Development of Open Source Functionality for the Analysis and Visualization of Remotely Sensed Time Series

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Abstract— The GEONETCast data dissemination system delivers low cost environmental data to users worldwide. Long time series of images from various satellites can be obtained to study dynamic phenomena. To explore the dynamics, displaying the images as animation with few controls is a common practice. However, some problems need to be addressed. We present how the current approach to animate time series of satellite images can be improved by pre-processing (pixel co-registration and resampling data from sattelites with different spatio-temporal resolution), by analytical functionality (detecting features of interests and feature tracking) and by enriching the visualization environment with more interactive functions. But even then, animations still lead to information overload. We discuss our attempts to reduce this problem, and describe the resulting software component that is fully dedicated to visual exploration and analysis of dynamic phenomena and will be added to the open source ILWIS software.

Index Terms—Multi-source time series, co-registration, integration, tracking, animated visualization, change blindness, Ilwis, Open Source.

INTRODUCTION

Earth system science is a multidisciplinary science strongly linked to remote sensing data. Using satellite sensors is often the only way to quickly obtain data with a large spatial coverage and a high temporal frequency. Currently, several satellite image providers have distribution networks that offer images at low cost or even for free. For example, images originating from a number of satellites, both geostationary and polar orbiting, are distributed to end users through the GEONETCast data dissemination system. These images are freely available for educational and research purposes [1].

The GEONETCast images are suitable for a wide variety of applications such as meteorology, climate monitoring, estimation of land and sea surface temperature, crop monitoring, calculation of various vegetation indices, fire detection and many more. In a typical set up, the user of the GEONETCast data dissemination system can receive up to 10 GB of satellite images per day, resulting in long time series that users can explore to study dynamic phenomena.

The purpose of such an exploration is to find patterns, trends and relationships in order to detect and predict the behavior of the phenomena under investigation at different spatio-temporal scales. One way of supporting the exploratory process is by providing animated visualization. This should, however, be coupled with analytical functionality since visualizing long time series of data acquired at different spatio-temporal resolutions is not a trivial task. In addition, for effective exploration, the visual representation and animation controls need to be improved.

1 CURRENT VISUALIZATION PRACTICES AND PROBLEMS

From a visualization perspective, satellite images are mainly explored by animating image sequences with video-type user controls (play forward/backward, pause/stop, etc.). This is very limited functionality for long time series, e.g. subsets cannot be extracted easily, and comparisons with a related data set are difficult to make. Another problem is that although animated satellite images mimic the complexity of the real world, users are bombarded with rapid sequences of changes, and important ones may pass unnoticed: a phenomenon known as 'change blindness'. One main reason for change blindness is that changes failed to attract attention, while attention is needed to bring changing stimuli into consciousness. But attention is limited, and can be distracted (e.g.: by too many motion signals). Another reason is that the encoding and comparison process to detect change was not successful due to the limited capacity and duration of working memory, where information is processed [2, 3].

The rapid sequence of changes in pixel values also make visual exploration of times series a rather subjective and time consuming process. Users who are interested in the evolution of phenomena have to identify relevant features and concentrate to visually sieve and track the often highly dynamic features to view their behaviour.

The problems sketched above point to a need to better support the exploratory process in animated time series of imagery. One way to realize that is by providing analytical support to the visual exploration process. Other ways are to provide additional interactions and improvements in the visualization. We propose an approach in which these methods will be coupled in an animated exploratory environment, but we will first describe two case studies that we will use to demonstrate how the environment works out: nowcasting precipitating clouds in equatorial Africa and monitoring desertification process in Sahel region.

2 CASE STUDIES

Nowcasting, or short–term forecasting, covers timescale from 0–18 hrs and operates on fine spatial scale. In nowcasting, remotely sensed data are mainly used to verify the numerical model since some fine spatial scale structures are usually not 'caught' by the numerical model. METEOSAT Second Generation (MSG) is a typical meteorological satellite included in the GEONETCast distribution system, observing the earth's full disk and monitoring the earth-atmosphere system. On a regular day, it collects ninety six images with the frequency of one image per fifteen minutes (and each image contains data on twelve spectral channels). These images are mainly used for meteorological applications.

