

## A NEW DIGITAL PHOTOGRAMMETRIC SYSTEM FOR GIS PROFESSIONALS

Younian WANG, Xinghe YANG, Mladen Stojic, Brad Skelton

Leica Geosystems, GIS & Mapping Division  
2801 Buford Highway, Atlanta, GA, USA  
younian.wang@gis.leica-geosystems.com

### Commission II, IC WG II/IV

**KEY WORDS:** Digital, Photogrammetry, Mapping, Software, Automation, Triangulation, Orthorectification, GIS.

#### ABSTRACT:

Most conventional digital photogrammetric systems (DPS) are designed for processing digitized images taken from aerial metric cameras and intended for users with strong photogrammetric background knowledge. On the other hand the geo-spatial information from remotely sensed images taken from various kinds of cameras are now more applicable and accessible for a variety of GIS professionals. These changes challenge photogrammetrists to find new ways to meet the new market developments. This paper analyzes the special demands of GIS professionals, and introduces a new softcopy photogrammetric system, OrthoBASE Pro™, which meets the requirements. Firstly, an innovative project management strategy has been developed for the new system. Its sensor modeling method covers a variety of sensors, ranging from satellite scanners to digital, video and non-metric cameras. The newly developed algorithm for automatic triangulation, which works not only with the regular block of aerial images, but also with images from pushbroom scanners, digital cameras, video cameras and other non-metric cameras, is introduced in the paper. The image matching strategy, the approaches for automatic triangulation, automatic gross error detection, automatic DEM extraction and automatic orthoimage generation are described. Several examples using different kinds of images are demonstrated. The test results show that the new system is highly automated in processes, very flexible and easy-to-use. It is not only a powerful and reliable system for advanced photogrammetrists, but also a powerful, yet simple tool for GIS professionals.

### 1. INTRODUCTION

In recent years, intensive research and development of softcopy photogrammetric systems have evolved photogrammetry from the analytical phase to the digital phase (e.g. Miller, etc., 1996, Lue, 1996, Zhang etc., 1996). The automation grade in digital systems has improved steadily, especially with the development of automatic aerial triangulation and automatic DEM (digital elevation model) extraction (e.g. Ackermann, 1995, Krzystek, etc, 1996, Schenk, 1997, Tang, 1996, Zhang, 1997). However, the majority of the current digital photogrammetric systems is designed mainly for processing digitized images taken from aerial metric cameras, and is intended for users with strong photogrammetric background knowledge. On the other hand the geo-spatial information from remotely sensed images is now more and more applicable and accessible for a variety of GIS professionals who normally do not have photogrammetric background. In addition to aerial metric cameras, pushbroom scanners, digital cameras, video cameras, etc., have also become important image acquisition tools. High-resolution digital imagery is also emerging as an important mapping source. These changes and developments challenge photogrammetrists to improve and expand their digital photogrammetric systems to meet the new market. They also challenge photogrammetrists to make their very specialized knowledge both understandable and applicable to the outside world.

Photogrammetry is still the most accurate tool for extracting 3D information from 2D images (Mikhail, 1998). With the availability of high-resolution images such as SPOT, IKONOS, DigitalGlobe, more and more GIS professionals want to get increasingly accurate results from their images. They normally don't have high-end photogrammetric education. In accordance to their needs, an innovative project management strategy has

been developed for the new system. It means a single and portable project file, hierarchical data management, intuitive and straightforward workflow and user friendly, easy-to-use graphic interfaces and image viewers. There are many more kinds of imagery available today than before, therefore the softcopy system should be able to process them. The developed new system can model a variety of sensors, ranging from satellite scanners to digital, video and non-metric cameras.

