WEB-BASED FRAMEWORK FOR PS-INSAR DATA INTERPRETATION ASSISTED BY GEO-SPATIAL INFORMATION FUSION

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ABSTRACT:

This study investigates the options of information mining to enhance interpretation of PS-InSAR results of land subsidence analysis. Persistent Scatterer (PS) Interferometric Synthetic Aperture Radar (InSAR) is one of the latest applications of SAR time series data analysis. The detection of coherent point target measurements i.e, persistent scatterers gives an opportunity of measuring sub-cm deformations of the earth's surface. At the end of the PS processing chain the coordinates, relative topographic heights, displacement, and time coherence parameters are estimated for individual scatterers. As the PS measurements are relative to a reference point, the precision of the estimates is high. However, the absolute localization accuracy of the scatterers is relatively poor due to orbit uncertainty, instrumental and propagation delays, and scattering center uncertainty. Also, the localized effects of foundation instability, groundwater fluctuation, hydrocarbon extraction etc. add further difficulty to the interpretation of deformation measurements by PS.

We explore the existence and the type of functional relations between PS-InSAR geo-spatial layers and other layers like topographic information, for interpreting the deformation results. The work consists of implementing open source GRASS Geographical Information System (GIS) utilities to combine various types of data sources. Radar image, digital orthomap, arial photograph, land use, cadaster databases etc. are linked together to facilitate interpretation of PS-InSAR results. To make the results understandable for non-expert users, a web map server approach is adopted to disseminate the results via the internet. The city of Delft in the Netherlands is presented as a test area with preliminary results of ground subsidence analysis and interpretation.

1. INTRODUCTION

Persistent Scatterer Interferometry (PSI) [Ferretti et al, 2001] is currently recognized as a precise and efficient method for the detection of small and slow deformations of the Earth's surface. The PSI technique evolved from developments in time series analysis of radar interferometric data (InSAR — Interferometric Synthetic Aperture Radar). Radar images acquired over the deforming region at different epochs (usually 30-100 images) are used in the analysis of coherent point targets or strong reflectors of the radar signal. The PSI technique is able to monitor systematic movements of buildings/urban areas with a precision of couple of millimeters per year.

However, due to the complex nature of radar observations, the interpretation of the signal poses quite a challenge in terms of relating the observations to the driving deformation mechanisms. Theoretically, the point targets are point reflectors, but in general the target (PS) signal may also be influenced by distributed scattering mechanisms of objects in the resolution cell (20×4 meters). Due to this reason, the localization accuracy of the deformation signal is difficult to realize. Moreover, the localized effects of subsurface instabilities, changes in water level, soil compaction etc. add a further ambiguity in inferences on the reasons of deformation. In principle, the PS measurements do not necessarily show a reliable estimation of the desired parameter — deformation due to different mechanisms or simply, *deformation regimes*. Moreover, in most cases, there may be more than one mechanism responsible for the detected deformation. To understand the driving forces behind the deformation shown by PS, the scatterers need to be classified on the basis of topographical features they represent on ground.

This research stresses the need of incorporating supplementary information sources as an approach for improved interpretation of the deformation. The classification of the scatterers on the basis of ground features is considered as an addition of qualitative information related to a particular scatterer. The datasets with different characteristics are combined together to extract potential information for explanation of behavior of the scatterers in relation to the physical features of the ground. Due to the large data volumes, Geographical Information Systems (GIS) become indispensable to systematically combine and analyze the various data sources. Open source GRASS (Geographical Research Analysis Support System) GIS [Neteler and Mitasova, 2004] is employed in the current work. After combination of various data, a Web Map Server (WMS) is used for dissemination of PS data to the user community (for example, decision making authorities, planners etc.).

