

3.1 Publishable summary

Project context and objectives

Earth observation data has increased considerably over the last decades as satellite sensors collect and transmit back to Earth many gigabytes of data per day. The aim of project TELEIOS is to increase the usability of the terabytes of satellite images lying dormant in archives by automating the relevant data management, integration and knowledge discovery tasks.



The main innovation of project TELEIOS is the development of a Virtual Observatory infrastructure that goes beyond the current state of the art Earth Observation portals and Image Information Mining systems.

This is achieved by combining advanced image mining, database, geospatial and semantic web technologies, and pursuing the following technical innovations:

- The query language SciQL that extends SQL with multidimensional arrays. This extension is appropriate for querying scientific databases in general and satellite image databases in particular.
- Techniques for discovering knowledge from satellite images, their metadata and other relevant data sets, especially geospatial ones.
- The data model stRDF and the query language stSPARQL. These are extensions of the W3C standards RDF and SPARQL for querying geospatial data that change over time. The data model stRDF and the query language stSPARQL are used in TELEIOS to query satellite image annotations that capture image metadata and knowledge discovered from the images, and are linked to relevant data sources available on the web as linked data.
- Visual query interfaces for stSPARQL with special emphasis on querying satellite image archives.
- Query processing and optimization techniques for SciQL and stSPARQL.
- Scalable implementations of the techniques developed in TELEIOS on top of MonetDB, the pioneer open-source, column-store database system. Scalability is shown using very large data sets, e.g., terabytes of image data.

The technologies developed in TELEIOS are demonstrated in the following use cases:

- A Virtual Observatory for TerraSAR-X data.
 - Real-time fire monitoring based on continuous acquisitions of satellite images and geospatial data.

Work performed and results achieved

From September 2012 to August 2013, we focused mainly on improving the first version of the TELEIOS infrastructure developed during the first 24 months of the project and continuing the implementation of individual components. This work led to the delivery of the second version of the TELEIOS infrastructure on Month 32.

Our detailed technical achievements in this period are:

- Improvements and enhancements to the first version of the TELEIOS infrastructure. These improvements took into account the feedback received from the TELEIOS User Community in the 2nd Workshop and from the internal users during the entire period.
- The improvement of query processing and optimization techniques for SciQL and their implementation in MonetDB.
- The development of the new versions of the system Strabon, for stRDF and stSPARQL. New functionalities include:
 - More optimization techniques and fine-tuning of the system.
 - The beginning of the implementation of query processing and reasoning for RDFⁱ.
 - The design of the temporal component of stRDF and stSPARQL, its implementation in Strabon and its experimental evaluation.
- The design and implementation of *Geographica*, a functionality and performance benchmark for geospatial RDF stores.
- The implementation of the TELEIOS framework for knowledge discovery from satellite images, their metadata, and relevant GIS data. Currently, the framework includes:
 - A data model generation module, involved with extracting relevant image descriptors (features) and enriched metadata of TerraSAR-X images, and enabling access to GIS or similar information
 - Two knowledge discovery and data mining modules, responsible for i) image semantic annotation using active learning methods such as Support Vector Machine (SVM) that utilize the previously extracted image descriptors, ii) KDD and data mining component based on relevance feedback, iii) Content-based image retrieval using compression methods, iv) Scene understanding component, v) Visual

data mining component. The components operating on spatio-temporal representations.

- Query by enriched metadata, including numerical, semantic, and spatio-temporal operators
- A Strabon-based prototype which demonstrates the capabilities of the knowledge discovery framework through stSPARQL queries to semantic annotations of TerraSAR-X data and linked geospatial data.
- Further prototypes of a visual query builder which was developed in order to enable a broad range of users without a technical background in semantic web technology to construct complex stSPARQL queries.
- The development and implementation of Sextant, a web-based tool that enables exploration of linked geospatial data as well as creation, sharing, and collaborative editing of thematic maps by combining linked geospatial data and other geospatial information available in standard OGC file formats. Sextant was demonstrated in the poster and demo session of ESWC 2013 and received the best demo award. Its “temporally-enabled” extension, called SexTant, that exploits all features of stRDF and stSPARQL to represent and query time-evolving geospatial data, will be demonstrated at ISWC 2013.