Automation is the most important factor for productivity and for the reduction of the demands for background knowledge. The approaches for automatic triangulation, automatic gross error detection, automatic DEM extraction and automatic orthoimage generation are introduced. The newly developed algorithm for automatic triangulation works not only with the regular block of aerial images, but also with images from pushbroom scanners, digital cameras, video cameras and other non-metric cameras. The automatic block connection procedure is very flexible, allowing for any of approximate exterior orientation parameters, orbit information, ground control points or image tie points to be used as the initial input. This feature is very critical in meeting the needs of different users with different applications. For DTM extraction, GIS users not only need high quality of matched points, but also flexible output, various user controls and easy to use user interface. The new DPS has not only included a new mass point matching algorithm, but also incorporated a lot of easy tools for user to fine tune the results and control the accuracy.

A new procedure for automatic image rectification is introduced in the paper. This procedure will orthorectify the images if a DEM exists, and it can also rectify the images for eliminating the misalignment caused by the exterior orientation. It can also carry out the image registration if only relative orientation is possible. Furthermore, it can rectify the whole

image block automatically, which significantly increases productivity.

Several examples are included to demonstrate the high automation, accuracy, flexibility and easy-to-use of the new system. The results show the new system is not only a powerful and reliable system for advanced photogrammetrists, but also a powerful, yet simple tool for GIS professionals to acquire spatial data from digital images for their GIS applications.

**2. SYSTEM DESIGN AND WORKFLOW**

Photogrammetric processing of digital images for geospatial data extraction involves many different steps of work. It includes image file input and management, camera data input, interior orientation, exterior orientation or ephemeris data input, GCP (ground control point) input or import, aerial triangulation, error checking and analysis, DTM extraction and editing, orthorectification and mosaicking, 3D feature collection etc. How to organize the softcopy system so that not only the photogrammetrists, but also the non-photogrammetric users can easily deploy the system for their different applications is very important for efficiency and productivity. The system workflow should be streamlined so that the users can simply follow the steps to get their job done, even though they don't know much about the photogrammetry. According to these requirements, the new system is designed in the linear processing which can be represented with the Figure 1. Each main step is represented with an action icon, therefore the user can finish the work by just following the icons successively, without a prerequisite for a fully educated photogrammetric processing order. The 3D feature collection module is not directed under the IMAGINE OrthoBASE Pro™ system, but as a separate product, because of production considerations. It takes IMAGINE OrthoBASE Pro triangulation results as its starting point. Functionally it still is part of the workflow as Figure 1 shows.

Automation is one of the most important ways to accelerate productivity and reduce the demands of special knowledge. In each step automatic or semiautomatic tools are integrated to ease the user's workload, such as automatic load of all image files, importer of camera and image parameters, semiautomatic interior orientation, automatic tie point collection and triangulation, automatic DTM extraction, automatic image rectification or registration for the whole block. Most automation tools are very sophisticated processes. The advanced photogrammetric users like to have the capability to guide and tune the process in order to achieve desired results in different situations, but novice users prefer the self-adjusted or self-adaptive and fully automated approach, since they normally don't have the special knowledge to optimally tune the processes. In order to meet both requirements, IMAGINE OrthoBASE Pro™ offers various interfaces for users to adjust different strategic parameters, their default values are provided as optimized for most common scenarios after thorough testing and analysis.

Many photogrammetric projects can involve several hundreds images which take time for preparation and processing. A single and portable project file in IMAGINE OrthoBASE Pro™ maintains almost every important piece of information associated with the project so that the user can resume their work from the stage where it is left off, without losing time and efforts. In addition, the project file is also served as the input for 3D feature collection, which is a standalone product so that many users can collect 3D features with the same project. User-friendly graphical user interfaces are very important for the efficiency and productivity a software system can offer. Robust and efficient image viewers are another important factor. In IMAGINE OrthoBASE Pro™ some innovative user interface and viewer design techniques are used so that a highly efficient, very easy-to-use softcopy system has been made available to the user. Since these features are not under the scope of this paper, details can be found in some relevant documents (ERDAS, 1999).

