AUTOMATIC TIE-POINT EXTRACTION USING ADVANCED APPROACHES

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ABSTRACT

The automatic extraction of tie-points for a block of images is probably one of the most demanding tasks of a digital photogrammetric workflow. The image matching is a fundamental task and has been a subject of research for many years both in the computer vision and in the photogrammetric communities. As the provider of the main bulk of data for Aerial Triangulation methods such as “Bundle Adjustment”, the tie-point extraction stage plays a crucial role in the success of the entire photogrammetric workflow.

Most of the popular commercial software available for tie-point extraction makes use of standard techniques such as Normalized Cross Correlation and Least Square Matching. These methods have proven useful under ordinary conditions found in most standard mapping projects. High quality tie-point extraction in these projects typically relies on the use of precise location and orientation measurement instruments. However, they lack the ability to deliver sufficient results in challenging scenarios such as oblique imagery, lack of or low quality Exterior-Orientation data and imagery captured by low-cost non-metric sensors.

Recent developments in image matching techniques have yielded a number of prominent advantages over traditional techniques. The main improvements are noticeable in higher accuracy, speed, robustness and indifference to low quality input data. These new techniques can provide satisfactory results even facing the most challenging circumstances such as variations in illumination, scale or even significant perspective changes.

This paper presents the MatchMe™ module by Icaros Inc. for the extraction of tie-points in a highly efficient, robust and precise manner and under the most demanding scenarios. MatchMe™ does not require any prior knowledge, except for partial location data, which will be used to reduce the search space of image pairs for execution. Any information regarding the image’s orientation is not required. Experiments on various scenes, including very challenging configurations such as oblique imagery, will show the validity and high potential of the proposed approach.

KEYWORDS: Tie-Point, Keypoint, Image Matching, Aerial Triangulation, Oblique Imagery, High Performance Computing

INTRODUCTION

Following the accelerated technological developments of recent years, a process of upgrading the photogrammetric equipment being used since the mid-20th century, is taking place. The photogrammetric systems are starting to receive a new digital design, which includes the replacement of old, 9" heavy analog cameras with advanced high quality digital equipment, which is also relatively cheap. This upgrade allows for the reconsideration of the equipment and platforms required to perform an aerial mapping mission. As a result, more and more companies are offering mapping systems designed for platforms which have not traditionally been used for aerial mapping until recently, such as light aircraft, UAVs, etc.

Simultaneous to hardware upgrading, the required deliverables from the photogrammetric community are also changing significantly. In recent years, the standard mapping products that have been supplied for many years, do not meet the current customers' expectation of real 3-D products enabling the visualization of reality. For example, urban 3-D mapping is currently being conducted for the world’s major cities by using oblique imagery and modeling all of the buildings in the city. For this purpose, a full photogrammetric process is needed for the oblique images used.

In order to bridge the gap created by performing a mapping mission with non-traditional equipment at one hand, and the market demands for enormous amounts of high quality geo-spatial data on the other hand, the center of gravity of the photogrammetric workflow turns toward the processing workstations. Modern mapping projects may contain a vast amount of images, and it is doubtful whether it is possible to process them adequately without the support of automatic or semi-automatic processes done by software.

One of the most demanding tasks of the photogrammetric work flow, in terms of complexity and processing time, is the extraction of tie points between images in the block. This is the first stage in the Aerial Triangulation process, which is used to compute the location and orientation of each image in the block. This stage requires that conjugate points in two or more images are extracted and is the most challenging for automation in the photogrammetric workflow, especially when the mission relies on non-standard equipment such as cameras mounted on UAVs or oblique imagery. The task is even more difficult if the Exterior Orientations of the images are partial or inaccurate.

There are two main methodologies for extraction of tie points in multiple images. The first is used by all mainstream photogrammetric software applications and includes a local search by algorithms such as Correlation or Least Squares Matching on the image data itself. The second and more modern methodology is based on extraction of interesting points in each image independently, after which a matching process is conducted between the various points from each image. The first method is more appropriate when there is accurate information on the camera orientation, ground height of the points and the features have the same scale in all images. In contrast, the second method is suitable for general cases where there are significant differences in perspective without prior information regarding the orientation parameters. Table 1 shows the difference between the two methods:

Table 1. Comparison of Tie-Point Extraction Methods

Category	First Method – Image based	Second Method – Keypoint based
Pre-requisites	External Orientation and accurate height	None
Number of extracted points	Small	Very Large
Processing speed	Usually slow	Fast
Identifying Gross Errors	Usually not available	Pointing methods (e.g. RANSAC) based on redundant number of points
Affine Robustness	Low	High

One of the biggest advantages in using Keypoint information is that after extracting the points there is no need for the actual images and the output data can be kept in a very compact format. However, the method requires a matching process in which every Keypoint is found accurately in each participating image and its information is store in the same format. Therefore, Keypoints found must be, on one hand, unique in their local environment (the initial image) so as not to match between two different features, and repetitive on the other hand, so that the same feature will be easily identified in two different images.

