City of Irving Utilizes High Resolution Multispectral Imagery for N.P.D.E.S. Compliance

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For many cities like Irving, Texas, the 1990s have brought radical changes to the ordinary processes of day to day government, often resulting in the abandonment of conventional thoughts and procedures and replacing them with a variety of technological solutions. Geographic Information Systems (GIS) are one of the technological tools which have begun to alter the business practices of government.

The City of Irving is a municipality covering approximately seventy square miles located between Dallas and Fort Worth, in North Texas. Irving's GIS project consisted of bringing the city's current data (maps, aerial photography, etc.) online in order to provide a multiple use capability. The project began in 1990 with the acquisition of aerial photography at a scale of 1 inch:100 feet (National Map Accuracy Standard). Digital planimetric and topographic maps were subsequently created from the photography using coordinate geometry. As an accuracy assessment, approximately 150 first and second order monumentation points were surveyed and entered into the GIS to confirm the accuracy of the orthophotos and resulting planimetric maps.

The planimetric and topographic maps were delivered to the city in hard copy and digital (.DXF) format. The following year GIS hardware and software was installed and initial system training was completed. Using the digital planimetric and topographic maps, the data was easily translated into the new GIS which consists of GDS software running on a DEC VAX computer system.

tIt was in 1992 that the GIS database began to take shape; the city had transformed its existing hardcopy map files into a digital format. Data conversions included subdivision plats, zoning cases, utility asbuilts, construction plans, and many others. A pilot project area of approximately sixteen square miles was selected to serve as the testing ground for this conversion process. The pilot area proved to be a valuable learning tool and was subsequently used for all applications involved in the GIS testing.

With this newly gained knowledge in hand, data conversion began for the remaining portions of the city. As of the end of 1993, approximately 75 percent of the land area and parcels were entered into the GIS. The comprehensive city digital map is expected to be online by late spring 1994. At that time the following graphic data will be available city-wide: subdivisions, lots, blocks, zoning, land use, building footprints, multi-family site plans, water, sewer, storm, utility appurtenances, trees, sidewalks, water bodies, tax parcels, fencelines, airport detail, and census tracts and blocks. For the first time in the history of the city, the ability to easily overlay multiple data elements simultaneously will be available.

Several applications utilizing the new GIS have been developed and are currently online in the user departments. Some of these applications include zoning change notification letters, fire incident tracking, address matching, census data mapping, land use, traffic flow analysis, multi-family inspection tracking, and many others. One of the most unique of these applications involves the procedure to create an assessment process for use in conjunction with the guidelines established by the U.S. Environmental Protection Agency (E.P.A.) for the National Pollutant Discharge Elimination System (N.P.D.E.S.). Historically, municipalities have been concerned only with the conveyance of drainage from rainfall and its flood damage potential. However, because of growing environmental concerns, cities are now being required to address not only the quantity of storm water run-off, but also the water quality aspect of the run-off.

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On November 16, 1990, the E.P.A. published new regulations requiring municipalities and industries to obtain N.P.D.E.S. storm water permits. This legislation is a result of the fact that run-off water flows into storm drains after picking up pollutants from a wide variety of sources such as oil and grease from roads and parking lots, pesticides and fertilizers from lawns, sediment from construction sites, toxic metals and other contaminants from industrial sites, landfills, junkyards, spills, and improper waste disposal. Unlike sanitary sewer waste water, which is cleaned before it is returned to the environment, storm water flows directly back into lakes, rivers, and streams without undergoing any treatment to remove pollutants.

Because no federal or state funds have been made available for this mandated program, each local government must generate funds to cover the cost of the increased water processing demand placed on the existing treatment facilities. To assist in this fund generation, the State of Texas passed legislation allowing municipalities to create Drainage Utilities. This is a utility fee which is not assessed based on property valuation, as has been done historically, but instead is associated with both the land use and the actual amount of run-off contributed by each parcel.

