Integrated GPS/INS/ISAT Processing – A Case Study Through Practical Requirements

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ABSTRACT

A team headed by Surdex Corporation of Chesterfield, Missouri, USA was awarded a large digital orthophotograhy contract by the United States Department of Agriculture in the spring of 2003 that challenged the standard tools, processes, and management of a mapping company. The project required approximately 220,000 square miles of color or color-infrared photography to be acquired in less than 10 weeks and over 15,000 digital orthophotos produced within 30 days of the close of the photography windows. Coordinating 6 teammates totalling 8 aircraft, and distributed image scanning, aerotriangulation, digital orthophoto production, quality control, and product delivery in a very short timeframe presented challenges requiring unique solutions. This paper discusses the project and how the challenges were overcome to meet the project objectives, with an emphasis on the utilization of the Z/I Imaging ImageStation Automatic Triangulation (ISAT) product.

1. INTRODUCTION

A team headed by Surdex Corporation of Chesterfield, Missouri, USA, was awarded a large digital orthophotography program by the United States Department of Agriculture (USDA), Farm Service Agency, Aerial Photography Field Office in Salt Lake City, Utah. The USDA has become one of the largest United States federal agencies responsible for the production of standard Digital Orthophoto Quarter-Quadrangle (DOQQ) products in the United States. The National Agriculture Imagery Program (NAIP) administered by the USDA is unique in that all photography must be acquired during summer peak crop growing seasons. Thus, “leaf-on” color or color infrared photography must be captured in windows of roughly 60-80 days ranging from early summer to early fall and specific to each state. All photography is acquired at a scale of 1:40,000 to support the generation of 1 or 2 meter DOQQs. The entire 2003 NAIP involves approximately 800,000 square miles of coverage and over 64,000 digital orthophotos produced by 9 contracting teams.

The NAIP is devised to provide timely digital orthophotos to Farm Service Agency (FSA) field offices around the country in support of the administration of the Farm Compliance Programs. Initial compressed imagery products must be delivered for each county within 30 days of the end of the photography windows. Field offices must check compliance for each agricultural tract by the end of the fiscal year by using a USDA GIS farm tract vector oriented database in conjunction with the digital orthophotos. Within 90 days of the photography window closure, uncompressed digital orthophotos are delivered.

Each DOQQ is 3.75 arc-minutes square in longitude and latitude, resulting in irregular sizes as a function of latitude, and averaging 5.6 X 7.0 km in size. The absolute accuracy of the 2 meter DOQQs is only 20 meters, whereas the 1 meter DOQQ product must be accurate to within 3 meters relative to existing, “reference”, DOQQs. All photography is pre-planned for exposures at each quarter-quadrangle center and edge along north-south flight lines, resulting in acceptable stereoscopic coverage. Although DOQQs are constructed only from the quarter-quadrangle-centered exposures (mosaicking is not required), aerotriangulation requires all exposures to be used.

The Surdex approach to this program was based primarily on the use of airborne GPS (ABGPS) to meet accuracy requirements, with visually identifiable points extracted from USDA-supplied reference DOQQs used only as check points in the aerotriangulation process. Surdex Corporation was awarded the Midwestern states of Missouri, Oklahoma, and Kansas. The following table summarizes the three state project areas.

Project Area	Product	Square Miles	Linear Miles	Exposures	DOQQs	Counties
Missouri	1-meter (CIR)	69,486	21,950	10,172	5,043	115
Oklahoma	1-meter (color)	69,919	21,252	9,849	4,945	77
Kansas	2-meter (color)	82,264	24,817	11,501	5,693	105
Totals		**221,669**	**68,019**	**31,522**	**15,681**	**297**

Surdex's team consisted of a number of subcontractors, some performing single functions and others providing multiple functions. A total of eight aircraft were utilized throughout the program, many times flying simultaneously in different areas within the same state. The team included:

- Keystone Aerial Surveys of Philadelphia, Pennsylvania acquired photography and performed image scanning.
- M.J. Harden and Associates of Kansas City, Missouri acquired aerial photography, performed aerotriangulation, and DOQQ production.
- Tuck Engineering of Big Stone Gap, Virginia provided aerial photography acquisition and secondary image scanning support.
- Science Applications International Corporation (SAIC) of Melbourne, Florida provided quality control functions on the 1 meter DOQQ products. SAIC also provided secondary image scanning support.
- Aerial Surveys International of Watkins, Colorado acquired aerial photography.
- JFK, Inc. of Indiatlantic, Florida provided aerotriangulation services.