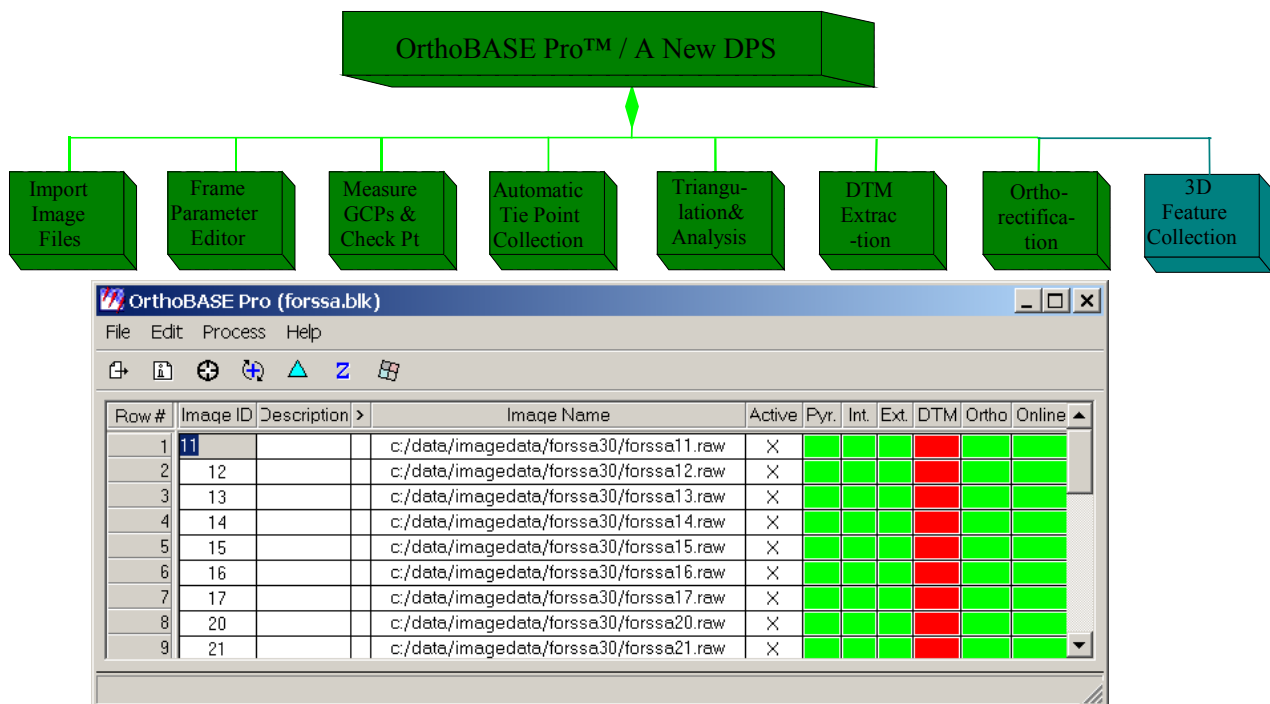


Figure 1. The linear workflow of OrthoBASE Pro™

### 3. AUTOMATIC TRIANGULATION

In recent years the research and development for automatic aerial triangulation has gained significant achievements (Heipke etc., 1998). Tie point measurement, DTM acquisition and 3D feature collection are the most time-consuming tasks in the photogrammetric image processing toward geospatial information extraction. Automation of these processes is very important for improving productivity. IMAGINE OrthoBASE Pro™ has included an advanced tool for automatic tie point measurement. Unlike other softcopy systems, the automatic tie point collection tool in OrthoBASE Pro™ works not only with images from aerial cameras, but also with images from digital cameras, non-metric cameras and satellite sensors. In order to make the tool work with all these different kinds of images, the algorithms should be adaptive for different overlaps, different rotations and different image sizes. This is achieved by using a very flexible block connection algorithm and a powerful search algorithm for image matching.

#### 3.1 Block Connection

The purpose of block connection is to determine the topology of the images in the block, mainly the neighboring images of each image, relations to it (left or right, above or below), the overlaps, the rotations etc. Some initial values are required for block connection. Either approximate exterior orientation parameters, or ephemeris information for satellite images, or two manually measured tie points for each pair, or two GCPs for each image can meet the need of block connection. Either the similarity transformation, or simplified space resection or the ephemeris transformation is used to determine the approximate center and rotation angle of each image. A 2D graph is generated based on this information. A search method is used to find the neighbors of each image. The algorithm works well even with cross-flight block. The user does not need to align the first image in each strip to its neighboring strip or to input this information from other sources such as flight plan.