It was quickly realized by the city that GIS would play a key role in developing the new assessment procedures. The needs were clear; however, the path to achieve the results was not. The required capabilities included the ability to view a current image of the city's ground cover and its structures, to view parcel lines/property boundaries, to determine the sources of storm water run-off, and to determine land cover type. All of these data elements had to be brought together for a detailed analysis at a parcel-by-parcel level and then linked to the city's existing utility billing system.

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After this preliminary evaluation of the project requirements, it was decided that the most efficient way to determine the amount of run-off generated per parcel would be through the utilization of aerial photography coupled with the existing vector parcel base map of the GIS. One of the initial plans proposed for implementation involved the scanning of existing 1990 photography into the GIS and then overlaying the vector parcel map. However, because the photography was three years old and the amount of change over this time had been significant, it was determined that new photography was required. Further review of the project goals concluded that the most cost effective methodology for determining the volume of stormwater run-off contributed by each property parcel was to compute the amount of water porous, or pervious (vegetative cover) versus water impervious (concrete, rooftops, etc.) surface area for each parcel. This computation could be accomplished with a vegetation analysis of each parcel coupled with the vector parcel maps (created via COGO at 1inch = 100feet accuracies).

Numerous manual analysis methodologies were discussed, but in order to maintain a timely implementation schedule, analysis through digital raster data was the chosen solution. Many digital image options were reviewed, including digital orthophotography, satellite imagery, and low altitude multi-spectral imaging.

Conventional black and white aerial photography would have provided the high resolution needed and was available at a moderate cost, but it proved to be somewhat limiting for spectral studies. Satellite generated imagery could have provided multispectral data for the project at a fairly low cost, but the low spatial resolution, inability to penetrate clouds, and the scale of the imagery were unsuitable for the micro-mapping needs of the city. The final digital technology reviewed, the Airborne Data Acquisition and Registration (ADAR) System 5000 designed and operated by Positive Systems, Inc., couples the multispectral capabilities of satellite technology with the scale and resolution advantages of low level aerial photography. Additional features of the ADAR System 5000 include: a full frame format which eliminates the line by line misregistration which can create problems with data from airborne scanning systems; data can be processed utilizing photogrammetric techniques, thus providing a true orthorectified product; no film processing is required because the image data is collected digitally, thus eliminating the use of environmentally damaging chemicals; the flexible scheduling allows imagery to be captured without cloud interference; the data is dynamic in that many spectral analyses can be performed on a single data set, resulting in a multidisciplinary tool; and rapid data update for incident time tracking.

A pilot project was scheduled for early March 1993 to ensure leaves would be absent from trees and shrubs (to avoid obstruction of the view of the surface below). This pilot project was limited to the same sixteen square mile testing ground used in previous test projects. The ADAR System 5000 was configured to record four spectral bands to provide both true color and "color infrared" composites: the four bands included blue (450 nm center wavelength/ 80 nm band-width, green (550 nm/80 nm), red (650 nm/80 nm), and near infrared (850 nm/80 nm). The images were captured at one meter per pixel resolution, and Global Positioning System (GPS) information was recorded simultaneously to determine the horizontal location of each image.

After acquiring the imagery of the test site, the 280 resulting multispectral digital images were compiled into a seamless, orthorectified image mosaic by TRIFID Corporation. This process consisted mainly of four tasks: data preparation, image mensuration, triangulation, and orthorectification.

The data preparation began with acquiring ground control for the ADAR System 5000 imagery. In addition to utilizing the GPS information captured with each image, supplemental ground control was also required in order to generate a pixel-level geopositioned orthorectified mosaic. It was determined that the use of the aerial photography acquired in 1990 was the most cost effective method to transfer ground control to the ADAR System 5000 imagery. The aerial photographs (1:15,800 scale) were scanned and used in a digital form. A digital terrain model (DTM) was also needed to support the orthorectification process. The city's 1990 aerial photography also provided the required DTM. The irregular pattern of the existing DTM was resampled to a regular grid for orthorectification.

The next step in data preparation was to perform coregistration of the separate spectral bands from the ADAR System 5000. This was completed using an autocorrelation method, based on a hierarchical pyramid combined with a symmetric matching algorithm to determine corresponding image points in the different bands. This was followed by a least-squares adjustment to determine transformation parameters between the bands.