2. PS-PROCESSING — DELFT, THE NETHERLANDS

In PSI, long time series of multi-epoch radar images of the deforming region are analyzed for detection of coherent point targets of the radar signal. A master image is chosen from the available SAR images on the basis of a favorable geometry in relation to other images, i.e, optimal relative temporal and perpendicular baseline, and Doppler centroid. After the co-registration and oversampling ($2\times$) of the master and the slave images, a series of interferograms is created with the use of precise orbit information. In the current work, DORIS (Delft Object Oriented Radar Interferometric Software) [Doris InSAR Processer, 2006] is used for the coregistration, oversampling and interferogram generation. In the current study, 73 ERS-1 and ERS-2 SAR images over Delft have been selected in the period from 1993 to 2003 and consequently 72 interferograms are generated.

The subsequent processing for the detection of Persistent Scatterers is done using the PSI algorithm developed by Delft University of Technology. Coherent targets are identified by their degree in amplitude and phase dispersion over time, before and after estimating topographic, displacement, and atmospheric phase contributions. Ensemble or time coherence estimation is performed for individual PS and serves as a quality parameter for the measurements. The number of selected PS locations depends on the coherence threshold value — the higher the coherence threshold, the lower the number of detected PS points. At the end of the PSI processing chain, the database of estimated parameters consists of locations (X,Y), relative topographic heights, displacement rates, ensemble coherence, displacement time series, and the atmospheric signal time series for an individual PS.

Persistent Scatterers usually correspond to solid or man-made structures which commonly have a high radar backscatter (for example, buildings, lampposts, street/road edges, exposed rocks, solid surfaces etc.). The number of detected PS is therefore higher in an urban area in comparison to a rural or vegetated area. Figure 1 shows the distribution of persistent scatterers overlaid on the time-averaged radar amplitude image. The color variation of points corresponds to the variation in linear displacement velocity of the persistent scatterers from $+20$ mm/year (blue) to -20 mm/year (red) with respect to the reference point. A clear trend of scatterers can be seen on roads, highways, and urban areas in Figure 1.

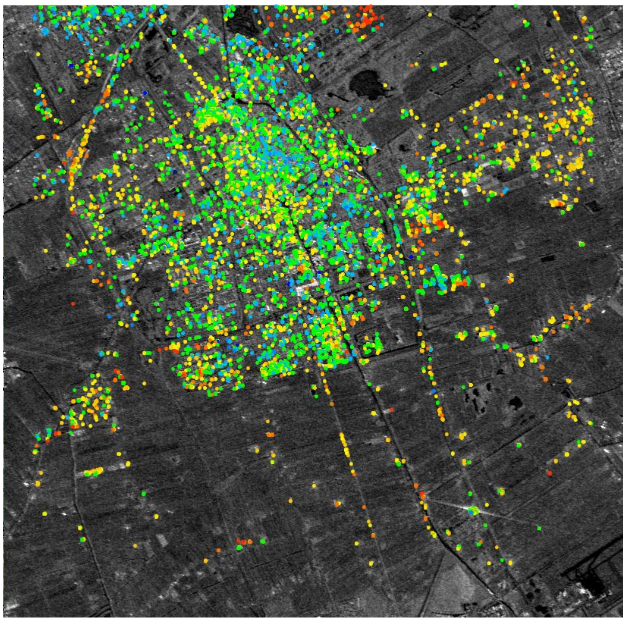


Figure 1. PS points with radar image as background (color variation shows displacement velocity from +20 mm/y (blue) to -20 mm/y (red), relative to an arbitrary reference point)

3. FUSION OF PS-INSAR RESULTS WITH DIFFERENT GEO-INFORMATION

The output of the PS processing chain consists of various parameters such as locations, relative height profiles, ensemble coherence, displacement rates etc. The realization and use of this vast PS information database could be a key factor in the geographical or geophysical interpretation of the signal. For this reason, a variety of datasets is combined in GRASS. The following paragraphs give an overview of the used information databases including the PS data.