#### 3.2 Feature Extraction and Image Matching

Image matching is a common technique used in photogrammetry and in other image processing related disciplines to find the correspondence between two overlapped images automatically. Most algorithms for image matching can be categorized as area-based matching, feature-based matching and structural matching (Wang, 1998). Considering the practical need for reliability, accuracy and speed, an integrated matching strategy is developed. Basically it is still a feature based matching, but area correlation coefficient, and geometrical and topological constraints are used to improve the results. Of course, the pyramid structure is also used for better speed and reliability. At the final stage, the least square matching is applied in order to assure the high accuracy. The main feature used is feature points. A modified Förstner Operator (Förstner, 1987) is used to extract the feature points with the improvement of accuracy, speed and memory usage. After least square matching, an algorithm is used to select the amount of points (user preset) based on the criteria of overlap, distribution and matching strength. The user may choose to keep all the points.

#### 3.3 Triangulation and Error Detection

After tie points are identified, the triangulation procedure is carried out. A flexible and powerful triangulation package has been developed. Triangulation based on frame camera geometry, pushbroom geometry and generic sensor geometry is

included. Self-calibration if the camera interior parameters are unknown, relative triangulation if there are no GCPs, or triangulation based on exterior orientation parameters and GPS/INS data are available. A gross error detection function based on robust estimation (Li, 1983) is integrated in the triangulation procedure. It uses an iterative variable weight function, which also counts the individual redundancy of each observation. The automatically identified tie points with gross errors will be excluded from the triangulation and reported back to the user for verification.

### 4. AUTOMATIC DTM EXTRACTION

Automatic generation of terrain models from overlapped images is currently the most important way to collect a DTM. This technique is already applicable for production. There are some outstanding issues which need to be improved when investigating existing packages and considering the customers' requirements (Baltsavias, 1998), mainly reliability, speed and productivity. In order to improve reliability and speed, an integrated image matching strategy is developed. It includes a feature-supported image correlation, geometric constraints, pyramid structure, on-fly resampling for rotation and distortion compensation, consistency checking etc. For improving speed and productivity, a block management function is developed, which generates DTMs for all the overlapped pairs in the block with the possibility of automatically mosaicking them to a single optimized output. For further flexibility, some easy-to-use graphical interface and tools are developed, with which user can manipulate their image pairs and different interest areas such as excluding regions and strategy parameters very easily and efficiently. It supports variety of input image formats and many output DTM types such as TIN, raster DEM, ESRI 3D shapefile and ASCII. Furthermore, one system works for all aerial images, digital camera images, video camera images and satellite images, which offers excellent economy for the customers.

### 5. RECTIFICATION AND REGISTRATION

After the block is triangulated and the DTM is available, the orthorectification procedure will generate orthoimages that are free from image distortions caused by image orientation and elevation differences. If there is no DTM data available, a rectified image can still be generated in which the image orientation distortion can be removed. If only a relative triangulation is available, the images still can be registered to a reference image, so that a mosaicked image can be created from them without the distortion caused by different image orientations.

The rectification algorithm is well known and standard in photogrammetry. The outstanding issues addressed with this new system are to improve speed and productivity. The implemented procedure here can work automatically on all images in the block. It can also work in a batch mode, so that nights and weekends can be utilized too. Besides creating a real orthoimage file, the rectified image can be also just a calibrated raw image, where no new image file is generated, only parameters for creating an orthoimage on the fly are saved. The calibrated images can be subsequently mosaicked without occupying additional disk space for resampled orthoimages.

