QUAD-LACC: A Proto-type System to Generate and Interpret Satellite-Derived Land Cover Products

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Abstract- A proto-type land cover mapping system, QUAD-LACC, has been developed to process archival Landsat Multi-spectral Scanner (MSS) imagery of the Great Lakes watershed. Its architecture has been designed to meet two key objectives, namely, spatially-detailed accuracy characterization and enhanced linkage between product generation and subsequent interpretation.

I. Introduction

Among the many challenges in large-area, moderate resolution (10-100 meters) land cover mapping are two that are addressed in this paper.

(a) Generators of land cover must address an 'information level trade-off' that arises when large-area products have to be derived from large numbers of discrete satellite scenes. Typically the scene population will encompass a broad temporal acquisition window (typically over 2-3 years) and include members imaged under diverse atmospheric conditions. As a result, the extractable level of information may vary considerably from scene-to-scene. The information generator must maximize data usage and accurately characterize spatial variations in information quality.

(b) The creation of tools so that end-users can effectively exploit these products within a broader geo-spatial context. First, there is a need for methods to weigh the relative reliability of satellite-derived products versus other available geo-spatial sources. Second, many end-users may have interests which are limited to only local areas (e.g. a municipality or watershed). As a result, it should be possible to exploit relevant source imagery of that area in conjunction with local expertise to enhance or customize the base information product.

In 2000, a joint project was begun involving the Canada Centre for Remote Sensing (CCRS) and the United States Environmental Protection Agency (US EPA) to derive land cover information for the Great Lakes watershed from archival Landsat Multispectral Scanner (MSS) scenes. The source imagery for this study includes (i) U.S. coverage from the North American Landscape Characterization (NALC) program [5], (ii) operational Canadian geocoded data and (iii) MSS scenes from the GEOCover global data set [1]. Although the land cover products being generated are synoptic in nature, they include set for each of the 3 NALC epochs (mid 70's, mid 80's and early 90's), each requiring the processing of approximately 50 scenes. To achieve this goal and address the issues raised above, a proto-type land cover generation and interpretation system, QUAD-LACC, has been developed at CCRS. The system has some unique features. First, it exploits the overlap coverage of scenes from adjacent orbital tracks to model and quantify classification consistency at the pixel level. As a result, a classification confidence layer is generated that portrays spatial variations in product accuracy. Second, product generation and interpretation are linked. This integration means that the end user not only has access to the final land cover layer but also seamless access to all of the base imagery and ancillary information used to generate it.

II. System Overview

A schematic of the overall architecture of QUAD-LACC is shown in Figure 1.The stand-alone system has been built upon standard hardware found on most low-end personal computers. The principal modules are briefly outlined below.

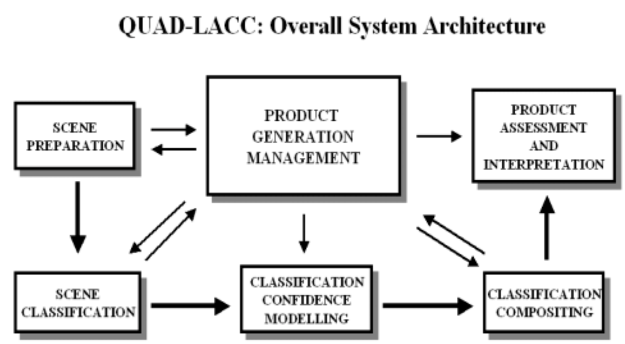

Fig. 1. Schematic illustration of the principal modules of the QUAD-LACC system.

A. Product Generation Management

A new land cover product is defined by user entry of its geographic context, (i.e. its cartographic projection and sampling interval (pixel size)), and a classification legend. The management module controls all processing functions used in the creation of the product from a large number (up to 100) of discrete geocoded scenes. These automated functions include

(a) meta-data generation and updating,
(b) transparent data management through the use of a standardized file naming convention,
(c) error/exception handling,
(d) context control of scenes within the product and inter-scene spatial relationships,
(e) generation of and seamless access to ancillary information such as the ground reference data base,

(f) full GUI functionality including image display.

B. Scene Preparation

The scene preparation module currently supports NALC, fast format and generic flat raster input of imagery and will be extended to include GEOCover Landsat MSS data. Preparation includes three principal steps.

(a) Scene re-projection onto the cartographic grid specified for the output land cover product.
(b) Haze-reduction based on the Haze Optimized Transform (HOT), [6]. This is a critical step since most scenes exhibit some level of degradation due to clouds and/or spatially-varying haze.
(c) Generation of a set of pseudo-bands that will be used for classification and enhanced display. Currently a 3-band set consisting of NDVI and the first two principal components are produced.

C. Scene Classification

Our initial goal is to generate a high level or synoptic classification consisting of the following classes; water, forest, urban/developed and other non-forest land although the system will support subsequent expansion to more detailed classes if supporting ancillary information becomes available. Scene classification is accomplished using a conventional approach involving unsupervised spectral clustering (K-means algorithm, default of 150 clusters) followed by cluster labelling. Label interpretation utilizes reference information in the forms of topographic maps and aerial photography. Reference sites can be manually located on a scene and subsequently saved in a product data base. In this way a watershed-wide, ground reference source of information has built up during processing of the 90's epoch scene set and is being accessed to automatically label a subset of clusters of scenes of the other two epochs

D. Classification Confidence Modelling

At the latitude of the Great Lakes, Landsat scenes exhibit about a 60-70 % coverage overlap with their four nearest neighbouring scenes. The classification quality of a scene can be estimated based on an analysis of classification consistency in these overlap regions. A detailed statistical analysis of consistency and its relationship to conventional accuracy is presented elsewhere [2], [3]. In brief, consistency is assessed at the cluster level to initially identify mis-labelled cases and finally to generate a 'confidence' overlay.