3.1 Time-Series Data of Persistent Scatterers

The PS database is point data geocoded and projected into the Dutch RD (Rijksdriehoeksmeting) coordinate system. For each individual PS, a time series of displacements is stored in the database. As a GIS object, each PS is a point vector consisting of the attached topographic height, velocity, and displacement time series as its attributes.

3.2 Raster Data

The Dutch topographic map of Delft (sheet number 37e) with scale 1:25 000 is used as a backdrop raster image for a visual inspection of the PS locations with respect to various man made features.

The radar Multi-image Reflectivity Map (MRM) is used after geocoding the image from range and azimuth to Dutch RD coordinates. The MRM is computed by averaging 70 radar images of Delft. Further, this averaged image is multi-looked by a factor of 5 in azimuth to account for the different resolutions in range and azimuth direction.

3.3 Vector Data

The *Top10* Vector Map of the Netherlands, maintained by the Dutch Land Registry Office [Webpage kadaster, 2006] is used in classification of land use. The map scale is 1:10 000 and it completely covers the features of railroads, highways, infrastructural boundaries of underground metro tunnels, hydrographical features, houses, streets, built-up areas, and other such land use classes. The *Top10* vector map is divided into different land use classes as line and polygon vector dataset. The primary reason to include this dataset is to classify the persistent scatterers according to what they physically represent, particularly in the urban environment. The following list covers the specific land-use information used in this work,

- Line vector for boundaries of infrastructures, namely railroads, transmission lines, metro and tram lines etc.
- Polygon vector for boundaries of water areas.
- Polygon vector for boundaries of forests and vegetated areas.
- Polygon vector for buildings and houses areas.
- Line vector for boundaries of buildings and built-up areas. This map is called as *large Scale Standard Map* and abbreviated to GBKN [Webpage GBKN, 2006] in Dutch. In suburban areas, the scale of this map is 1:500 or 1:1000.

3.4 Geological maps

Geological map of the Delft city and surrounding areas is used for determining the spatial distribution of local shallow geology. The information about the shallow subsurface i.e, soil types and underlying layers is very useful in understanding the localized behavior of anomalous persistent scatterers. However, the use of these maps is done for a qualitative comparison of PS distribution. This data is obtained from the Delft municipality office.

4. USE OF OPEN SOURCE GRASS-GIS

In recent years, open source software has become a synonym for progress and innovation [Neteler and Mitasova, 2004]. Freely available use, distribution, and modification of the source code proves to be a key factor in sharing and development of ideas. Both users and developers contribute to the innovative application additions/extensions in the form of reusable modules.

GRASS (Geographical Research Analysis Support System) [Neteler and Mitasova, 2004] is an open source Geographic Information System released under GNU General Public License. Originally it was developed by the United States Army Construction Engineering Research Laboratory (USACERL), and currently it is developed and supported at the Istituto Trentino di Cultura in Europe and Baylor University in the USA [Webpage GRASS, 2006]. The system runs on different platforms under one of the UNIX family operating systems, macintosh, and windows (currently with cygwin). It provides modules for raster and vector data geo-processing, manipulation, selection, intersections, and similar functionalities. Advantage of module based operations of GRASS is that it saves system resources by executing only the required module. The GRASS GIS program works in various modes i.e, the Graphical User Interface, the interactive parser mode and the command line mode. GRASS is integrated with the GDAL (Geospatial Data Abstraction Library) and OGR libraries to support an extensive range of vector and raster data formats, including OGC [OGC Inc., 2006] conformal simple features. Pixelwise operations on raster maps is also one of the features of GRASS GIS.

Applications can be written with shell scripts to automate the GIS work-flow. For example, once the program has been launched, a procedure can be automatically executed without any intervention by the user up to the production of the final map. This functionality is useful when a dedicated application is required to be created for a particular geo-processing scenario, for example PSI visualization. In addition to the basic and advanced GIS functionality, GRASS also provides the possibility to invoke other programs or common command line unix software tools. A simple example would be calling an AWK command to read a particular column of attribute and further transferring the selected database to a plotting program such as GNUplot to create a plot of the selected column. This functionality is of high value if the database columns need to be analyzed individually, for example behavior of individual Persistent Scatterer time-series of linear displacement velocity.

