of it encoded already in RDF,[8] portals such as LinkedGeoData[9] demonstrate that the development of useful Web applications might be just a few SPARQL queries away.

Regarding EO data, EO data centers have only just started to organize archived data so as to make them available to EO scientists for research purposes. Data centers typically offer Web interfaces such as EOWEB[10] for searching, inspection, and ordering of EO products. While EOWEB organizes archived data in a simple, hierarchical way, more sophisticated and expressive approaches are being explored that are based on ontologies [6–9]. In this context, TELEIOS extends previous work aiming at capturing also the semantics of the content of products that will be generated by knowledge discovery algorithms (e.g., fire detection algorithms) applied on EO images.

3. Service description

In this section, we give a detailed description of the real-time wildfire monitoring service and discuss the architectural design of the web application that offers this service.

3.1. The wildfire monitoring service

The wildfire monitoring service relies on an MSG/SEVIRI acquisition station that is operated by NOA. The station receives satellite images every 5–15 min which are stored in the state-of-the-art column-store DBMS MonetDB.[11] In MonetDB preprocessing operations (e.g., cropping, georeferencing) and a fire detection processing chain [10] are applied to the images. The processing chain detects areas (pixels of the images) where fire may exist. These areas are called *hotspots* and for each satellite image a geospatial vector file (ESRI shapefile), which describes the detected hotspots, is produced. A hotspot is mainly described by the time at which it was detected, its spatial extent and a confidence value denoting the probability that there is a fire in this area. The hotspots derived by the processing chain have dimensions equal to the resolution of the sensor, in this case 4×4 km. This spatial resolution is low, compared to other high resolution sensors. However, MSG/SEVIRI has geostationary orbit, which allows a very high observational frequency (5–15 min) over the same area of interest. Other satellite platforms with better spatial resolution have very low observational frequency (e.g., 12 h), so they are not suitable for a real-time monitoring application.

In order to increase the inherent coarse spatial resolution an important algorithmic advancement of the hotspot service integrates static geo-information and dynamic meteorological weather prediction data, aiming at enhancing the inherently coarse MSG/SEVIRI spatial resolution (3.5 km). Based on the result of the initial fire detection process (hotspot detection), a fire danger estimation model was designed. This model divides the initial SEVIRI pixel into a 7×7 grid, resulting into 49 subpixels, of 540 m spatial resolution. For each sub-pixel a new confidence value is attributed according to (i) the initial fire confidence level of a SEVIRI pixel, (ii) the type of the available fuel, based on CORINE Land Cover[12] data, (iii) the direction of the wind during the fire event (based on daily weather prediction models by NOA meteorological monitoring network[13]), and (iv) the geomorphology of the area, where the fire event is taking place (altitude and aspect).

5 http://strabon.di.uoa.gr/.
6 http://ocean.space.noa.gr/seviri/fend_new/.
7 http://challenge.semanticweb.org/2012/.
8 http://data.gov.uk/linked-data/.
9 http://linkedgeodata.org/.
10 http://eoweb.dlr.de/.
11 http://www.monetdb.org/.
12 http://www.eea.europa.eu/publications/COR0-landcover.
13 http://www.meteo.gr/.