Base Mapping
High Resolution Urban Mapping

Background

Urban growth and change places a heavy demand on local governments to seek better planning and management approaches. Increasing urbanization puts pressure on natural resources and existing infrastructure. Elected officials in these local governments require timely information products to support policy decisions on issues that are often interrelated and can span several political boundaries. As a result, local governments have invested considerable resources in developing Geographic Information Systems (GIS) to aid them in their planning and decision making processes. A digital image basemap is a key information layer in many local government GIS systems. In addition, products derived from the image basemaps like urban land cover, road and building footprint maps, and impervious surface maps can provide value-added layers for integration and use in many local government GIS applications.

User Community

Image basemaps and derivative products are used by city planners and engineers for tax assessment, inventory, construction planning (roads, bridges, etc.), utility planning, stormwater management, and other civil planning activities (greenbelt preservation, emergency 911, etc.). A major stumbling block to the effective application of remote sensing imagery for these applications is the positional accuracy of the image basemaps and derivative products. Existing vector data layers (road centerlines, parcel and zoning boundaries, etc.) are routinely superimposed upon the image-based products for planning and assessment applications. If vector data layers do not line up with the image products, then the products are perceived to be of limited value and will not be integrated into standard operations and decision-making processes within the local government. Thus, the horizontal accuracy of a remote sensing information product is a critical measure of its utility for application in local government GIS systems.

The specific user community for this work was a diverse group of managers from within various departments (Planning and Development; Public Works; Tax Assessor's Office) in the City of Columbia and Boone County, Boone Electric Cooperative, Boone County GIS Consortium, and Boone County Regional Sewer District. These users were engaged on the front-end of this process to identify their needs and attending basemap product requirements using the QFD analysis approach demonstrated in Synergy I activities. The key requirements identified through this user involvement were:

1) One-meter resolution digital image basemaps with positional (horizontal) accuracies of 3-5 m CE90 were required for to be useful for local government GIS applications.
2) County-wide basemap coverage for use by all members of the GIS consortium. Since the consortium spans several political boundaries and local government departments, a single-source basemap was required for effective sharing of GIS data and layers between members of the consortium.

3) Cost effective basemap generation so that updates can be acquired on a regular basis.
4) Development of derivative products from the image basemap to further increase the cost-effectiveness by providing key GIS data layers useful in other applications.

Objectives

To address these user identified needs and requirements, specific objectives of our work for Synergy II were:

1) To produce a 1-m panchromatic image basemap from Ikonos imagery acquired during Synergy I which covered about 40% of Boone County, MO. The Ikonos basemap was to be integrated with a 1996 DOQQ basemap to provide a county-wide 1-m basemap.

2) To acquire new Ikonos imagery to cover all of Boone County and produce up-to-date panchromatic (PAN) and multi-spectral (MS) image basemaps for the entire county.

3) To use the existing PAN and MS Ikonos imagery to develop 1-m resolution urban land cover maps for the City of Columbia, MO.

4) To develop specialized image processing tools to extract road and building footprints from the PAN/MS Ikonos image basemaps. The specialized tools would use a variety of spatial/contextual information (texture, directional correlation, neighborhood analysis) in conjunction with fuzzy logic and pattern recognition techniques.

These objectives leveraged initial results produced under the Synergy I effort.

Product Development

Ikonos Image Basemaps

During the Synergy I effort, we developed and demonstrated a methodology to generate highly accurate orthoimage basemaps using the lowest-cost commercial Ikonos high-resolution satellite imagery. The methodology used a limited amount of ground control (8-10 GCPs), 30-m resolution USGS DEMs, and Commercial Off The Shelf (COTS) software to orthorectify the lowest cost, lowest precision Ikonos high-resolution satellite imagery. We performed a rigorous assessment of the horizontal accuracy of an image basemap derived for a selected test site in southern Boone County. The results showed that we could produce Ikonos digital image basemaps with horizontal accuracies of 2-5 m CE90. Thus, the methodology we developed can be used to deliver up-to-date, cost effective orthoimages from the lowest cost Ikonos image products that yield horizontal accuracies suitable for use as digital image basemaps by local governments. The image resolution, horizontal accuracy, cost-effectiveness, and ability to acquire up-to-date imagery satisfied all key requirements identified by our user group.

