Integrated Photogrammetric Systems at Science Applications International Corporation

Clifford W. Greve, Ph.D.
Scott E. Webster

KEY WORDS: Photogrammetry, Orthoimage, Integration, GIS

Abstract:

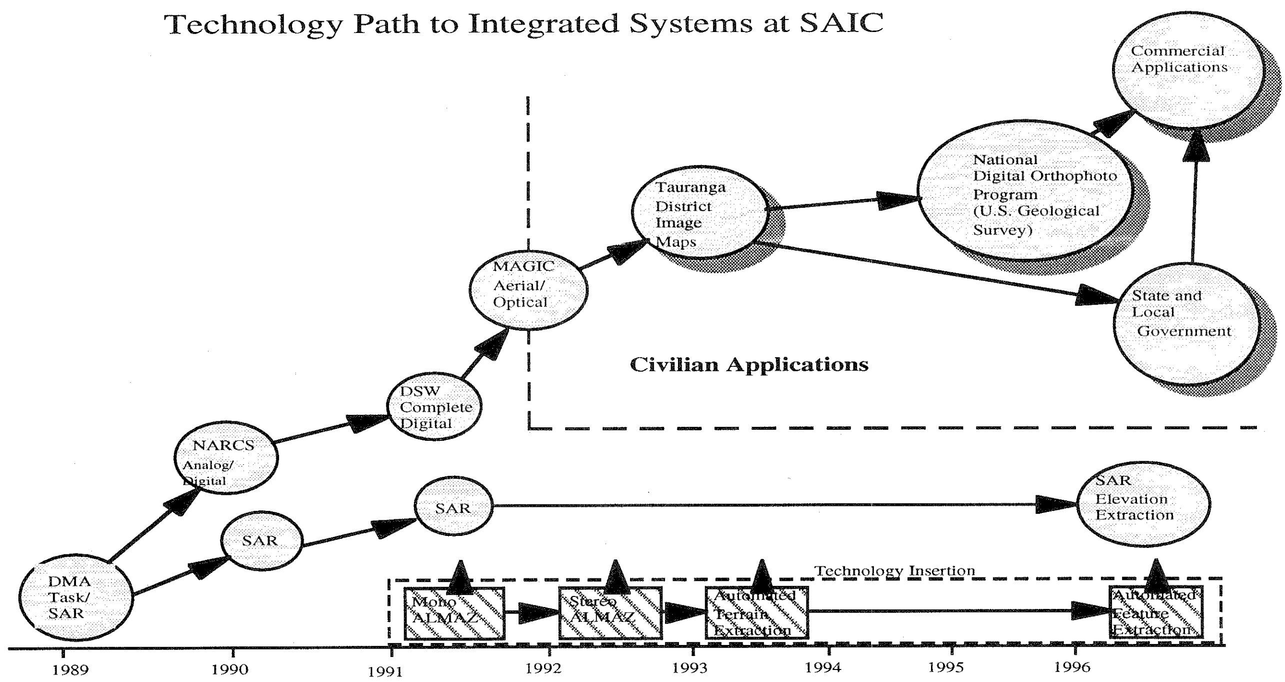
Science Applications International Corporation (SAIC) develops photogrammetric systems for a broad range of applications, varying from national intelligence applications, through military mapping, to commercial remote sensing and orthophoto production. The breadth of these activities provides opportunities for synergy between the various applications. Technology developed for the defense applications can be readily applied to commercial mapping and remote sensing applications, while production process experience gained from the commercial operations can be applied to better designed systems for the government agencies.

1. INTRODUCTION

The term "Integrated Photogrammetric Systems" implies many things to many people. At Science Applications International Corporation (SAIC), we consider the ingredients of an integrated photogrammetric system to be:

- A common, simultaneous aerotriangulation procedure involving data from all sensor types
- Capability of viewing data from any combination of sensors in "stereo", whether the human mind can fuse the data into a meaningful stereo image or not
- Capability of incorporating analysis in the spectral domain with analysis in the spatial domain
- Capability of generating orthophotography from any of the sensors which may be processed
- Capability to generate data directly into a geographic information system, or at least into a system which creates a data format which can then be imported to a geographic information system.

SAIC has developed several systems which have various aspects of the above, mostly as a result of government development contracts. We have used the technology developed on these government contracts as a basis for additional development under internal funding to integrate the capabilities into the systems which we use today.



The figure above traces the development of the current applications to their roots in systems developed for the government and other customers. The areas labeled "technology insertion" were developed on SAIC internal development funding, in support of planned government efforts and with the intent of generating a commercial production capability.

SAIC, at the present time, does not sell these integrated photogrammetric systems, but uses them internally to generate data for various commercial and government applications. We are one of the U.S. Geological Survey's National Digital Orthophoto Program contractors, and under that program have produced or have in production over 5000 digital orthophoto quarter quadrangles using the GIS MAGIC™ system which is described below. That same system has been used to produce high resolution orthophotos at a ground resolution of 0.125 meter for Tauranga, New Zealand.

