WEB MAP SERVICES (WMS) GLOBAL MOSAIC

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Abstract

The WMS Global Mosaic provides access to imagery of the global landmass using an open standard for web mapping. The seamless image is a mosaic of Landsat 7 scenes; geographically-accurate with 30 and 15 meter resolutions. By using the OpenGIS Web Map Service (WMS) interface, any organization can use the global mosaic as a layer in their geospatial applications. Based on a trade study, an implementation approach was chosen that extends a previously developed WMS hosting a Landsat 5 CONUS mosaic developed by JPL. The WMS Global Mosaic supports the NASA Geospatial Interoperability Office goal of providing an integrated digital representation of the Earth, widely accessible for humanity's critical decisions.

1. WMS Global Mosaic Concept

The mission of NASA's Geospatial Interoperability Office (GIO) is to increase the scope and adoption of geospatial interoperability standards in order to facilitate access to and use of geographic information by a broad range of users. Paramount to this mission is the deployment of useful datasets accessible via geospatial interoperability standards developed by open consensus standards bodies. The OpenGIS Web Map Service (WMS) is a prime example of an open standard for geospatial interoperability. Landsat is a flagship of the land remote sensing efforts of NASA, with several generations of satellites providing data for the last 30 years. To provide easy access to a global mosaic of Landsat 7 data is the goal of this project. The WMS Global Mosaic Project will create a seamless image of the whole Earth at the native Landsat resolution of 15 and 30 meters, accessible on the Internet through the OpenGIS© Web Map Service (WMS).

1.1 OpenGIS Web Map Service

The OpenGIS® Web Map Service specifies an interface for a standard web browser to request a map from a web map service[i]. The main WMS operation is as a GetMap request and is defined using WWW protocols. In response to a GetMap request, a web map service produces a map of georeferenced data. A "map" is a visual representation of geodata; a map is not the data itself. Individual map layers requested by the client from different servers can be overlayed in the web browser. The WMS specification thus enables the creation of a network of distributed map servers from which clients can build customized maps.

The WMS specification is a remarkable technical and commercial breakthrough. Software conforming to the specification is able to automatically overlay, in ordinary web browsers, map images obtained from multiple dissimilar map servers. Digital maps and earth images, which until now could not be accessed and used without special skills and software, can now become an integrated part of the broader Information Infrastructure. Such maps and images show, for example: transportation routes, land use and ownership, zoning, watersheds, elevation, population density, average income, utilities, and remote sensed imagery.

1.2 Landsat Global Data Sets

The Landsat satellites have collected data of land and coastal areas for more that 30 years, but the first systematic compilation of a global, orthorectified, generally cloud free Landsat data set was not initiated

until 1998[ii]. Then NASA contracted with the Earth Satellite Corporation (EarthSat) to compile global Landsat data sets for three eras - the early to mid 1970s, circa 1990 and 2000. The Landsat global data sets are the highest resolution, multispectral, orthorectified, global data available. The program was managed through a solicitation issued by the NASA Stennis Space Center. The individual scene circa year 2000 GeoCover-Ortho database includes 8,500 orthorectified Landsat ETM+ scenes. The completion of the 2000 data set now affords a unique opportunity to apply Landsat type data for land cover mapping and change detection over multi-decadal period. The global data sets are available on a scene-by-scene basis through the USGS and other sources. Additionally the GIO identified this as the source for a WMS Global Mosaic.

Previously, a WMS developed by the Jet Propulsion Laboratory (JPL) serving a mosaic of Landsat 5 images had become a de-facto base map layer for OpenGIS WMS activities[iii]. The JPL WMS served Landsat 5 data for the contiguous United States (CONUS). Since its unofficial deployment in 1999 its use has steadily increased and is now a standard image layer for many OpenGIS based applications. MapUS delivers over 15,000 custom images per month to clients.

The combination of the JPL CONUS server and the Landsat 7 Global Data Sets, provided the basis to contemplate a WMS Global Mosaic. But as CONUS is roughly 5% of the World's landmass, a global mosaic is an increase of a factor of 20 in data volume. The 15m panchromatic band, characteristic of the Landsat7 TM+ instrument almost doubles the amount of data again. A trade study was undertaken to study possible approaches and determine a selected approach.