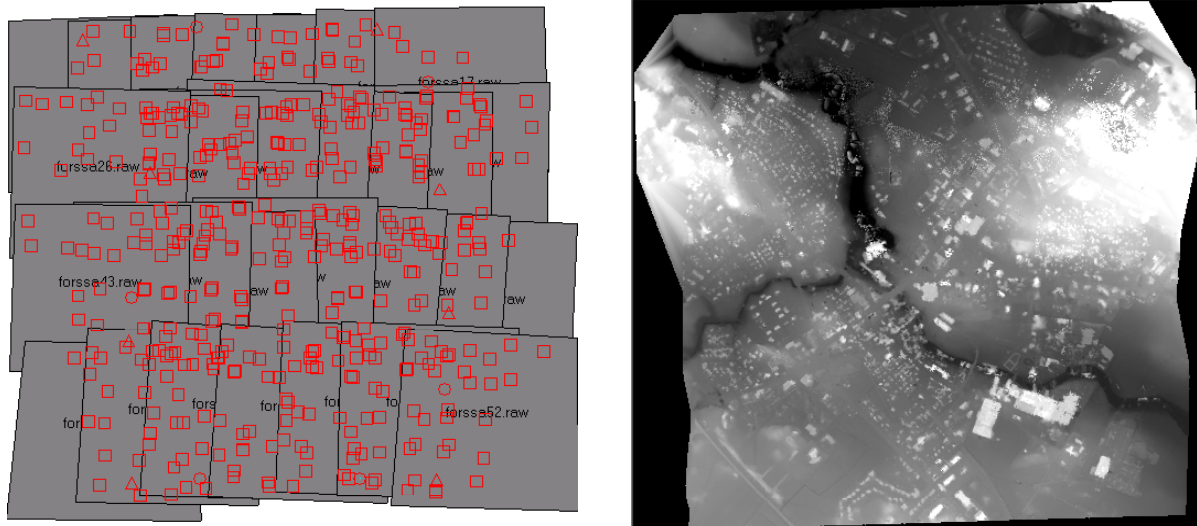


Figure 2. Left. Graphic overview of the test block with GCPs, check points and automatically collected tie points. Right: Automatically extracted DEM for the whole block with grid size 1x1 meters without any editing.

Auto. tie com. time	Total tie points	Tie points per image	Standard deviation	GCP residual accuracy			Check point residual accuracy		
				mX	mY	mZ	mX	mY	mZ
32 min.	1477	53	0.23 pixel	0.016 m	0.016 m	0.033 m	0.041 m	0.054 m	0.055 m
Total: 8 GCPs, 6 check points, 437 tie ground points. Per ground point appears averagely on 3.4 images.									

Table 1. Triangulation results of an aerial metric image block

6. EXPERIMENTS

6.1 Aerial metric Camera Images

The first example is an aerial image block with 28 images used in the OEEPE test. It covers an area of the town Forssa in Southern Finland. The image scale is 1:4000 and flight height is about 600 meters. The image overlap in strip is 60% and side overlap varies from 24% to 49%. The film is positive color and is scanned as black and white. The pixel size is 30 micrometers, each scanned image has 8000x8000 pixels. There are 14 known ground points available for the test. The image coordinates of these ground points are measured manually with IMAGINE OrthoBASE Pro™ measurement tool. The automatic tie point collection tool works well using the provided approximate coordinates of image photographic center. The whole processing of automatic tie point collection takes 32 minutes on a Pentium III PC with 700 MHz and 256 MB RAM. The default strategy parameters are used. It generates 437 object points with 1477 image points. The triangulation computation includes automatic gross error detection and 4 additional parameters. 8 of the 14 known ground points are set to be GCPs and the remaining 6 are used as check points. The Figure 2 Left shows the graphic report of the triangulation results. It is the footprint of the block with ground point positions and residual vectors. The triangle symbol represents GCPs, the circle symbol represents check points, and the rectangle symbol represents the automatically collected tie points. Since the residuals of GCPs and check points are very small, they are difficult to see from the graphics. The table 1 shows some useful data from the triangulation report. Considering the real conditions of the block the accuracy of the triangulation results looks very reasonable. Figure 2 Right shows the automatically extracted DEM for the whole 28 images with ground cell size 1x1 meters. The whole automatic DEM extraction computation

takes only about 1.5 hours for 28 images. Using 383 triangulated tie points (excluding the tie points outside DEM boundary and 11 points on building tops and trees) as ground check points, the automatic DEM has an accuracy about 0.2 meters. The result shows the automatic DEM process is very fast and accurate.