Exploring, analyzing and nowcasting precipitating clouds in equatorial Africa (where they are most frequently occurring) is such an application, since one type of precipitating clouds (convective clouds) is often associated with storms and severe weather conditions. Convective storm can affect, amongst others, agricultural production. Their storm cells can produce heavy rain, particularly of a convective nature, hail and flash flooding, as well as straight-line winds. These clouds also contain severe convection currents, with very high, unpredictable winds, particularly in the vertical plane and therefore can be dangerous to aviation. Convective clouds are highly dynamic: a cloud may become convective in 30-60 minutes (2-4 MSG images), suddenly creating lots of motion signals if animated.

In the second case study, we use satellite time series acquired from the GEONETcast system to study spatio-temporal dynamics of the so-called Sahel region [4]. The Sahel is a biogeographic zone of transition between the Sahara desert (North) and the savannas of Sudan (South). This zone, covered by dry grasslands and acacia

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savannas, forms a belt that stretches between the Atlantic Ocean and the Red Sea. Studying spatio-temporal dynamics of the Sahel is essential for a number of reasons. For instance, to understand Sahel droughts which are linked to famine episodes in several African countries. For this application, the analysis is based on vegetation indices (arithmetic combinations of the data acquired in two or more spectral channels), which are commonly used to monitor vegetation dynamics over large areas.

In both case studies, the use of animated visualization could certainly help researchers, but some visualization and analytical issues need to be solved to facilitate an effective visual exploration of the complex spatio-temporal dynamics in both cases. Challenges already start at the data integration and pre-processing levels. For instance, for the fusion and synergic use of images collected by different satellites, issues like image co-registration and filling of missing pixel values should be properly addressed. At the analytical and visualization level, we have already indicated that interventions are needed to avoid that too many of these signals and distractions hinder visual exploration of the animated images.

3 Analytical functionality

Integration of data acquired at different spatio-temporal resolutions starts with co-registering pixels.

One issue here is the projection of the images that compose the time series to a common grid. This operation, known as gridding, basically can be done in two ways: a predefined dataset is used as a reference (for instance an existing land cover map of the Sahel area), or one of the images of the time series is used as a reference. In both cases, the user of the animated visualization should realize that polar orbiter satellites scan the Earth surface from different orbits and this, in turn, implies that the observed areas are slightly different for each image [5]. In addition to the gridding, the user should consider the best method to resample the images. For instance, nearest neighbour interpolation –preserving radiometry – might create ‘blocky’ effects on the images and cubic interpolation – giving a good and smooth appearance – modifies the observed values, which might introduce biases in the analysis.

Another important issue is the interpolation of missing pixels. Missing pixels can be due to malfunctioning of the sensor, or be artifacts of the interpolation/scanning method but most commonly, in the case of land optical remote sensing, they are caused by clouds as they cover the surface under study [6].

Also relevant is the smoothing of time series so that the evolution of the animation looks ‘natural’ to the human interpreter. Several methods for the smoothing of time series are found in the literature [7], and we would like to add this functionality to the software component.

With respect to the analytical functionality, visual approaches require effective ways to extract features of interest from time series. For this, we use the physical and spectral properties of the features under investigation to track features and bind them into object paths. In our approach, tracking solves an identity problem based on overlap criteria [8]. The underlying assumption of tracking using overlap is that the sampling frequency of the sensor is high enough to detect overlaps in at least large objects.

4 Visualization functionality

Default animation of time series of images can be improved by all the functions described above. Proper pre-processing definitively improves the visual appearance of the time series; features and object paths can be used as input to the visual environment to facilitate the exploration of dynamic phenomena like precipitating clouds or vegetation units. Another improvement to conventional animated visualization of time series is the display of additional information about the (tracked) features, like the size of the features or their spectral/spatial properties.