In our Synergy II effort, we applied this methodology to generate a 1-m panchromatic digital image basemap from April 2000 Ikonos imagery acquired during Synergy I which covered 40% of Boone County. Figure 1 shows a sample of the image basemap covering the MU campus in the City of Columbia. We conducted a rapid static GPS survey to collect 210 independent check points to validate the accuracy of the image basemap. The results in Figure 2 show that the horizontal accuracy was about 4.0 m CE90, and this satisfies the accuracy requirement specified by our users.

Figure 1. One meter resolution Ikonos image basemap of MU campus. The horizontal accuracy is about 4 m CE90.

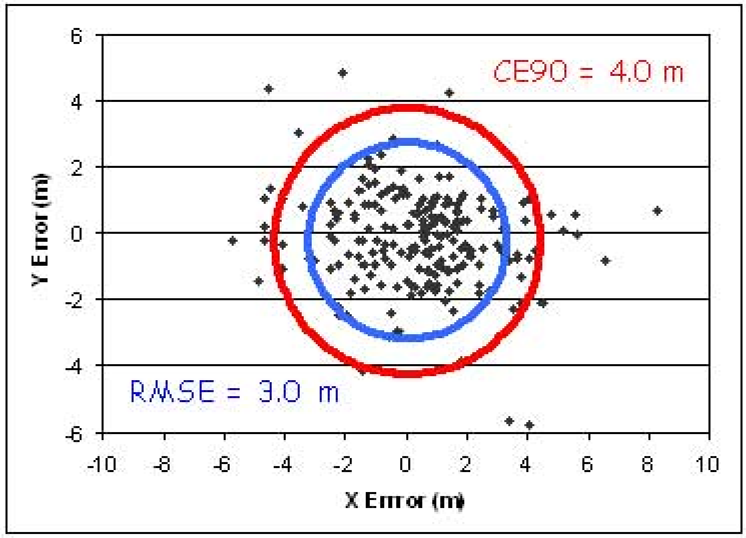

Figure 2. Horizontal accuracy of Ikonos image basemaps from 210 independent check points derived from rapid-static GPS survey.

The Ikonos PAN image basemap was integrated with a DOQQ basemap (circa 1996) produced by the Geographic Resources Center (GRC) in order to provide complete coverage of Boone County. The Ikonos/DOQQ basemap was delivered to the GIS consortium and is being heavily utilized by all members of the consortium. This satisfied Objective #1. A summary of the users experience with the Ikonos/DOQQ basemap is provided in a subsequent section. In addition to the 1-m Ikonos PAN basemap, we also orthorectified the 4-m MS Ikonos image scene also acquired in April 2000 during Synergy I. We then fused the 1-m PAN and 4-m MS basemaps to produce a 1-m pan-sharpened multispectral (PS-MS) image basemap that preserved the full 11-bit information content of the imagery. The 4-m MS and 1-m PS image basemaps were distributed to our UMC Synergy partners for use in their work. In addition, the 1-m PS basemap is used for our research on image processing tools for feature extraction.

Airborne Image Basemaps

In order to meet Objective #2, we requested complete Ikonos PAN and MS image coverage for all of Boone County for our Synergy II data request. We learned in May 2001 that this request could not be met in a timely fashion. We therefore contracted for an airborne digital imaging survey to provide complete coverage of Boone County, MO at 1-m resolution with fully multi-spectral capability (R, G, B, NIR). The airborne MS imagery has only 8-bit information content, so it has less contrast/clarity than Ikonos, but this is compensated to some extent by the enhanced 1-m resolution for the MS data compared to 4-m for Ikonos.