The tie point and control point mensuration for this project was performed using manual methods in a softcopy environment. Recently, TRIFID has developed software employing automatic tie point correlation methods, thus allowing this process to be completed automatically on future projects.

The next step was triangulation. A simultaneous triangulation of the ADAR System 5000 imagery and the scanned control photographs was performed to provide optimal geometry as well as procedural simplicity. A self calibration adjustment of the ADAR System 5000 was possible because of the availability of GPS data for the image exposure stations and the ground control photographs. To accommodate this variety of measurements and parameters, a unified least-squares adjustment approach was used.

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The last step was the preparation of the multispectral, orthorectified mosaic. This began with preparation of a preliminary orthorectified mosaic of the red spectral band (650 nm) sampled at the full scale size of one meter per pixel. This was followed by manually placing feather lines between the individual images in the mosaic. The feathering process uses a pyramid feathering method based on spatial frequency to provide a seamless mosaic. The feather lines are in the same location for each of the bands. The orthorectification process was repeated for each band using the feathering method and the result was four bands of multispectral orthorectified seamless mosaicked imagery. A subset composed of approximately 20 ADAR System 5000 scenes from the resulting mosaic is shown in Figure 1 (displayed in color infrared: red/green/blue display showing near infrared, red, and green spectral bands, respectively), including a vector overlay of property parcel data.

Following completion of the image mosaic, the process of image classification was undertaken by American Geographic Data. As noted previously, the method to be employed for determination of pervious versus impervious surface areas was a vegetation analysis of each parcel. Those areas covered with vegetation would be considered water porous, or pervious, and thus expected not to contribute substantially to stormwater runoff. Those areas devoid of vegetation were to be classified as impervious. While this approach was subject to minor ambiguities, it appeared to be the most cost effective method available within the cost and finan cial constraints faced by the city.

Image classification was completed in two main steps. Easily identified surfaces, such as golf courses and lawns (pervious) and rooftops, streets, and parking lots (impervious) were classified first. This was done to eliminate as much unambiguous area in the image data as possible using the simplest effective multispectral classification rules. The second step, classification of the remaining areas, will be described in further detail below.

Since the goal was to identify areas within the image mosaic covered with vegetation, a classic vegetation index was applied for the first-stage classification. The index used was the Normalized Difference Vegetation Index (NDVI), which compares data in the near infrared and the red spectral bands. At each pixel within the image data, the following calculation was applied:

$$\mathrm{NDVI} = \frac{(\text{near infrared}) - (\text{red})}{(\text{near infrared}) + (\text{red})}$$

The NDVI pixel values, with an allowable range of -1.0 to $+1.0$, were then scaled to (0,255) to allow the resulting data set to be viewed and processed as an 8-bit grey-scale image. Figure 2 shows a subset image of the project area (red spectral band), with the same area after NDVI processing shown in Figure 3. Vegetation-covered areas appear bright in the NDVI image, with streets and other bare areas appearing dark.

Comparison of full color imagery with the NDVI image allowed two thresholds

Figure 1. A Subset Composed of Approximately 20 ADAR System 5000 Scenes (In Color Infrared: RGB Display Showing Near IR, Red, and Green Spectral Bands, Respectively) Including a Vector Overlay of Property Parcel Data.

to be selected in the NDVI image, identifying the brightest areas as pervious and the darkest areas as impervious. Those pixels thus judged to be pervious and impervious were classified accordingly. The remaining surface area, displayed as dark- to light-grey in the NDVI image, was left in an "ambiguous" category; a more rigorous classifica-ion algorithm (as described below) was applied to these areas. The dual-threshold NDVI method allowed a rapid classification to be applied to approximately 80 percent of the original image mosaic. The surface area which remained was classified separately. A mask was applied to eliminate all surface area already classified, leaving an image mosaic populated only by pixels deemed "ambiguous" by the NDVI method. Whereas NDVI examines only two spectral bands, the second-stage classification utilized all four bands in the image data.