Interactive options to filter and animate only objects, attribute values, time intervals, or user-defined sub-areas of interest will already diminish change blindness effects, since users will be better able to focus attention on selected parts of the animation. We also investigate options to reduce the disadvantage of filtering that likely useful context information cannot be seen simultaneously in the animation, for instance by making selected objects or attribute values stand out as ‘figure’, while a subdued ‘ground’ is maintained to provide context. Elements that form the ‘figure’ can be highlighted or emphasized in other ways, with a de-emphasized visualization of the surrounding context. To reduce the effect of change blindness due to rapid sequences of motions signal, that hinder encoding and comparison of changes in working memory, there should at least be a function to control the display speed of the animation.

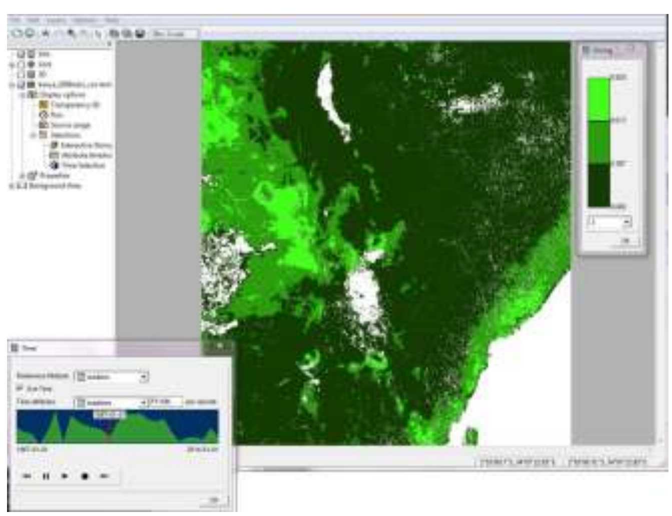
Some of the functions mentioned above were already available in a research prototype called aNimVis (Animated Image Visualization) [9]. Based on this prototype, a new component has been developed as plug-in to the already existing ILWIS software.

5 Why ILWIS?

Considering the above, analytical and visualization functionality to handle long time series should be embedded into existing image processing software. Developing such tools as ‘Open Source’ enables quick detection of software problems and further development; free availability is also important, since many users of GEONETCast data are from developing countries, and we want to preserve the original GEONETCast philosophy.

ILWIS is free and open software and it already has a plug-in to access GEONETCast data [10]. Our choice was therefore to extend this further and develop additional functionality for the analysis and animated visualization of time series. ILWIS is software developed over the past 20 years at the ITC. In 2007, the C++ source code of ILWIS was made available as ‘Open Source’, and maintenance responsibility is passed on to one of the communities of the open source software initiative 52°North [11].

Strong points of ILWIS are that it is lean and fast software, easy to learn for end users. Most of its functionality can be extended through a plug-in mechanism, but if demanding functions require changes to ILWIS itself, it is possible because users have access to all the source code. In addition to this, ILWIS already provides analytical image processing functions. This includes basic functions like image visualization, default animation, re-projection/resampling, interpolation, filtering, clustering, overlay and (geo)statistics, but also advanced functions like atmospheric correction and energy balance calculations. Furthermore, it has a very strong image mathematics component and a batch processing component with



which defined processes can be applied to thousands of images.

Fig. 1. Main window of the ILWIS component for the analysis and animated visualization of remotely sensed time series (alpha version).

6 Discussion, Current status and future research

The presented functionality improves visual exploration compared to using a conventional animation of time series, because issues like co-registration of images, tracking and binding of objects, the selection, quantification and visualization of objects and the reduction of change blindness problems will be addressed. Although the idea of visualizing the events and object paths is not entirely new (see e.g. [8]), the novelty of our approach is that access to the GEONETCast distribution system, pre-processing, analytical and extensive animated visualization functionality will be packaged into a single Open Source environment, ILWIS.

Currently, the extended visualization functionality for long time series is being integrated into ILWIS. An alpha version containing one window to display the animation is ready (fig. 1) but ultimately there will be two display windows to enable comparison between time series, like in aNimVis. Investigations into ways to include object tracking (as described in section 3) and improve the animated visualization (as discussed in section 4) are ongoing.

After the implementation, the next step will be user evaluation of the software. This evaluation, however, is beyond the scope of the current paper.

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