1.3 WMS Global Mosaic Trade Study

To determine the optimal approach to pursuing a WMS Global Mosaic, a trade study was undertaken by GIO. The requirements from NASA management in summary were:

- OpenGIS Web Map Service interface
- Industry involvement
- Full resolution Landsat
- Early, partial deployment to support the World Summit on Sustainable Development.

GIO examined six options relative to the requirements. Two of the options were selected for detailed evaluation: an extension of the JPL MAPUS and a commercial GIS vendor solution. The OpenGIS WMS and the full-resolution Landsat requirements warranted the selection of the JPL MAPUS approach. To meet the industry involvement requirement, once the mosaics are created, a deliverable package of data, documentation, and procedures will be available for hosting on other WMS servers as designated by NASA.

2. Building the WMS Global Mosaic

A team at JPL led by Lucian Plesea is constructing the WMS Global Mosaic. The various components of the construction are described in this section.

2.1 Mosaicing the scenes and storage

The Orthorectified Landsat 7 data set is comprised of 8600 individual scenes. Each input scene is organized as a collection of nine monochrome images one for each band, stored in the GeoTIFF format, in the UTM projection. There are three possible spatial resolution; 30m for the Landsat bands 1,2,3,4,5,7; 60m for each of the high and low gain thermal band ; 15m for the high resolution panchromatic band. Since each complete scene takes about than 550MB of storage, 8500 CDs would be needed to store the complete dataset. Based on this estimate, an on-line storage of 10TB or more is needed to produce a derived composite dataset.

Past experience with storage systems together with budget as a consideration led to the selection of a Linux storage cluster. Other projects with similar storage requirements joined the development, with the result

being a ten-system Linux storage cluster offering 40TB of storage space. The system, named Raid Again Storage using Commodity Hardware And Linux (RASCHAL), has been operational since April 2003. Each unit is built around a rack-mountable PC case containing one Intel XEON 2.4GHz CPU hosting two separate 3-ware IDE RAID controllers, each controller being configured as a 7+1 RAID 5 disk. The IDE drives used are Maxtor 250GB drives, selected for maximum capacity and minimal power requirements. At the next level, two virtual drives residing in the same case are stripped together using the Linux metadrive facility, thus the RAID again name. Dual Gigabit ethernet is standard on every RASHCAL unit, and a 24 port Gigabit Ethernet router provides the communication matrix to the client systems. To make the whole system simpler to maintain, the storage units are configured to boot from a remote host machine.

As far as the software involved, the development branch of the Linux OS was required to handle disk block devices larger than 2TB. Each disk unit is configured as a single 3.5TB drive using reiserfs, and shared on the network using NFS version3[iv]. This storage system performs as expected, with sustained read and write rates of more than 20MB/sec. While extracting a 12.5% storage capacity penalty, the RAID5 configuration at the 2TB level greatly increases the reliability and availability of the storage system.

The WMS mosaic project is the first user of this storage system, having, to date, restored more than 7000 of the original Landsat 7 scenes, and produced a few continent size mosaics. This storage system is being used for the mosaic building project and for hosting the data for the WMS site.

2.2 Mosaicing code

With a storage system available the next step was to create the mosaics. When the previous Landsat 5 CONUS mosaic was produced, a set of important design decisions were made. The most important one was the complete elimination of any temporary products that require storage, the final mosaic being produced in a single step, always starting with the raw input scenes. This means than any required operation such as reprojection, brightness adjustment, blending of adjacent scenes have to be done in memory, as a processing chain. A second decision was to completely separate the data processing engine from the problem of solving the color balance problem. And finally, a mosaic in a geographic projection is to be generated regardless of the input projection.

This software is implemented using the SGI Image Vision Library, a high performance, extendable object oriented image processing library. It operates in a data pull model, with the image operators organized in a tree, taking care of the memory management and the multiprocessing aspects. Only a few custom image operators had to be added, for example a UTM to geographic projection warp and a multispectral image blender.

The mosaic engine builds the output mosaic a fragment at a time. For each fragment, the required input scenes are selected. In the next step, colorimetric corrections consisting of multiplicative and additive constants are applied to each individual scene and band. The resulting images are reprojected to geographic coordinate relative to the current output fragment. In the final step, all selected scenes are masked and blended together using a weighted average algorithm, to produce the output fragment. A control program then loops over all the fragments of the output mosaic. The fragment size is the main control variable for the process efficiency. A large fragment optimizes caching of temporary results reduces the initial setup overhead. But a large fragment will also select more scenes, increasing the computational load and reducing the throughput. As a rule of thumb, selecting an output fragment of similar size to an input scene is a good compromise.