Well-established classification techniques were applied to the ambiguous surface areas. A statistical clustering method was applied to identify the primary spectral signatures present within the remaining image data. Statistical clustering collects signatures based on homogeneity within contiguous pixels, thus utilizing spatial as well as spectral information in the data set. An additional feature of the statistical clustering technique is that both scaled and unscaled spectral distance is used. As a result, classes may be spectrally similar, but remain distinct if there are many pixels within each cluster.

Once prospective spectral signatures had been developed, the next step was to manually review the various classes and reclassify each as either pervious or impervious. Reclassification decisions were based on review of true color composite imagery as well as ground truth information.

One aspect of using image data at one meter resolution was the delineation of the shaded side of buildings, trees, etc. In the final regrouping of spectral classes, it was a relatively straightforward task to determine the appropriate final class for the shaded components of the image mosaic.

At this stage of the classification process, a final reconciliation of special cases is necessary. Specifically, bodies of water (such as a swimming pool) appear


Figure 2. A Subset Image of the Project Area (Red Spectral Band).

dark and thus impervious in the NDVI image. However, since stormwater is retained by some water bodies, those must be reviewed on a case by case basis to ensure accurate classification.

Another special case to be addressed is the presence of small "islands" of one class within large areas of the opposite class; examples could include a concrete pad in the middle of a grass field or a landscape planter in a large parking lot. In each of these cases, the small island was properly classified as being different from its surroundings, but based on the city's appli- cation these islands should be eliminated since they do not alter the effect of the larger area on the stormwater runoff volume.

For the sake of expediency, the classified image data was used to generate preliminary reports at the stage prior to final reconciliation of the special cases. Special cases will be reviewed prior to generation of the final reports, but adjustments to the preliminary results are not expected to exceed a few percentage points.

The final phase of the project consisted of the calculation of the amount of pervious versus impervious surface within each tax parcel. In order to determine the percentage of each class within individual tax parcels, the city's existing tax parcel vector data was utilized. This vector information was overlaid with the classified raster data file. This enabled creation of reports based on the number and type of classified pixels within defined polygons. In this case, the property parcels served as the defined polygonal areas.

The report consisted of a listing of each tax number and the associated pervious/impervious surface area (in either acres or square feet) which corresponded to the parcel represented by the tax number. This data was then linked to the city's existing water utility billing system, which calculated the amount payable by each property owner, and included said amount in the monthly billing statement.

Reviews of the preliminary reports generated above provided excellent results. Surface area reports for individual parcels, generated from overlay of the raster-format planimetric maps with the classified image data, showed correlation of better than 1 percent with the city's area calculations.

Based on the success of the pilot project, the city has decided to utilize this technology in the mapping of the entire city of Irving (seventy square miles). Some of the procedures that were completed manually during testing have been automated for