6.2 Digital Camera Images

Figure 3 shows three images captured from the Space Imaging PALS-1 digital camera, each image has 6 exterior orientation parameters derived from the airborne GPS and INS system. The camera focal length is known as 28 millimeter and the principal point is at the image center. Each image has four bands (colors) with an image size of 1024x1024 pixels. The pixel size is 12 micrometers and corresponding to a ground resolution of 1 meter. The red cross marks on the images represent the automatically collected tie points. If we assume the exterior orientation parameters from GPS and INS are accurate enough, we can rectify the images using these exterior orientations and the factory provided camera parameters. In this case there is no real photogrammetric processing involved (rectification and mosaicking functions are available in most remote sensing software packages). The mosaicked image is shown in Figure 4. The displacements at boundary areas are about 10 to 12 pixels. The another approach is to utilize advanced features in the digital photogrammetric system to determine if the results can be improved. In this example we run the automatic tie point collection tool of IMAGINE OrthoBASE Pro™ with the default strategy parameters. The extracted tie points are shown in Figure 3. Triangulation is then run using these tie points and the given exterior orientations as weighted observations. The new exterior orientation parameters will be used for rectifying the images again. The mosaicked image of these rectified images is shown in Figure 5. The displacements at the



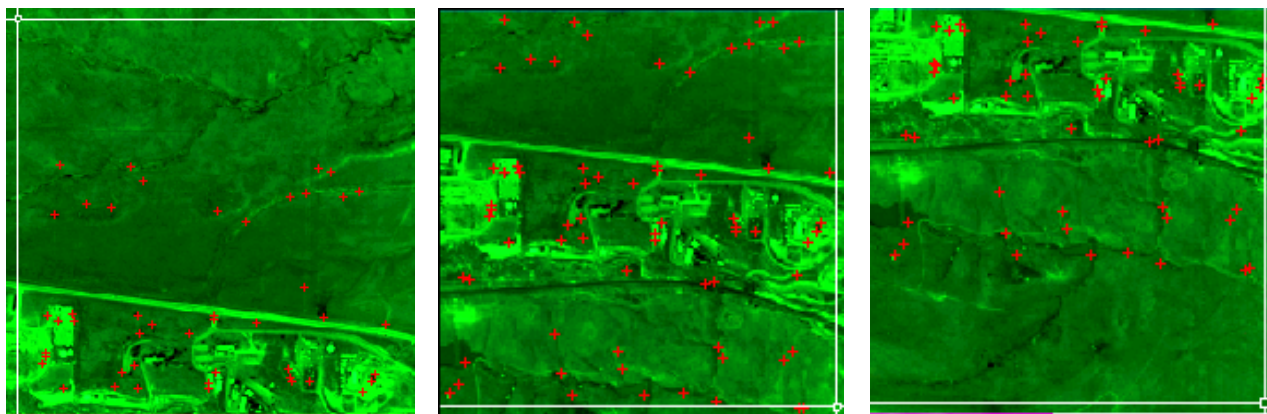


Figure 3. Three digital camera images with automatically collected tie points



Figure 4. Mosaicked rectified images with the original exterior orientation parameters



Figure 5. Mosaicked rectified images the new triangulated exterior orientation parameters

boundary areas are reduced to 1 to 2 pixels. Therefore we see the photogrammetric triangulation has improved the results significantly in this case. There is no manual measurement involved in this test. The computation for automatic tie point collection takes less than 30 seconds on a Pentium II PC. The whole process from starting project till generating image mosaic can be finished in less than 5 minutes.