An initial airborne survey was done in July 2001 and the survey was completed in October 2001. As a result, we have approximately 2100 MS image scenes with 2 x 2 km footprint at 1-m resolution. The image scenes are precision georeferenced to about ± 4 m RMSE horizontal accuracy using a highly accurate GPS/IMU position/attitude solution for the aircraft imaging geometry. We have completed georeferenced (Geo) mosaics of each flight line of data and made these available to our UMC Synergy partners. In addition, we have completed a GeoMosaic for the City of Columbia metropolitan area and also distributed this to our UMC Synergy partners. We are in the process of producing an OrthoMosaic basemap of the airborne MS data for the City of Columbia metropolitan area as well. Figure 3 shows a sample OrthoMosaic of 10 MS image scenes in the City of Columbia. We expect to deliver a completed 1-m MS OrthoMosaic to the City of Columbia in the beginning of CY2002 (end of Synergy II). We hope to be able to produce a complete OrthoMosaic for all of Boone County using the airborne dataset as part of our Synergy III activities to fulfill our commitment (Objective #2) to the GIS consortium.

Figure 3. OrthoMosaic of 1-m resolution airborne multi-spectral image data (10 scenes) in Country Club area of the City of Columbia, MO. The horizontal accuracy of the mosaic is 2 m CE90.

Urban Land Cover Maps

During the Synergy I effort, a general land cover map was produced from the 4-m MS Ikonos images acquired in April 2000 for the City of Columbia. This was based upon the georeferenced Ikonos images and was therefore positionally inaccurate, thereby limiting its utility and adoption in GIS applications. In addition, the 4-m resolution and general land cover classes were also disadvantages. We developed a 1-m urban land cover map from the 1-m PS MS basemap discussed in the preceding sections. A custom data fusion algorithm was used to produce the 1-m PS-MS basemap so as to preserve the 11-bit information content and facilitate the classification procedure. The urban land cover classes were: road, building, grass, tree, bare soil, water, and shadow. The distinctive "road" and "building" classes rather than the more general classes of "urban built up" or "impervious" is an important improvement over the Synergy I land cover maps. Road network and building footprint vector layers are important data layers in local government GIS applications. The ability to distinguish these urban features facilitates utility and transportation planning, as well as vector migration of other GIS data layers that are routinely referenced to the road and building vector layers.

A supervised maximum likelihood classification of the 1-m PS-MS Ikonos basemap was used to produce the 1-m urban land cover map shown in Figure 4. The ability to distinguish between the roads and buildings is very good, though not perfect. Approximately 36,000 pixels derived from polygons containing homogeneous pixel classes were used for training the classifier. The classification accuracy was checked using over 500,000 validation pixels selected independently of the training set data. The overall classification accuracy was 82% with a Kappa coefficient of 0.77. If the road and building classes are combined into a single impervious surface class, the classification accuracy improves to 87%. Impervious surface area is important for stormwater runoff calculation, stormwater tax assessment, and water quality studies. The nearly 90% accuracy indicates that this urban land cover map would be very useful for applications requiring impervious surface area. The additional advantages are the higher resolution and improved positional accuracy relative to the products developed during Synergy I.