To produce the WMS Global Mosaic, new features have to be added. Most important, using a single output resolution of half arc-second will produce considerable storage waste. To address this problem, three separate resolutions will be produced, one of each of the input band resolutions. Further improvements, especially for execution speed are being implemented.

2.3 Color balancing

Color balancing for a global mosaic is not a simple problem. The main input to this process is the sum of all the metadata collected about the input scenes, including the coverage and the statistical brightness characterization. The output has to be the corrections values to be applied to each band for each scene.
But there are many aggravating factors. The original scenes have been collected at different times, months and even years apart. As a result of the seasonal changes, the vegetation and the solar angle can be very different between neighboring scenes. Clouds are also a sizeable problem since when present they skew the average brightness of a scene, even if the scenes have been selected for minimal cloud coverage. Scenes with large areas of water, such as ocean shores are a special problem, since water can change from completely dark to bright green and even to white. To make matters worse, duplicate scenes covering the same areas are frequent, and scenes missing in the original mosaic will have to be added at a later stage, without doing a new global color balance. Large areas of very bright such as ice cover are a special problem.

The current algorithm is driven by the requirement to build a visually pleasant mosaic, yet preserve most of the features in the original bands. This means that the output mosaic has to have considerable and almost constant brightness, and at the same time allow for large variations in hue and saturation. Since the 15m panchromatic band contains most of the detail information, it is being used to drive the color balancing. In an initial step, the statistical distribution of this band is clipped between a low and a high value, in an attempt to eliminate the clouds and dark water areas. The resulting panchromatic band brightness is then compared to a given target value, and the corresponding correction values for a given scene are determined. The same constants are used as initial values for all the bands in a given scene. This operation is done so that the ratios between bands are preserved. In a second step, a filter is applied recursively, allowing for only small differences between neighboring scenes, but considerable ones over large areas. In a further refinement, scenes can be flagged as "boundary conditions", making it possible to insert scenes in a pre-existing color balance solution.

2.4 Serving Landsat7 Mosaics using WMS

Access to the seamless worldwide mosaic of scenes will be provided using the OpenGIS Web Mapping Service (WMS), Version 1.1.1. A WMS produces georeferenced maps, which are requested and transferred using a simple HTTP mechanism. A WMS can provide access to multiple data layers, providing a mechanism for a single server to host several different data sets. The Style Layer Descriptor (SLD) is an addition to WMS which gives clients significantly greater control over how the maps are to be rendered, such as which bands to display, or what colors to use in drawing particular features types.

The Enhanced Thematic Mapper (ETM+) instrument on Landsat 7 takes images in 8 bands. Three of the bands use the visible part of the spectrum, at 30 meter spatial resolution (bands 1, 2, and 3), three infrared bands at the same 30 meter resolution (bands 4,5 and 7), a thermal infrared band (band 6) at 60 meter spatial resolution with two different gain values to cover the dynamic range of the thermal values, and a pan-chromatic band (8) at 15 meter resolution which spans the visible and near infrared spectrum.

Because of the wide spectral range and high resolution of the pan band, it can be used to effectively increase the detail sharpness of images taken with the other bands through a process known as pan-sharpening. The selected color image resulting from any combination of the 30m resolution bands is converted to a Hue-Saturation-Value (HSV) color-space, resolution is increased to 15m, then the brightness values are replaced with pan data. The resulting image is then converted back to the RGB color space at the resolution of the pan band. The resulting image effectively has the color information from the selected band combination and the brightness from the panchromatic band.

Due to the number of bands, plus the choice of pan-sharpening any color band combination, providing all possible combinations as separate WMS layers is not a good solution. A better solution is to use some of the advanced features of WMS such as the Style Description Layer.

Although SLDs are very flexible, and provide band selection support for the red green and blue components, they do not provide explicit support for the pan-sharpening operation. Of course, a pan-sharpened and a non pan-sharpened image can be presented as separate layers. However, the pan-sharpening can lead to unexpected consequences, such as when a client requests an RGB image where all 3 colors are drawn from a single band. Due to the RGB-HSV-RGB conversion, the resulting image will the pan-chromatic band itself, with no contribution from the single band that was requested. Currently, the WMS Global Mosaic development team is working with other OGC SLD implementers to develop an effective approach to WMS requests using SLD for pan-sharpened images.