GRASS can be used as a data combination tool by joining all the data into one reference system (Dutch RD coordinates). Basic geo-processing steps such as intersection of layers, selection based on buffering etc. are carried out, for example, persistent scatterers classified according to the soil type or landuse. Scatterers on or near building boundaries, road/street boundaries, water areas (within a buffer of 2 to 5 meters) are also classified. All the classified data layers are stored in an internal GRASS Vector format or shapefiles and are further used as input for Web-GIS visualization interface. Figure 2 shows a screenshot of PS data visualization using GRASS applications. An overlay of radar amplitude image and engineering geology map is shown with PS points in a gradual color scale of displacement velocity (mm/year).

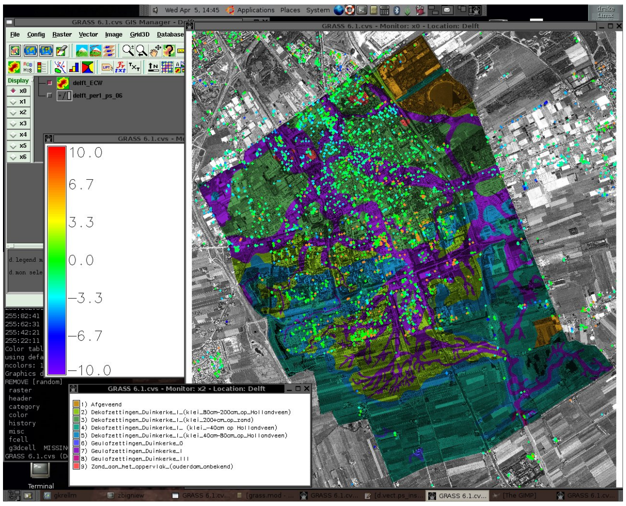
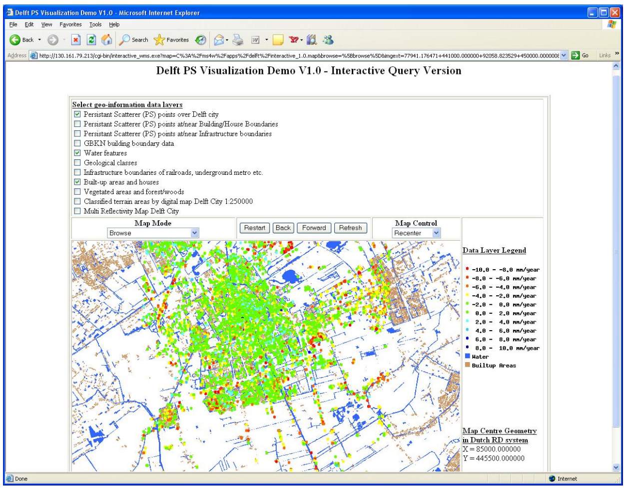


Figure 2. Screenshot of data overlay by GRASS GIS: radar map, engineering geology map and PS points

5. WEB-GIS VISUALIZATION OF PS-INSAR DATA CLASSIFICATION

Internet or Web-based GIS can play a key role in the collection and dissemination of pertinent information in a fast, relatively inexpensive, and straightforward manner during various stages of PS-InSAR data analysis. That is, by assimilating geo-datasets from various online spatial data networks into one (OGC) standard(s) [OGC Inc., 2006] vital spatial information is readily available to numerous users without requiring high-level technical skills on the hardware, software, data collection, data fusion and data transformation side [Gehlot et al, 2006]. This advantage is harnessed in the present work of PS data and results in a visualization using a server-based geographic information combination. Another substantial benefit of web GIS is that it is independent of the computer platform or the information database type (CAD, oracle, ESRI shapefiles, postgres, microstation etc.). Soliciting local expert information is also feasible by updating the database via web. The open source utilities that are used in the work have a key advantage that apart from being free, they can be easily customized to meet a variety of end user requirements.