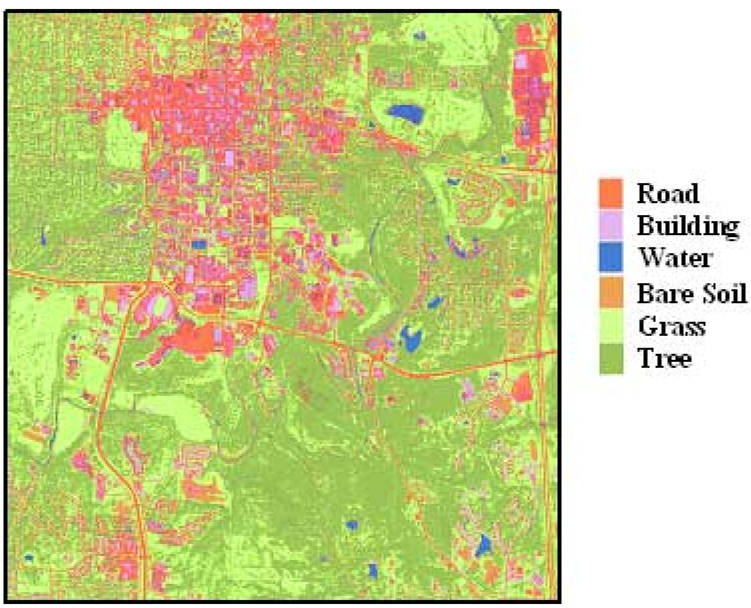

Figure 4. Subsection of urban land cover map of the metropolitan area of Columbia, MO derived from Ikonos PS-MS imagery acquired in April, 2000. The resolution of the map is 1 m and the classification accuracy is about 82%.

Image Processing Tools for Feature Extraction

The largest source of misclassification error in the urban land cover map described in the previous section was due to confusion between the road and building pixels. The confusion between road/building and building/road ranged between 15-30%. This is intuitively expected since the spectral signature of many roads and commercial/residential rooftops are very similar. The second greatest source of misclassification error was confusion between tree and grass, where the confusion was around 15%. To improve the overall classification accuracy we have begun to develop customized image processing tools to extract road and building footprints from the PS-MS 1-m Ikonos imagery. We are presently investigating the use of spatial/contextual information (texture, directional correlation, neighborhood analysis) in conjunction with fuzzy logic and/or pattern recognition techniques. The specialized tools seek to extract the road and building footprint information directly from the imagery or utilize the spatial contextual information in a fuzzy logic classifier to improve upon the standard maximum likelihood classification approach.

A comparison between the standard maximum likelihood classification and a fuzzy contextual classification for an urban test site is shown in Figure 5. Contextual spatial information (shape, surroundings, directional correlation, etc.) is used in the fuzzy classification to greatly improve the discrimination between the road and building classes relative to the standard maximum likelihood classifier. A variety of methods and approaches are under development to further improve the road and building extraction capability. We plan to conduct further work on this during Synergy III to produce custom image processing tools that would constitute licensable intellectual property. This effort would be an important part of the overall effort towards sustainability of ICREST and the BoCoMO infomart.

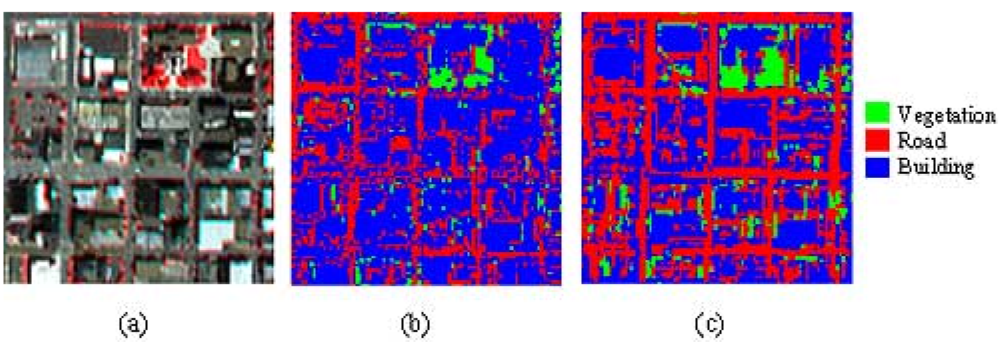

Figure 5. (a) Color IR (NIR, R, G) Ikonos image of commercial urban area. (b) Maximum likelihood supervised classification. (c) Fuzzy contextual classification. Note the greatly improved road connectivity and building classification in the fuzzy contextual classification.

Experience of User Community

The Ikonos/DOQQ basemap was delivered to the Boone County GIS consortium in mid-2001. In a QFD analysis completed during Synergy I for the basemap application, the top three technical requirements were: 1) co-registration with existing vector layers, 2) spatial resolution, and 3) positional accuracy. The Ikonos/DOQQ basemap with 1-m resolution and 4.0 m CE90 resolution (see Figures 1 and 2) met the user requirements specified by the GIS consortium. In addition, it provided one seamless basemap for use by both City and County departments and planning personnel. The basemap was used by the Department of Geography in the vector migration of the city/county parcel boundaries to the image basemap, thereby satisfying the first technical requirement.