2. THE PROGRAM CHALLENGES

The NAIP posed several serious challenges to the team:

- The acquisition of aerial photography during difficult Midwestern United States summer flying conditions.
- Scanning imagery after film processing, inspection, and titling.
- Processing large volumes of data through aerotriangulation and product processing in very short timeframes.

The acquisition of photography within the allowable time windows was the most critical factor in the program. In Surdex project areas, Midwestern United States summers are notorious for relatively high heat (85-100 degrees Fahrenheit) coupled with extreme humidity. Flight planning required around-the-clock monitoring of weather and tight coordination of flight crews. Very "aggressive" flying was required to take advantage of the average 1-5 hour flight windows and GPS ground stations had to be maintained over large areas to support the multiple flight crews. Managing multiple teammates involved in the aerial photography presented a large a challenge as well as coordination with the Federal Aviation Administration, since the aircraft must operated at altitudes in the Positive Controlled Airspace (PCA). The Midwestern areas are also dotted with a number of Military Operations Areas (MOAs), which required advance arrangements for airspace clearance.

Scanning all photography became the second limiting factor in the project. High speed image scanners were driven to operate on an average 20 hour day, with operators monitoring progress in a nearly around-the-clock fashion. The aggressive flying produced countless rolls of film with discordant strips of photography, especially later in the program as hard-to-get areas emerged as the final challenge for the flight crews. It was necessary to assess the status of image scanning multiple times each day to establish priorities to allow the processing of data into final county deliveries.
Aerotriangulation had to be accomplished in very short periods of time, with a focus on the selection of adequately sized areas based on product delivery areas. Though the accuracy of the end products was not, in itself a challenge, the fact that new DOQQs must agree with prior versions meant that absolute and comparative accuracies needed to be monitored and achieved.
Orthorectification required the use of the United States Geological Survey (USGS) National Elevation Dataset (NED) surface model. This data was purchased by Surdex for the entire United States. For the NAIP, subsets were extracted and re-projected for each project area and distributed to teammates requiring its use.

3. OVERALL APPROACH

During the investigation of the NAIP and its challenges in the fall and winter of 2002-2003, it became clear to Surdex that a number of steps would have to be taken to both win a large share of the program and to execute:

- Extremely high automation must be utilized given the volume of work to be accomplished in a very short timeframe.
- Each functional area (photography, image scanning, etc.) had to be approached using conservative capacity estimates to ensure success.
- Each teammate must be equipped with the common software operating at the highest levels of performance.

Various vendor offerings in a number of functional areas were reviewed for possible assistance, but it quickly became obvious that a relatively high level of customization was required. The NAIP and its specific requirements required even more customized software to solve logistics issues and lessen the scripting efforts generally required of the production staff. Some investigation was also spent in focusing on software that literally “looked for something to do” in an attempt to not rely upon human initiation of tasks that completed at any hour of the day. A number of custom database systems and applications were developed to support project logistics and reporting requirements of the USDA. These focused on providing information from a variety of viewpoints and were developed to operate within the context of an existing, Surdex-developed internet/intranet project management solution. The Collaborative Project Management System (CPMS) has been used within Surdex for over three years and provides comprehensive status and reporting for Surdex, the client, and teammates via a web interface.
The use of common software amongst the team members was mandatory to achieve consistent results within program specifications and allow progress monitoring and planning. This included:

- The Z/I Imaging ImageStation Automatic Triangulation (ISAT) software was quickly selected as the softcopy aerotriangulation environment, based on its extensive successful use within Surdex.
- Digital image dodging, reduced resolution data set (RRDS) generation, automated digital orthophoto accuracy assessment, and orthorectification software were standardized based on software developed by Surdex over the past few years. These tools were conveyed to all teammates for use in conjunction with NAIP 2003.
- The ISO-certified quality control software developed by SAIC for the USGS DOQQ programs became the standard means of final-checking all 1 meter DOQQ products.