For various customers, we have developed processing capabilities which we are adding to our integrated solutions as the need arises. Of course, applications developed for a specific customer must be tailored to operate properly within the environment used by that customer. Within these limitations imposed by the customers for compatibility with their systems, we make a concerted effort to ensure that the technology which we develop for them is compatible with our internal integrated system, so that we can incorporate those capabilities into our internal systems at minimum expense. We benefit internally from this approach, because our integrated internal systems are continually growing in capability, but the government customers who pay for the development also benefit because of the potential for re-using algorithms developed for other government customers to minimize new development costs.

2. The GIS MAGIC™ System

The roots of the GIS MAGIC™ system are in a system which SAIC developed for the U.S. Defense Mapping Agency, called the Digital SAR Workstation (DSW). DSW was originally designed for mensuration, triangulation, orthorectification, and mosaicking of Synthetic Aperture Radar (SAR) imagery. However, the generality of the approach used in that project allowed the same orthorectification software, and the solution framework of the aerial triangulation software, to be used for optical imagery as well. The current system will process SAR, aerial photographs, and SPOT data, with the capability of easily adding dynamic camera models from various reconnaissance sensors. The various photographs are essentially objects, in the object oriented programming sense. Each photograph comes with a key to an imagery type, which dictates the software to be used to produce the projective equations and the partial derivatives. These elements are simply entered into the appropriate slot in the solution template. This is the key to an integrated photogrammetric workstation; the basic software architecture is entirely modular, and new sensors fit into the existing framework with only new projective equations and their partial derivatives needing to be computed.

The key to the generality of the GIS MAGIC™ system is in the fact that rational functions are used to model the sensors in all operations beyond the aerial triangulation. The use of rational functions allows a common mathematical formulation for all imaging sensors, and thus allows the applications software to operate without regard to the actual sensor involved. In fact, combinations of sensors may be readily accommodated. The rational function has the form:

$$x = R_1 (X,Y,Z)$$
$$y = R_2 (X,Y,Z)$$

where:

- x,y are image coordinates (these could just as well be line and sample pixel coordinate)
- X,Y,Z are ground coordinates of the point in some desired reference system
- R_1 and R_2 are rational functions of the form:

  $R_1 = P/Q$, $R_2 = S/Q$

  where P, and S are polynomials of the form:

  $a+bX +cY +dZ +eX^2 +fY^2 +gZ^2 +hXY +iYZ +jXZ +kX^3 +lY^3 +mZ^3 +nXY^2 +oX^2Y +pXZ^2 +qX^2Y +rYZ^2 +sY^2Z$

  and Q is of the same form, with "a" set to a constant 1 to preclude an ambiguous scale.

The evolution from a system for processing SAR data to one which processes standard aerial mapping images is not a simple transition. It comes from the adherence to the tenets expressed in the introduction to this paper, namely modular construction, with an eye to the eventual goal. Not only does SAIC benefit from this approach; the government also benefits because of the ease of maintainability and modification of the software.

The system is hosted on a Sun SPARC -S-Bus workstation conforming to IEEE 802.3. The Sun hardware is enhanced with a Tech Source Image Display board to permit high speed display of imagery. The Tektronix 1024x1024 display provides high resolution monochrome viewing. Stereo viewing is achieved with an active liquid crystal polarizing screen, which permits the use of passive polarizing eyewear. These passive glasses are less bulky, easier to use, do not require batteries, and are much less expensive than the active eyewear used in some other displays.

3. USE OF GISMAGIC™

The GIS MAGIC system is designed to derive image maps which are precisely geocoded to an absolute coordinate frame. Every pixel in the output image can be related exactly to a specific location in ground space. In order to accomplish this geocoding, the photogrammetric imaging event must be precisely modeled. GIS MAGIC™ contains the ability to rigorously model the taking geometry of the photogrammetric camera. Although GIS MAGIC™ has the capability of performing the aerial triangulation solution, it will also accept solutions performed by outside service firms, when it is determined that such an outside service is cost effective. During the planning process, the hardcopy photo prints are placed on a digitizing table, and the position of the chosen control and pass points is recorded relative to the fiducial coordinate system, so that patches of digital data in those locations may be obtained to permit the softcopy aerial triangulation procedure.

The digital data, when it becomes available, is used to select these small patches surrounding the control and pass points. The position of these points is measured precisely on the softcopy display, and the points are also transferred to all other images on which they appear, using the softcopy stereo approach. It is important that the stereo approach be used, since otherwise passpoints must coincide with identifiable objects in the imagery, which while desirable may not be practical in all terrain. In difficult areas, points may have to be selected based upon stereo fusion of the data, in much the same way that points are transferred in hard copy triangulation using a stereo point transfer device.