In a briefing to the City and County, the head of the City/County GIS consortium stated that the city and county departments "… that can benefit from this (basemap) are ALL departments involved in GIS." ICREST submitted a user survey to assess the impact of all ICREST remote-sensing information products delivered to city and county departments and personnel. Under the category of "General/Financial Management", which was the highest ranked application area, the basemap ranked the highest amongst all other applications/uses. The Ikonos/DOQQ basemap has been distributed by the GIS consortium to all city and county departments involved with GIS and is therefore being widely used. The impact is just beginning to be assessed, but the initial feedback has been overwhelmingly positive. The Ikonos/DOQQ basemap delivered a highly accurate seamless basemap that could only have been produced via conventional means at a cost on the order of $60k. The retail cost of the 1-m Ikonos georeferenced PAN imagery is about $17,000 (800 km2 x $21/km2). We estimate that the processing and labor costs for orthorectification of the Ikonos imagery and the integration with the DOQQ images for the areas outside of the Ikonos coverage is about $15,000. Thus, the approach demonstrated for this project represents a cost savings of around $30,000. Equally important, the demonstrated use of the basemap for migration of parcel vector layers could not have been accomplished by the GIS consortium. The ability to upgrade the positional accuracy of historical vector data layers using the image basemap provides functionality and utility with a value that is difficult to measure. Nevertheless, the impact on planning and management activities will be widespread given the broad dissemination and operational use of the basemap within the city and county GIS communities.

Lessons Learned

As GPS survey techniques are now widely used throughout the local government community, city and county mangers have come to realize the low positional accuracy of many of their historical vector data layers. In addition, a common basemap used by all departments involved in planning and management is often not available. This is further complicated by political boundaries (e.g. city/county). The City of Columbia, Boone County, and the Boone Electric Cooperative formed the GIS consortium to pool resources and address these issues. The GIS consortium was formed well in advance of the Synergy effort. A seamless high-resolution digital image basemap with a high degree of positional accuracy was the primary objective of the GIS consortium. Such a basemap is the foundational element in many local government GIS applications. We have demonstrated that commercial high-resolution satellite imagery can be used to provide a cost-effective and positionally accurate image basemap. This has gone from basic R&D during Synergy I to operational use by all city/county departments involved in GIS applications during Synergy II.

Activities for Synergy III

The one major disadvantage of the Ikonos/DOQQ basemap was that 60% of the map was based on 1966 DOQQ data. One major goal for the Synergy II effort was to deliver an up-to-date county-wide basemap. This could not be done using the preferred Ikonos approach due to unavailability of the data. We have produced a county-wide GeoMosaic using 1-m MS airborne image data. However, the production of the county-wide orthoimage basemap could not be accomplished within the Synergy II timeframe because of the large number (>2000) of individual airborne image scenes. One major goal for the Synergy III effort would be to complete this task to honor our commitment to the GIS consortium and completely satisfy this major objective.

An important component of the ICREST plan for sustainability is to develop products, tools, and services capable of generating alternate sources of revenue beyond NASA/Synergy support. Certainly the Ikonos basemap is an important product that should have wide appeal to many other local governments. Beyond this, we believe the specialized image processing tools that we have under development for improved mapping/extraction of urban features can lead to licensable intellectual property in addition to service-based use for revenue generation. We plan to develop several of these tools during Synergy III to fully-functioning stand alone image processing programs. We believe there is great licensing potential for these specialized image processing tools. Equally important, the use of the tools in conjunction with the 1-m PS-MS Ikonos basemaps can improve the cost-effectiveness of the commercial imagery by providing a variety of high-quality "value-added" products (urban land cover, road network, building footprint, etc.) for GIS applications.

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