The coordination of flight crews, daily reporting of photography status, prioritizing and tracking image scanning progress, and overall progress reporting became the immediate focus of the Surdex research and development staff after the program award. A series of databases, data entry forms, and reporting applications were developed using SQL Server and made available to the production staff in an intranet environment. The most important data contained within the database included:

- Acquired photography and ABGPS data, using both USDA exposure nomenclature and aliases required for mission planning and mission support systems.
- Tracking reflights for specific frames.
- Tracking of film rolls and mapping of individual frames to rolls.
- Image scanning progress including mapping image names to rolls and frames.
- Aerotriangulation information, including tracking exposures and county coverages.
- Digital orthophoto production progress.
- Delivery and quality control progress.

The tracking of progress and prioritization of the aerial photography portion proved to be the one of the most critical components of the project. Since photography crews took an aggressive approach and worked around weather patterns on a daily basis, a number of logistical problems were created. The collection of large, but often isolated, blocks of photography were common early in the project, leaving holes in the coverage. In addition, occasional excessive cloud cover or cloud shadows resulted in a number rejections leaving more holes. Thus, the final 5-10% of the aerial photography collection resulted in an inefficiency as the isolated holes and reflights were addressed.

Each field crew was responsible for submitting electronic or hardcopy (facsimile) reports at the end of each day of activity. Surdex project management staff used this information to update the internal databases via an intranet form. Electronic versions of progress were transmitted to the USDA each day, as per contractual requirements, and field crews updated as to the current situation. All aircrews were also responsible for performing initial checks on ABGPS data after each mission, although final data reduction was performed by Surdex prior to aerotriangulation.

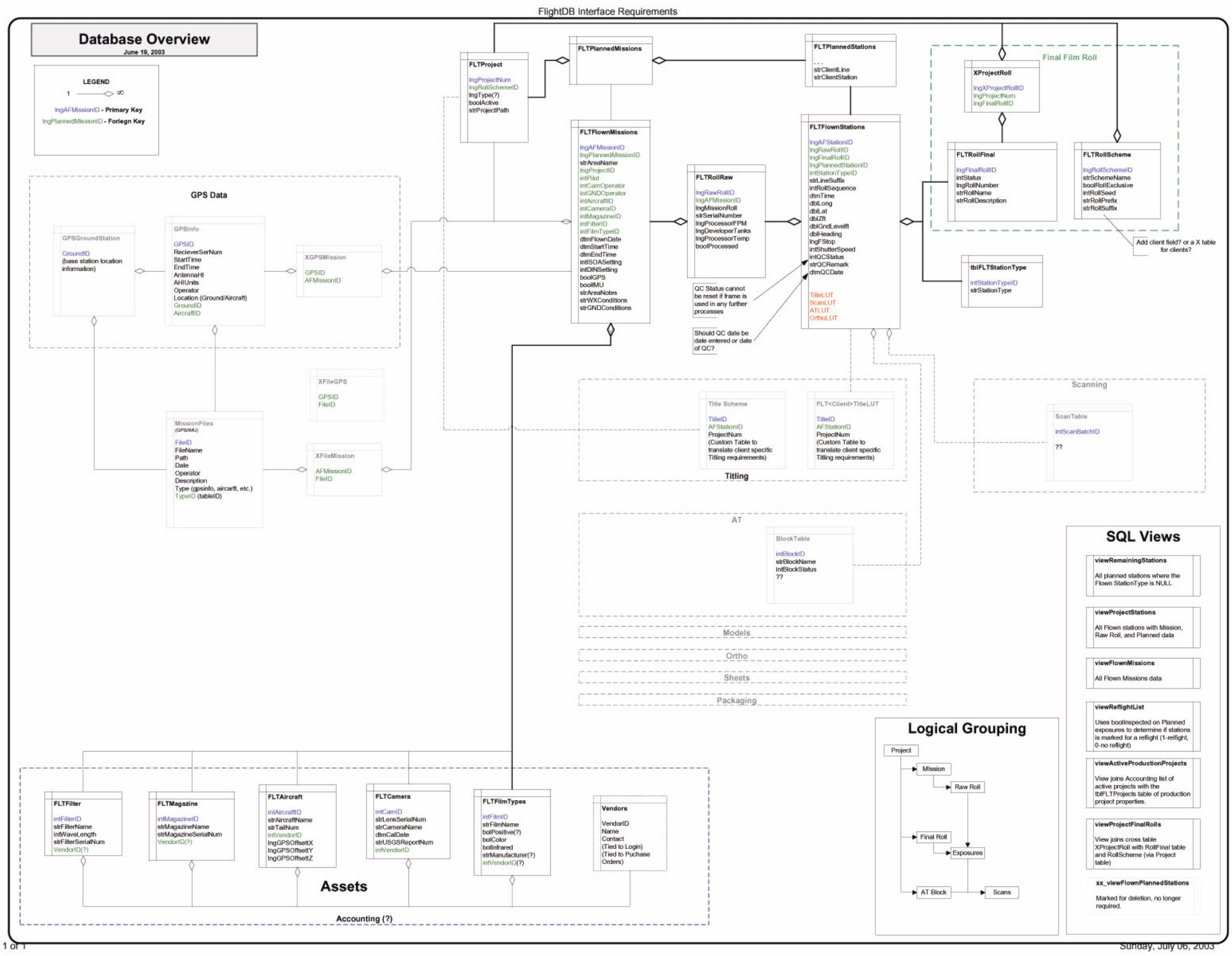
The scanning of photography early in the project was focused simply on scanning each roll as it completed inspection and titling. However, the filling of holes and reflights beginning midway through the project resulted in rolls with coverage ranging over large areas. Priorities were then set on a daily basis to ensure that most of data could be obtained from the backlog of film rolls. Aerotriangulation and scanning technicians constantly reviewed pending work and priorities to ensure production could continue efficiently.