Currently, MapServer [Webpage UMN Mapserver, 2006] Web-GIS tool is used to create the internet visualization interface of PS-InSAR data. Originally developed by the University of Minnesota, MapServer is a core mapping engine aided with open source development environment. Since MapServer is designed and developed to support the evolving OGC standards, it can be used to incorporate any remote data sources that publish data consistent with these standards. One of the main advantages of a web based system is the ability to provide mapping capability to anyone who can run a Web-browser, even in low bandwidth conditions. Gigabytes of spatial data can be manipulated on the server side and only small compressed images (usually less than 100 KB) are sent to the client. Via Mapserver, the dedicated GIS operations on the server can be called with simple buttons on the client or the internet explorer. The HTML client (browser) with a query string sends variable values to the server, and the Mapserver CGI parses/renders the variables, reads the digital geo-data (in form of shapefiles) described in the mapfile, draws the requested map, prepares an HTML page (according to template definition) for publishing and sends this HTML page to the client browser. This process continues each time the browser sends in a variable request to the server.



Address: http://130.161.79.213/cgi-bin/interactive_wms.exe?map=C%3A%2Fms4w%2Fapps%2Fdelft%2Finteractive_1.0.map&browse=%5Bbrowse%5D&imgext=77941.176471+441000.000000+92058.823529+450000.00000

Delft PS Visualization Demo V1.0 - Interactive Query Version

Select geo-information data layers
- ☑ Persistant Scatterer (PS) points over Delft city
- ☐ Persistant Scatterer (PS) points at/near Building/House Boundaries
- ☐ Persistant Scatterer (PS) points at/near Infrastructure boundaries
- ☐ GBKN building boundary data
- ☑ Water features
- ☐ Geological classes
- ☐ Infrastructure boundaries of railroads, underground metro etc.
- ☑ Built-up areas and houses
- ☐ Vegetated areas and forest/woods
- ☐ Classified terrain areas by digital map Delft City 1:250000
- ☐ Multi Reflectivity Map Delft City

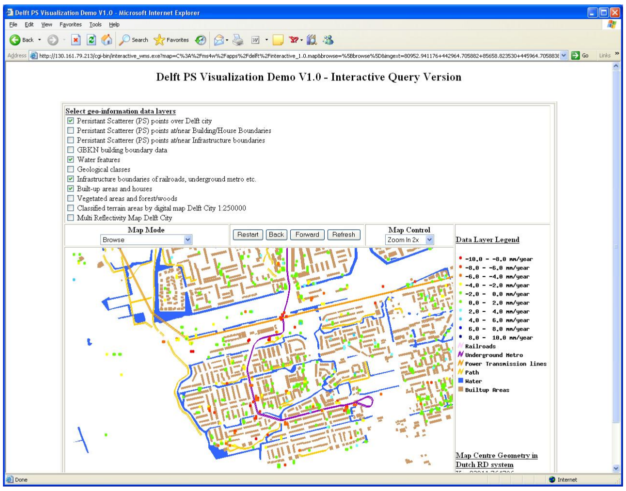
Map Mode: Browse

Map Control: Recenter

Data Layer Legend
- ● -10.0 - -8.0 mm/year
- ● -8.0 - -6.0 mm/year
- ● -6.0 - -4.0 mm/year
- ● -4.0 - -2.0 mm/year
- ● -2.0 - 0.0 mm/year
- ● 0.0 - 2.0 mm/year
- ● 2.0 - 4.0 mm/year
- ● 4.0 - 6.0 mm/year
- ● 6.0 - 8.0 mm/year
- ● 8.0 - 10.0 mm/year
- ■ Water
- ■ Builtup Areas