### 6.3 Satellite Images

Satellite images are used very often in the GIS community. The Figure 6 Left and Middle images show a pair of SPOT panchromatic images. The image pair covers Palm Springs, California of the USA. The image size is 6000x6000 pixels with a ground resolution of 10 meters. The small crosses that appear on the images shown the measured GCPs, the check points, and the automatically collected tie points. There are 22 known ground points that have been prepared. The horizontal coordinates come from an orthorectified SPOT multi-spectral images with 20-meter ground resolution. The height information comes from an existing DEM with grid size of

75x75 meters. Therefore the GCPs are not very accurate. 14 points have been chosen randomly as GCPs, the remaining 8 points as check points. In addition there are 50 tie points automatically extracted. It takes only about 1 minute on a Pentium II PC with 300MHz clock-speed. The triangulation results are shown in Table 2. Though the check point accuracy are not very high, it is very reasonable when considering the accuracy of GCPs. The existing DEM also shows the elevation difference in the area ranges from -75 meters to about 3200 meters. Even with so big terrain relief, OrthoBASE Pro's automatic DTM extraction tool still works very well with this pair. Using some standard strategy parameters and a ground grid size of 100x100 meters, the automatic DEM extraction is finished in about 2 minutes. 36 tie points are located inside the automatic DEM boundary. Using them as check points to compare with the automatic DEM, the root-mean square error is about 11.0 meters. Figure 6 Right shows the extracted DEM with a ground grid size of 100x100 meters in painted relief.

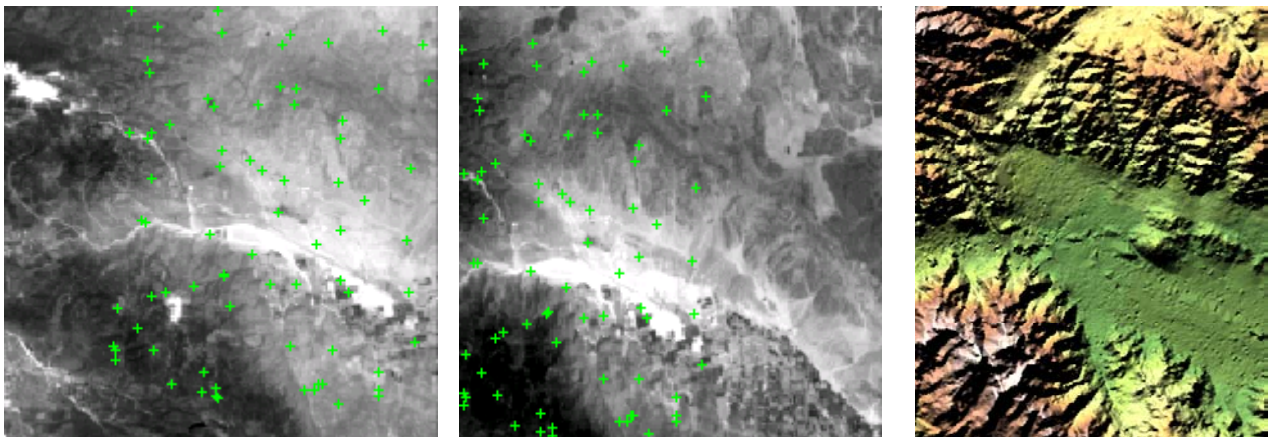


Figure 6. Left & Middle: A SPOT image pair with GCPs and automatically collected tie points.  
 Right: Automatically extracted DEM with a ground grid size 100x100 meters presented in painted relief.

Standard Deviation	GCP residual accuracy			Check point residual accuracy		
	mX	mY	mZ	mZ	mY	mZ
0.35 pixel	0.72 m	3.92 m	0.33 m	8.5 m	10.1 m	20.8 m
Total points: 14 GCPs, 8 checks, 50 tie points						

Table 2. Triangulation results with SPOT image pair

7. CONCLUSIONS

This paper has introduced a new softcopy photogrammetric system: IMAGINE OrthoBASE Pro™. Its main functional modules and system workflow are described. The algorithms for automatic triangulation, DTM extraction and rectification of different kinds of image data are introduced. Several examples are demonstrated. From the analysis and test result several conclusion remarks can be drawn as the following:

- The new system is very easy-to-use thanks to its linear workflow, optimized system design and high automation.
- The new system is very flexible for different kinds of applications since it can process many types of images such as images from aerial metric cameras, digital cameras, pushbroom sensors, etc.
- The developed approach for automatic tie point collection works well not only for aerial images, but also for digital, video and satellite images. It can significantly reduce the human work time.
- The procedures for automatic triangulation and image rectification are highly automated and optimized with different options including orthoimage generation, image rectification, image registration and image calibration. The automatic DTM extraction algorithms work fast and accurate with many kinds of images.