A “NAIP Database” was created for distribution to all teammates involved in processing and was based on information distributed by the USDA. A Relational Data Base Management System (RDBMS) interface provided the following for various application programs:

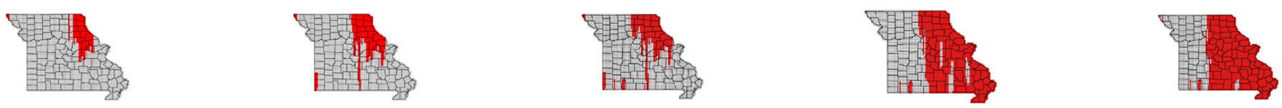
- Lists of all counties involved in each state and the Universal Transverse Mercator (UTM) zone required as a reference frame (the three states involved four (4) UTM zones).
- Lists of DOQQs required for each county delivery.
- Federal Information Processing System (FIPS) state and county codes required in deliverable metadata files.
- Extracted and re-projected elevation model surfaces for each UTM zone area derived from the NED.

Note that the lists of DOQQs for each county were not solely based on a geographic analysis, but rather upon additional analysis by the USDA and FSA field offices. The figures on the following page illustrate the sophistication of the NAIP database system (presented only in general detail) and an example of reporting information that can be gleaned from it.

Sophistication of Supporting Databases for the NAIP



Example Database Reporting: Time-Sequenced Status of Missouri Photography



06-15-03 06-16-03 06-19-03 06-22-03 07-01-03

4. THE AEROTRIANGULATION PROCESS

Based on past similar experience with NAIP and from an ideal standpoint – photography and product delivery schedules aside – each state would normally be broken down into 700-1,000 frame blocks for aerotriangulation. This would have amounted to approximately 30-45 blocks with an average of 5-10 full counties in each block. However, a practical view envisioned up to 20% more blocks.

The use of AGBPS under normal circumstances would ensure that accuracies on the order of 1-2 feet (0.3-0.6 meter) would be easily achievable, with most of the error coming from the NED elevation model surface. However, since 1 meter DOQQs (Missouri and Oklahoma only) required agreement with reference DOQQs, Surdex was driven to develop a number of ways to guarantee and assess product accuracy and to isolate suspect areas stemming from the use of the NED surface.