Map Centre Geometry in Dutch RD system
X = 85000.000000
Y = 445500.000000

Figure 3. Screenshot: Web-GIS functionality to show PS data online with geo-data



Address: http://130.161.79.213/cgi-bin/interactive_wms.exe?map=C%3A%2Fms4w%2Fapps%2Fdelft%2Finteractive_1.0.map&browse=%5Bbrowse%5D&imgext=80952.941176+442964.705882+85658.823530+445964.705883

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- ☐ Persistant Scatterer (PS) points at/near Infrastructure boundaries
- ☐ GBKN building boundary data
- ☑ Water features
- ☐ Geological classes
- ☑ Infrastructure boundaries of railroads, underground metro etc.
- ☑ Built-up areas and houses
- ☐ Vegetated areas and forest/woods
- ☐ Classified terrain areas by digital map Delft City 1:250000
- ☐ Multi Reflectivity Map Delft City

Map Mode: Browse

Map Control: Zoom In 2x

Data Layer Legend
- ● -10.0 - -8.0 mm/year
- ● -8.0 - -6.0 mm/year
- ● -6.0 - -4.0 mm/year
- ● -4.0 - -2.0 mm/year
- ● -2.0 - 0.0 mm/year
- ● 0.0 - 2.0 mm/year
- ● 2.0 - 4.0 mm/year
- ● 4.0 - 6.0 mm/year
- ● 6.0 - 8.0 mm/year
- ● 8.0 - 10.0 mm/year
- Railroads
- Underground Metro
- Power Transmission lines
- Path
- ■ Water
- ■ Builtup Areas

Map Centre Geometry in Dutch RD system

Figure 4. Screenshot: zoom of high velocity PS points over infrastructural boundary features

A Mapfile [Webpage UMN Mapserver, 2006] is created for the Mapserver to connect the stored shapefiles and database of the persistent scatterers and the supplementary information data. The attribute appearances, color scales, and definition symbology for the desired display of vector data (points, lines, polygons) can be controlled by the layer definition in the mapfile. The Mapserver CGI is called by the means of an HTML template linked to the mapfile.

The visualization interface is initialized by the request of URL (mapserver link url to the data server of PS + geo-data) from the client or the web browser. The basic geo-information data included for the current study are raster images of topographical map and radar multi-image reflectivity map, and vector data of cadaster maps (refer section 3.3) and engineering geology maps. PS data points as vector objects are overlaid with the other datasets to have a better understanding of the PS behavior according to ground features. At present, all the data layers are used in form of shapefiles. The layers included in the map have an on/off option for display. The WebGIS interface also supports ancillary map graphics showing a legend, scale bar, display control buttons etc. The interface provides basic options for querying the PS points database for details of individual PS point records i.e., their location, topographic heights, ensemble coherence, yearly linear deformation and time series of linear deformation. Figure 3 and Figure 4 show the screenshots of the web visualization interface of PS-InSAR data combination with geo-information using Mapserver CGI.

6. CONCLUSIONS AND FUTURE WORK

The PS-InSAR data is the combined with supplementary geo-information using open source GRASS GIS utilities for interpretation of displacement observations. A web-based dissemination and information sharing platform is proposed to publish the results and make them understandable to different users. The open source utilities used in the current research are found to be equally efficient as any commercial GIS package. Moreover, the advantage of web-based GIS is pointed out where a user does not need to install expensive and dedicated GIS tools to explore geo-data. A simple web browser can be the means to visualize and interact with various data combinations.

Future research will focus on decomposition of the PSI deformation signal into various components such as, foundation instabilities, changes in ground water levels, thermal variations, subsidence related to soil compaction, geological phenomena etc. Solicitation of qualitative information by local experts via the webGIS interface to add to the PS database is one of the tasks to be explored.

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