E. Classification Compositing

The final step in land cover product is the merging of scene-based classifications into a seamless large-area product. This accomplished using a 'compositing' process [2]. The two most important reasons for selecting scene-based classification compositing are the following. First, the process allows us to fully utilize all available imagery. As a result, in areas of inter-scene overlap, we have at our disposal multiple independent estimates of land cover. Rationalization of these should result in improved labelling quality. Second, statistical arguments suggest that comparison of the level of agreement among multiple classifications provides a valuable and spatially detailed insight into classification performance. Net confidence is accumulated in this process and saved as an ancillary overlay that encapsulates, at the pixel level, both the number of independent scene classifications available and their relative agreement. As an example, Figure 2 illustrates a portion of a 3-class land cover product (water (dark), non-forest land (grey) and forest (white)) of the central portion of the Great Lakes watershed. Figure 3, the corresponding accumulated confidence layer (confidence proportional to brightness), shows the enhanced level of confidence associated with areas of inter-scene overlap.

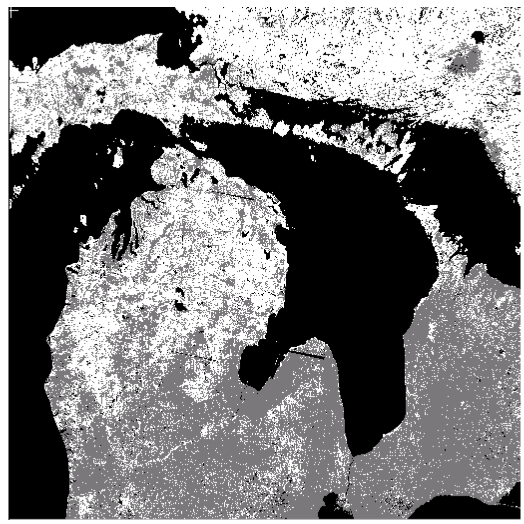

Fig. 2. Example of a 3-class land cover classification of the central portion of the Great Lakes watershed.

F. Product Assessment and Interpretation

The conventional view of product interpretation is that it is de-coupled from the generation phase. In this scenario, the final land cover layer is interpreted/exploited within an environment that may draw on external information sources such as digital maps but with little or no reference to either the parent imagery or auxiliary information used by or created during the product generation phase. We believe that interpreters can benefit from maintained linkages with the generation phase databases. With this in mind, the interpretation module within QUAD-LACC has been designed and developed on the following premises:

(a) Any large-area (i.e. multiple-scene) information layer must be at a synoptic level in order to achieve a high quality and consistency throughout [7],
(b) There is a wealth of further image detail and information that cannot be reliably extracted product-wide but may be extractable locally, i.e. within specific scenes or sub-scenes,

(c) While there will be applications that require the full area coverage of large-area products, there are also potential applications that are local in nature. In these cases, the expertise of the interpreter regarding local conditions can be brought to bear to support the creation of refined local products.

The interpretation toolkit should include extended functionality. First, there must be access to both the base imagery and all ancillary information used in the generation process in order to support more detailed information extraction. Second, it should include a suite of interpretation tools that allow for the generation of refined 'local area' products that have an information linkage with the parent large area product.

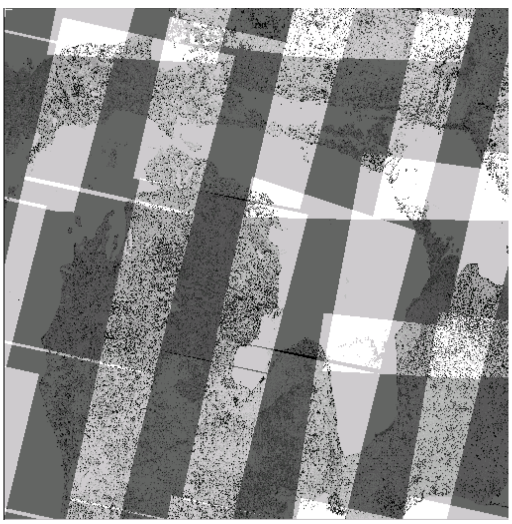

Fig. 3. Accumulated confidence layer associated with the land cover classification of Figure 2. Confidence is proportional to brightness.

The development of a full-blown interpretation capability is beyond both the spirit and the objective of QUAD-LACC, however, we have implemented a display capability to illustrate some of the above concepts and potential 'value-added' products. The main features of this development include,

(a) Ready access to all source imagery in a 'virtual mosaic' mode even though individual scenes were not fused into mosaics prior to classification. If the interpreter selects a local area of interest (AOI) for study, the QUAD-LACC interpretation module automatically identifies the scene encompassing the AOI and its relevant sub-area.

(b) Ready access to the ground reference data set generated and used during scene classification. This can be seamlessly accessed at all levels, i.e. product-wide, scene or AOI. Access to these data can be used to refine or add new classes to the base information layer.

(c) Creation of 'hybrid' products. We define a 'hybrid' product as one that combines thematic layer(s) and image data for enhanced visual interpretation.

III. Conclusions

A proto-type system, QUAD-LACC, has been developed for land cover mapping based upon archival Landsat MSS. Its design has been directed to address two major issues. First, inter-scene overlap coverage is used for improved accuracy characterization that accounts for landscape diversity and the disparate information content of constituent scenes. Second, a seamless linkage between product generation and interpretation is included to support enhanced product exploitation by non-remote sensing specialists and customization for local area applications.

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