In a summary, IMAGINE OrthoBASE Pro™ is not only a powerful and reliable system for advanced photogrammetrists, but also a powerful, yet simple and easy-to-use tool for GIS professionals to acquire spatial data from digital images for their GIS applications accurately and efficiently.

ACKNOWLEDGMENTS

The authors are grateful to Institute for Photogrammetry and Engineering Surveys, University of Hannover and Space Imaging Inc. for offering the test data.

REFERENCES

Achermann, F., 1995, Automatic Aerial Triangulation, Proceedings of 2<sup>nd</sup> Course in Digital Photogrammetry, Bonn.

Baltsavias, E., Käser, C., 1998, DTM and Orthoimage Generation – A Thorough Analysis and Comparison of Four Digital Photogrammetric Systems, *International Archives of Photogrammetry and Remote Sensing*, Vol. 32, Part B4, pp.42.

ERDAS, 1999, *ERDAS Field Guide*, Fifth Edition, and *ERDAS IMAGINE V8.4 Tour Guide*, Atlanta, GA.

Förstner, W. and Gülch, E., 1987, A fast operator for detection and precise location of distinct points, corners and centers of circular features, Proc. of Intercommission Conf. on Fast Processing of Photogrammetric Data, 2-4 June, Interlaken, Switzerland, pp. 281-305, Available from Institute of Geodesy and Photogrammetry, ETH Zurich.

Heipke, C., Eder, K., Brand, R., Winkler, R., 1998, The OEEPE-ISPRS Test “Performance of Tie Point Extraction in Automatic Aerial Triangulation” – Status and First Results, *International Archives of Photogrammetry and Remote Sensing*, Vol. 32, Part B2, pp. 104-112.

Krzystek, P., Heuchel, T., Hirt, U., Petran, F., 1996, An Integral Approach to Automatic Aerial Triangulation and Automatic DEM Generation, *International Archives of Photogrammetry and Remote Sensing*, Vol. 31, Part B3, pp. 405-414.

LI, D., 1983, Ein Verfahren zur Aufdeckung grober Fehler mit Hilfe der a posteriori-Varianzschätzung, *Bildmessung und Luftbildwesen*. Vol. 5.

Lue, Y., 1996, Towards A Higher Level of Automation for SoftPlotter, *International Archives of Photogrammetry and Remote Sensing*, Vol. 31, Part B3, pp. 478-483.

Mikhail, E.M., 1998, Is Photogrammetry still Relevant? Keynote Address, ISPRS Commission III Symposium, Columbus, OH, July 6-10, 1998.

Miller, S.B., Paderes, F.C., Walker, A.S., 1996, Automation in Digital Photogrammetric Systems, *International Archives of Photogrammetry and Remote Sensing*, Vol. 31, Part B3, pp.250-255.

Schenk, T., 1997, Towards Automatic Aerial Triangulation, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol.53, pp.110-121.

WANG, Y., 1998, Principles and applications of structural image matching, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol.53, pp.154-165.

TANG, L., 1997, Automatic Aerotriangulation: Concept, realization, and Results, *Proceedings of SPIE*, Vol. 3072, pp. 11-17.

ZHANG, B., 1997, Adaptive Automatic Terrain Extraction, *Proceedings of SPIE*, Vol. 3072, pp. 27-36.

ZHANG,J., ZHANG, Z., SHAN,W., WANG,Z., 1996, VirtuoZo Digital Photogrammetric System and Its Theoretical Foundation and Key algorithms, *International Archives of Photogrammetry and Remote Sensing*, Vol. 31, Part B2, pp.424-429.