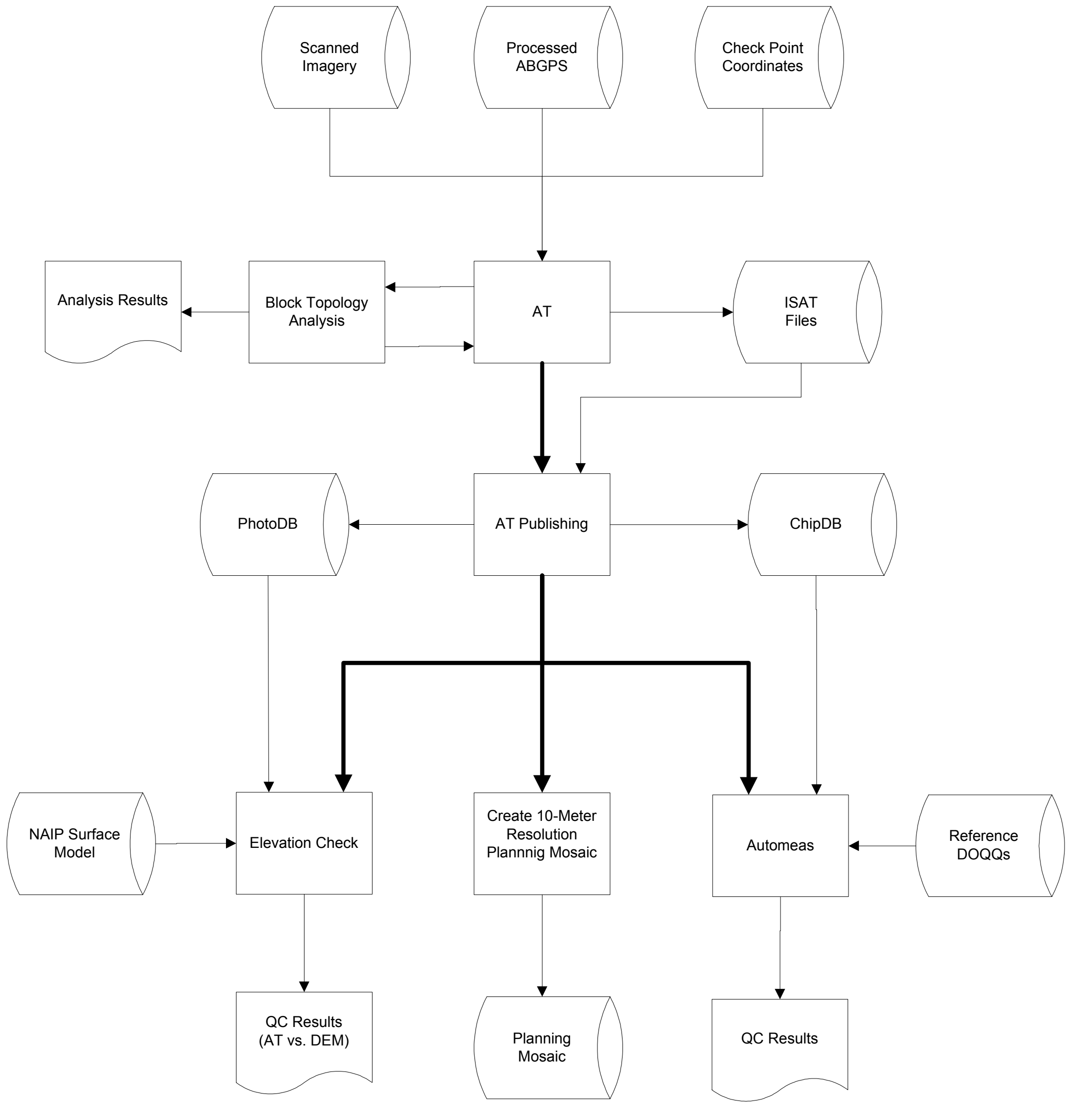
This included the collection of visually identifiable "check points" from the reference DOQQs, with elevations derived from the NED, for use in aerotriangulation. It also included additional analysis developed and/or integrated by Surdex's research and development staff. The following figure illustrates the overall aerotriangulation process, showing some aspects unique to Surdex capabilities and the NAIP:

- Aerotriangulation includes the importing of ABGPS data, automatic tie/pass point collection, measurement of check points, and cleanup of bad points, including adding visually identifiable quality control ("QC") points.
- "AT publishing" refers to the final step in aerotriangulation and reflects the exporting of results for access by the production system. This includes generation of the "PhotoDB" and "ChipDB" Microsoft Access files containing all aerotriangulation results and pictures ("image chips") for all points.
- A "block topology analysis" based on Surdex-developed software analyzes the suitability of the pass and tie points in the block. Given the large amount of aerotriangulation performed in a short time period, this was provided to allow photogrammetric technicians to determine whether additional points needed to be added. The analysis examines pass points in models within a strip and tie points between models in adjacent strips against standard requirements adopted for the program. This is based on ISAT data access software provided by Z/I Imaging.
- An elevation check is performed by comparing the final aerotriangulation point elevations to values interpolated from the NED. Since the NED is possibly the greatest source of accuracy errors, this provides a glimpse into possible problems ahead.
- A 10 meter resolution "planning mosaic" is created to both provide a visual backdrop for project management and to review the quality of photography, image scanning, and digital image dodging.
- The Surdex-developed "AutoMeas" programs uses data from the ChipDB to provide an analysis of the agreement of the aerotriangulation results to the reference DOQQs.
- Assessing the difference between aerotriangulation point elevations and corresponding elevations of the points from the NED.
- Automatically comparing the aerotriangulation points to the reference DOQQs to assess accuracy agreement.
- Automatically comparing the aerotriangulation points to the produced DOQQs to assess accuracy agreement principally based on the NED surface quality.

The reference DOQQs averaged 5-7 years in age and were primarily based on USGS DOQQs from the national database. Extracting at least five points for each county resulted in each aerotriangulation block containing an average of 20-50 check points. To support aerotriangulation technicians during check point measurement, "image chips" were extracted for each point portraying the surrounding area and marking each point with a colored cross. These were made available in both digital geocoded image format and in printed handbooks.

Over the last year, Surdex research and development staff developed software over capable of automatically assessing the accuracy of digital orthophotos using aerotriangulation data and based on the matching of rectified point chips against any geocoded imagery. The image affording the "most nadir view" of each aerotriangulation point is selected and used to rectify small (nominally 63x63) "point chips" centered at each point. Using area-based matching augmented by least squares refinement the point chips were matched against each reference DOQQ. This operation is not only highly automated, but typically executes in less than one half hour for an average-sized block.

The NAIP Aerotriangulation Process



Though the reference DOQQs were old and only available in panchromatic (black-and-white) format, both color and color-infrared point chips yielded a very fast assessment of agreement and aided in the isolation of areas to be more exhaustively checked during production. Approximately 20-30% of the aerotriangulation points were generally found on the reference DOQQs. This same software is used to assess the agreement of the produced DOQQs to the aerotrianguation results.

A reduced resolution planning mosaic, at a nominal resolution of 10 meters, was also automatically generated by rectifying each image in an aerotriangulation block and "collaging" the results into a single geocoded image file. At this point, production staff was able to judge the overall quality of the source imagery, the quality of image scanning, and the effectiveness of digital dodging. The planning mosaic could actually be generated after ABGPS data was associated with each image – either prior to, during, or after aerotriangulation.

5. RESULTS

The unique software and databases developed by Surdex for the 2003 NAIP successfully met production requirements. Some of the reports generated for the USDA are even now under consideration for an overall program requirement in the coming years. The experiences surfaced additional desirable improvements needed for coming NAIP efforts and even standard production efforts.

The performance of ISAT throughout the production process was outstanding, though the image and product resolutions were lower than that normally encountered by Surdex. Although final results drawn from the project are not yet available, the following general observations have been made:

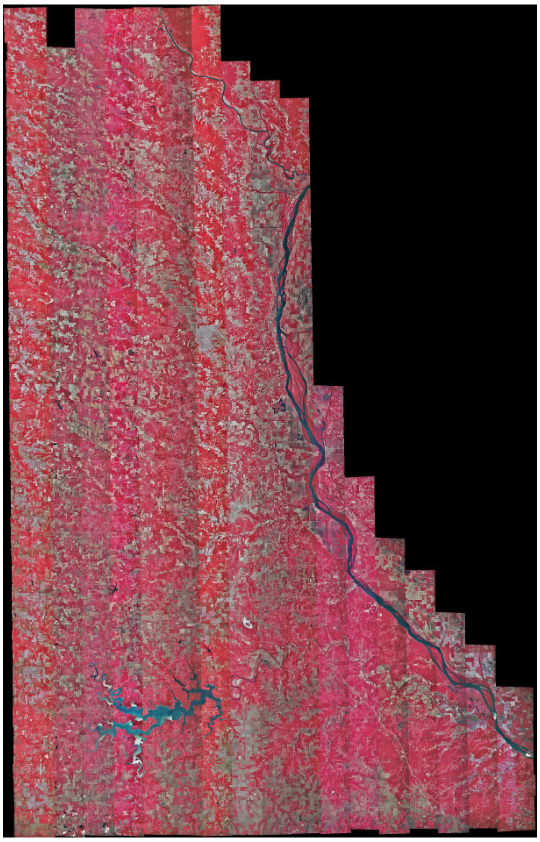
- Both color and color infrared imagery took an average of 45-60 seconds per frame to extract pass and tie points. An average 750 frame block thus took about 9-12 hours on a standard 1-3 GHz workstation processor.
- The results from the ISAT automatic point collection generally were very good and typically only required 1-3 hours of cleanup time.
- The accuracies of the check points were found to be around 1-2 meters horizontal root mean square error (RMSE) in each axis. Vertical RMSEs ranged from 1-5 meters, though a number of check points were demoted to only horizontal checks when apparently erroneous elevations from the NED surface were encountered.
- The sigma naught results were typically 0.5 pixel or less, though the program requirements allowed acceptance of up to 0.75 pixel. Standard procedures adopted for the program required all residuals in excess of 1.0 pixel to be resolved.

Most of Surdex's previous experience with ISAT involved larger photographic scales and the results for 1 and 2 meter products was surprisingly good. With a large number of joint federal and state initiatives focusing on DOQQ production, this bodes well for further business.

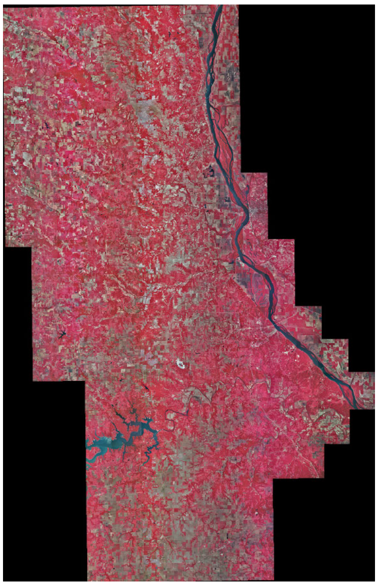
The graphics on the following page show selected interim and final products from initial processing in the state of Missouri. All photography for this state was based on color infrared positive film. The examples are from the northeast portion of the state and were acquired in late June under reasonably good weather conditions.

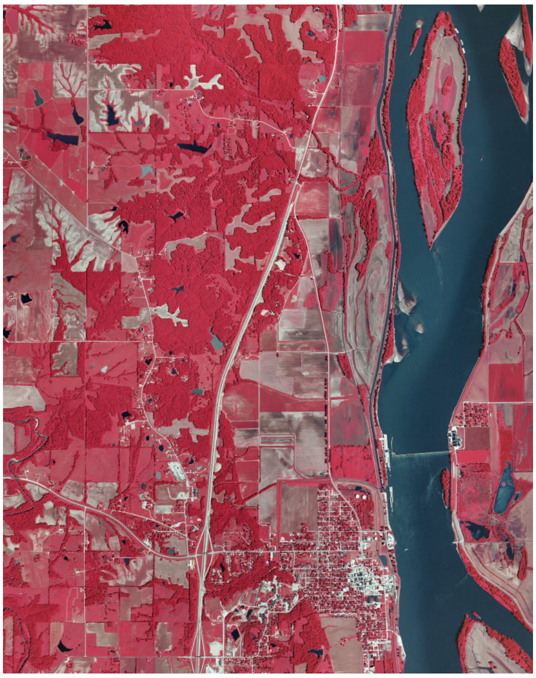
- An overview of a 10-meter resolution planning mosaic consisting of approximately 400 exposures rectified to an average ground elevation for each frame.
- A overview of the collage of the final 159 DOQQs (1 meter resolution) for the three full counties covered by the block.
- An overview of a single DOQQ from the northeast portion of the block.
- Selected detail from the DOQQ.

Note that the resulting planning mosaic illustrates some radiometric banding. This was due to photography acquired on separate days and by different aircraft/camera systems. The collage of the county DOQQs illustrates good results from radiometric balancing.



A Planning Mosaic (left) and An Embedded Three County DOQQ Area (below)





A DOQQ (left) and DOQQ Detail (below)