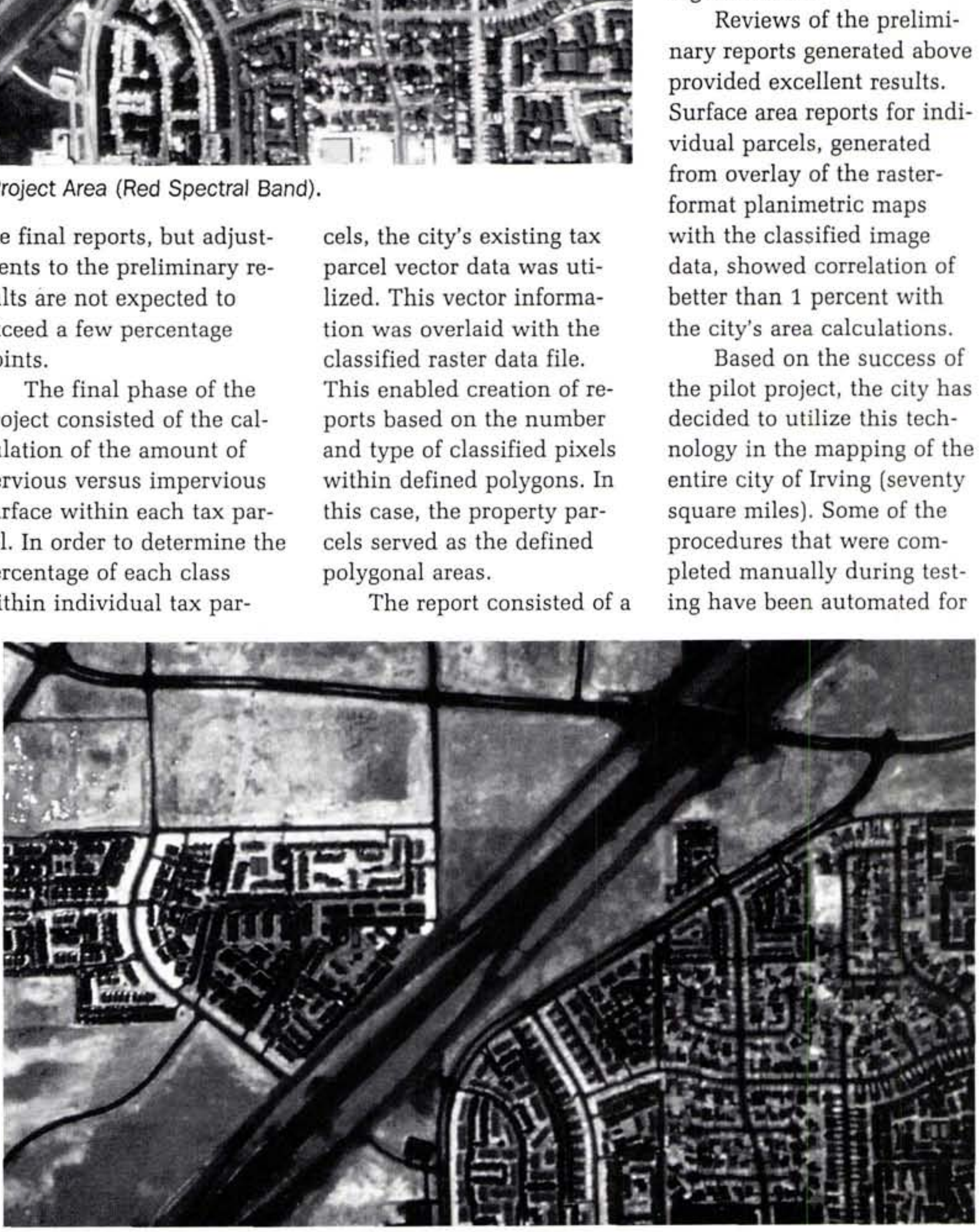
Figure 3. The Same Area as Figure 2 After NDVI Processing.

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the larger project, thus accelerating the process.

Without the utilization of this automated low-level multispectral imaging technology, a minimum of three years would have been required to complete the calculation of pervious/impervious surface areas within the city, given current staffing conditions. In contrast, approximately eight months of effort are projected to collect the data, orthorectify the imagery, and conduct image analysis for the entire seventy square miles of the city. Not only will timeliness be a critical issue for this project in order to meet N.P.D.E.S. compliance guidelines, but the accuracy of the data acquired is also extremely important. According to Jill Urban, GIS Analyst for the City of Irving, "Through the utilization of the selected imaging process, not only was the time factor reduced significantly, but the achieved accuracies exceeded the expectations of all involved, and provided the city with a current view of itself from which to produce the assessments."

Although the initial image acquisition costs are approximately one-third higher than those associated with conventional orthophotography, the additional advantages of spectral analysis, timeliness in receiving the results, multiple project uses, and simplified and cost effective updates for special projects or growth areas on an annual or semi-annual basis ultimately serve to reduce the project cost. While the utility application was the primary justification for the acquisition of this imaging, numerous opportunities are available for usage of the data by other departments for specific projects. Examples include flood plain evaluation, comprehensive planning, parks management, and hazardous material monitoring. This imagery is being utilized and manipulated to meet the requirements of a variety of projects. The dynamic nature of the data has opened the door for innumerable studies and special projects which would have been either cost prohibitive or technically unachievable for the city prior to the collection of this multispectral data.

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