3. Using the WMS Global Mosaic

Due to the size of the mosaic and the incremental availability of the Landsat scene, the Global Mosaic is being developed incrementally. This section describes plans for using the mosaic event as it is being developed.

3.1 Use in the OGC Interoperability Program

The initial use of the WMS Global Mosaic was for the World Summit on Sustainable Development (WSSD) in August 2002. The Open GIS Consortium conducted an initiative in support of WSSD: the Geographic Information for Sustainable Development (GISD) initiative[v]. To support the GISD, the WMS Global Mosaic displayed the Landsat scenes for the common study areas for GISD. The WMS Global Mosaic is unique in comparison to other Landsat mosaic sources by providing the full resolution Landsat 7 over the Internet.

Beyond the GISD initiative, the Landsat 5 CONUS WMS mosaic developed by JPL has been a regularly used as a base layer for the OGC Interoperability Program activities. It is anticipated that the WMS Global Mosaic will find similar and broader usage in OGC initiatives.

3.2 International Plans

Several international activities anticipate using the WMS Global Mosaic when it is available.

NASA has donated the Landsat Global Data sets to the United Nations Environmental Programme[vi]. The data sets contain Landsat satellite information from 1992 and 2000 and are valued at some $20 million dollars. The NASA data sets will assist UNEP with their role in managing, analyzing and distributing information for sectoral assessments, implementation of environmental conventions and the Millennium Ecosystem Assessment. The distribution of the Landsat scene data in Africa for example is difficult given the slower bandwidth networks and relatively limited number of facilities for handling remote sensing data. The vast majority of users do not need the Landsat data but rather an image of the data would satisfy their needs. Networks in Africa provide sufficient bandwidth for WMS images. Recently CEOS conducted a study on "Web Mapping In a Low-Speed Environment[viii]" specifically in support of the GISD efforts. The study concluded that based on average bandwidths in Africa, WMS images can be seen in 20 seconds or less. By providing full-resolution Landsat images with user selectable false-color rendering, the Global Mosaic provides a partial solution to the distribution of the NASA donation of Landsat Global Data sets to the United Nations.

Currently the Committee on Earth Observation Satellites (CEOS) is developing a plan to put the Landsat Global Data sets online for access by WMS and OpenGIS Web Coverage Services (WCS). WCS provides access Internet access to image data, i.e. floating point, in formats defined by the server. The WMS Global Mosaic is being offered and considered as part of this CEOS plan.

3.3 An element of Digital Earth

The 3rd International Symposium on Digital Earth deals with: "Earth observation and processing technologies for Digital Earth, the meaning of sustainability and policy of its formulation, delivery, monitoring and evaluation in the conditions of the Information Society". The WMS Global Mosaic provides the most comprehensive observation of the Earth, i.e., the Landsat Global Data sets, in the most internationally accessible delivery mechanism of today's Information Society, i.e., the Internet. With the WMS Global Mosaic, anyone with a WWW browser and a low-speed Internet connection has access to remote sensed images. While there are many people in the world without the technology of the Information Society, the WMS Global Mosaic brings this technology to many more decision makers to support analysis of sustainability and the related policy formation.

From a historical perspective, the WMS Global Mosaic is a first that can be compared with the first complete maps of the Earth. The first maps of the Earth were made in the first half of the 16th Century: in 1513 by Piri Reis a Turkish Admiral; and, in 1538 by Gerardus Mercator, a Flemish mapmaker and inventor of the map projection of the same name.. The Landsat Global Datasets provide the first, complete, medium-resolution observation of the Earth – an event similar to gathering the data from the voyages of discovery in the late 15th Century, e.g, Columbus voyage to America. The OpenGIS WMS provides a means of distribution maps to the general public – an event similar to the development of atlases based on the voyages of discovery. The WMS Global Mosaic makes the Landsat Global Datasets accessible via the OpenGIS WMS. The WMS Global Mosaic supports NASA's Geospatial Interoperability Office goal of providing an integrated digital representation of the Earth, widely accessible for humanity's critical decisions. The WMS Global Mosaic provides a never before available means to explore and understand the Earth. The WMS is a partial realization of the Digital Earth vision.

References

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