The measured point coordinates are stored in a data base which permits later editing should errors be found. The aerial triangulation software, using banded-bordered techniques to allow for self calibration of the sensors involved, performs the solution and presents the results to the operator in both tabular and graphic presentation.

The Digital Elevation Matrices (DEM's) are extracted by automatic correlation, which searches along the epipolar line for matches. This approach is considerably faster than simple area correlation, because it uses the underlying physical phenomena of the taking event to guide the correlation. The elevation matrix is collected at the specific posts specified by the user, as opposed to some systems in which collection is tied to pixel space which requires a resampling to generate the final grid. If desired, geomorphological data may be added to improve results in rugged terrain. The data is edited for blunders using a figure-of-merit parameter computed during data collection, and other parameters such as maximum terrain slope. Any missing points are interpolated from surrounding points prior to the editing process. For larger scale projects it is also possible to model the terrain using a Triangulated Irregular Network (TIN).

The editing process is performed by superimposing the data over a softcopy stereo model. Extensive editing tools are available to the operator to permit individual points to be modified, or entire areas to be modified. This latter case applies to fitting a plane surface to a parking lot, enforcing a uniform water level surface on a lake, etc.

After manual editing, all adjacent DEMs are adjusted together by a least squares procedure, which enforces edge join constraints between models, and control points derived during the triangulation process. The output may be formatted in USGS DEM format, or DMA's DTED format.

The rectification process projects points rigorously from the ground plane into the image plane, using the known position of the pixel in the ground plane and the DEM. These X,Y,Z values are introduced into the rational function, yielding the position within the photograph from which the gray shade should be derived for inserting into the output orthophoto array. For each output pixel, the corner coordinates are transformed to the input image, yielding a trapezoid in the input image. Resampling can be done by nearest neighbor, bilinear, or cubic convolution. Images are then enhanced to improve the radiometric quality. If film developing were consistent, and scanning processes perfect, the process would be routine. However, at this point in time, there is considerable empirical effort needed to produce orthophotos which are pleasing to the eye and also maintain optimum detail. GIS MAGIC™ contains histogram tools which permit this interactive enhancement to proceed efficiently.

The geocoded images are mosaicked together along a series of user-designated line segments. A cursor is maintained by the system at a corresponding ground point in each of the two images. Thus, it is very simple for the user to digitally join two images along any desired cut line. An automated capability is also available, which provides digital feathering to smooth the transition along the join line.

GIS MAGIC™ also has the capability to generate GIS data. USGS DLG data may be read into the system, and displayed over orthophotos for determination of the accuracy of the data. Modifications to those data may be made interactively, and the resulting data exported in DLG format, with full topological structuring. Other GIS formats may be supported.

4. Other Technologies which are being added to GIS MAGIC™

As we have mentioned, SAIC is constantly developing advanced technology for our government customers, and on internal development programs. Some of the capabilities which we have developed and will be eventually added to GIS MAGIC™ will now be discussed.

The first such tool is lines of communication extraction using multispectral imagery. This technique has proven very successful in extracting lines of communication, roads, railroads, and waterways, from Landsat and SPOT imagery. The incorporation of this capability into GIS MAGIC™ will permit feature extraction to be performed far more efficiently than at present, and will reduce operator fatigue considerably. Although the technique is certainly not perfect, the robust editing capability within GIS MAGIC™ will permit any erroneous extractions to be easily corrected.

Another approach which will be added to GIS MAGIC™ is the resolution sharpening capability being developed by our Tucson, Arizona office. This approach uses a hierarchical resolution pyramid coupled with compacted wavelet compression to permit sharpening of lower resolution imagery using higher resolution data in one or more related bands. This offers promise of sharpening multispectral data such as Landsat using higher resolution panchromatic imagery at resolutions equivalent to the National Aerial Photographic Program (NAPP) at a ground resolution of approximately 27 inches. The approach yields far superior quality data to that produced by the typical transformation from RGB to IHS, replacing the intensity with the higher resolution intensity, and retransforming.

This approach, coupled with the capability to orthorectify so as to create a much more precise image match than can be obtained by "rubber sheeting" polynomial fits used by most image processing systems, promises to permit a whole new order of high resolution features coupled with the context of multispectral information.

5. Conclusion

SAIC is active in developing integrated photogrammetric systems. The systems which we have developed are not yet complete, but they are continually evolving toward completeness. We are using technology developed for government customers, which is in the public domain, to build systems which produce data for the private community. These systems also benefit the government in that future related developments are more efficient because of the integrated, coordinated, approach to development. This approach has allowed SAIC, which until three years ago had never done commercial photogrammetric work, to become a key supplier of orthophotos to both the U.S. Government, and local governments around the world.