We also undertook various dissemination activities. A total of 71 scientific publications authored by members of the TELEIOS consortium were presented or accepted during the third year of the project. The most notable of the joint dissemination activities that were undertaken by the consortium are as follows. We organized the 3rd User Community Workshop at Kolympari, Chania. Fraunhofer, with the contribution of all partners, organized and chaired the TELEIOS Workshop “Exploiting the integration potential of Semantic Web and Linked data technologies for geospatial applications” at the INSPIRE Conference 2013 in Florence, Italy. NKUA and NOA also prepared a demo of a semantic web-based fire monitoring application that was based on technologies developed in TELEIOS and the SWeFS project and won the third place on the Semantic Web Challenge 2012. Also, Sextant was demonstrated in the poster and demo session of Extended Semantic Web Conference 2013 and received the best demo award. Another notable joint dissemination activity was the demonstration with title “Data Vaults: a Database Welcome to Scientific File Repositories”, which was authored by CWI and DLR and presented at the International Conference on Scientific and Statistical Database Management 2013 (SSDBM 2013).

Expected final results

The expected scientific and technological results of TELEIOS are the following:

- The data models stRDF and the query language stSPARQL. These are extensions of the W3C standards RDF and SPARQL for querying geospatial data that change over time. These extensions are appropriate for specifying and querying satellite image annotations capturing image metadata and knowledge discovered from the images, and being linked to relevant data sources available on the web as linked data.

- The data model RDFⁱ which extends RDF with the ability to represent incomplete information about property values that are unknown or partially known using constraints. A detailed study and efficient implementation of this model for the case of incomplete geospatial information.
- Theoretical results for the data models stRDF, RDFⁱ and the query language stSPARQL.
- Query processing and optimization techniques for the the query language stSPARQL, and efficient implementation in the system Strabon.
- Query processing and reasoning techniques for the model and its implementation in Strabon.
- The query language SciQL, an extension of SQL with the concept of a multidimensional array.
- Query processing and optimization techniques for SciQL and efficient implementation of them on top of MonetDB.
- The Data Vault concept and its implementation in MonetDB.
- The TELEIOS framework for knowledge discovery techniques from satellite images, their metadata, and relevant geospatial data sets.
- A data generation concept and the associated enriched Data Model which is the actionable information for KDD and Data Mining functions
- A methodology and algorithms for semantic annotation of EO images
- Algorithms for knowledge discovery and data mining in the TELEIOS knowledge discovery framework.
- Concept and algorithms for Scene Understanding and multitemporal analysis of VHR EO images
- Concept and algorithms for Visual Data mining
- The TELEIOS Virtual Earth Observatory architecture.
- The TELEIOS Virtual Earth Observatory infrastructure.
- A real-time fire monitoring service developed by NOAA.
- A Virtual Earth Observatory for TerraSAR-X data developed by DLR.
 - A large TerraSAR-X annotated Data Base
 - Taxonomies and an ontology for TerraSAR-X data
 - Tools for supporting Rapid Mapping
 - Tools for creation of semantic and enriched metadata catalogues for TerraSAR-X archives.

Impact of final results

TELEIOS enables the wider EO community to deal with the challenges posed by the huge scale and complexity of EO data.

The TELEIOS infrastructure enables better leveraging of the skills of EO scientists, improved quality and quantity of output, and reduced time and cost for their research.

Using the TELEIOS infrastructure, EO scientists are able to search for satellite images using semantic criteria, integrate satellite images and other relevant data sets, and use them in applications cutting across domains and organizational boundaries.

TELEIOS allows organizations with large sets of EO data (ESA, our partners DLR and NOAA, other national space agencies etc.) to mine the content of their archives and extract meaningful knowledge that can be made available publicly as linked data, and can be used to develop new applications. Expected main impact is for the enhanced access, utilization and value adding of DLR TerraSAR-X and near future ESA's Sentinel 1 and 2 data.

TELEIOS has developed a new generation of EO portals that function as Virtual Observatories for archived satellite products (we call them Virtual Earth Observatories). In addition, TELEIOS has developed more precise real-time fire monitoring techniques based on continuous acquisitions of satellite images and geospatial data.

Through a focused set of research, development, dissemination and exploitation activities, TELEIOS contributes to the objectives of international efforts in the area of EO such as GEOSS and GMES. The research and technological contributions of TELEIOS will advance the state of the art in the areas of Semantic Web and Linked Data, Scientific Data Management and Image Information Mining.

Project public website

The public website of TELEIOS can be found at <http://www.earthobservatory.eu/>. The website reflects the public image of the project through a clean functional design, and provides up-to-date information about the progress of the project. The various parts of the web site have been fully organized (or re-arranged) to reflect the complete sets of achievements of the project at its completion. Notably, a video has been created which is available on the front page of the website which highlights the major achievements of the project.