Most of the current tie-point extraction methods that appear in the literature (Schenk, 1999; Mikhail et al. 2001), especially those that were implemented in most commercial software, were designed about 20 years ago. These methods were very useful for most of the widespread mapping projects at that time, which consisted of Nadir images taken by photogrammetric equipment and complemented by fairly accurate external orientation parameters. However, these methods have not shown sufficient results in challenging scenarios such as oblique imagery, lack of or low quality Exterior-Orientation data and imagery captured by low-cost non-metric sensors. In addition, the required time resources for these implementations are very high and they are restricted by the overall amount of images, which can be handled.

Icaros Inc. has created an entire software package named IPS (Icaros Photogrammetric Suite) to automate the whole photogrammetric workflow. This paper will present and detail the MatchMe™ tie-point extraction module, which is part of the IPS. MatchMe™ was designed to handle extremely difficult cases of large perspective differences caused by changes in scale and different camera orientations as well as for the solution of oblique images blocks.

While MatchMe™ works in a fully automated manner, the module, along with all the other modules in the IPS, offers the user a complete user interface. The interface allows the user to configure the process parameters, thus allowing the use of different solution approaches for different terrain types and project demands. In addition, tools for editing the generated points using a simple and yet comprehensive visual interface are supplied.

This module, as all other IPS modules, was implemented in a manner that utilizes the full capability of multi-core CPUs by using all available cores in parallel. MatchMe™ also uses the machine GPU in order to achieve extremely high performance by using the massively parallel structure of the GPU. Tests have shown that MatchMe™ produces highly accurate results that consist of many high quality tie-points with virtually no outliers.

THE PROPOSED METHOD

In order to fulfill the requirement of the extraction of tie points regardless of their image source (standard mapping systems or oblique systems), a software module was created for a semi- or fully automatic process. The module enables very fast and robust extraction and matching of points even in cases where there are no known initial values for the images External Orientations.

The MatchMe™ module consists of the following stages:

Keypoint Detection

There are many methods for extracting Keypoints but they all have a common goal, which is to find a large number of unique and distinctive points in each image that can also be easily found in multiple images. The MatchMe™ algorithm is aligned with modern methods which search for points in multiple scales contrary to a single scale (Forstner, 1986; Harris and Stephens, 1988) and has faster computational times for complex inputs. In addition, the algorithm shows better dispersion of the data resulting in a much more robust solution. Our experiments indicate that the extracted points in each image using the MatchMe™ module are significantly more distinctive than other modern methods. An additional positioning refinement process is carried out both in and between scales, similar to current extraction methodologies.

Feature Descriptors

For each Keypoint a dominant orientation is calculated in the selected scale in order to achieve rotation invariance. The invariance to scale has already been achieved since all calculations are done in relation to the optimal scale described in the previous section. The invariance to illumination is gained by applying an algorithm, which takes into account the relative values between neighboring cells. Once the local orientation and scale of each Keypoint have been estimated, a scaled and oriented patch around the detected point can be extracted to form a Keypoint descriptor (Szeliski, 2010). The resulting non-negative values form the descriptor vector which is normalized to unit length to reduce the effects of contrast or gain and clipped to make it robust to other photometric variations. In addition we have found that the method described above has also been very robust in cases where significant perspective differences were found (wide baseline, oblique imagery, etc.).

Matching and Filtering

After the creation of the descriptors for each point, a matching process between the extracted points in different images is applied. At this point, the original images are not needed since the information is composed of descriptor vectors. The matching process is based on the principle that vectors describe the same point if they are its nearest neighbors (Euclidean distance) and if there is no other neighbor who is close enough to one of the vectors.

This process of vector matching can be very time consuming. There are several known algorithms (Szeliski, 2010) which can greatly reduce the computation time from $O(n^2)$ – caused by simple implementation – to $O(n*\log(n))$ by creating complex trees which holds the images' descriptors. These algorithms create the tree by assigning the most significant values first and the least significant values last. In this manner, it is relatively fast to find the sub-group containing the points nearest to the vector in question.

Another time-consuming issue in the matching process is choosing which pairs are to be matched. The proposed method uses initial values for location and orientation in order to reduce the search space by matching only images covering the approximate same location. However, there are cases when this information is not available and then a matching process must be carried out for all images. To avoid such complex computations for each image pair in the block it is possible to work on lower resolution images so that only images, which are estimated to be matched, are later processed in full resolution. Moreover, recently reported methods have been developed for building skeletons and sub-groups of the images. In this manner, each additional image is adjusted only to the central image and not to each one of the images in the block (Snavley et al. 2006).

An additional voting-based filter can be utilized on the matching results for the removal of gross errors using the Fundamental matrix comprised of at least 7 points (Hartley and Zisserman, 2004) *or* the Essential matrix (Nister, 2004; Philip 1996) comprised of at least 5 points.

Unification and Point Selection

The matching process above describes the process only between image pairs. During the Aerial Triangulation stage a tie point between more than two images has high importance in preventing discontinuities caused by lack of information. Unifying several tie points is done based on the basic principle that if the same point has been matched in two image pairs it can be deducted that the point appears in three images altogether, etc. In cases where a closed sequence of connections have been detected there are even redundant observations for the process and if any outlier connections are observed, the point can be discarded and prevented from degrading the resulting bundle adjustment process.

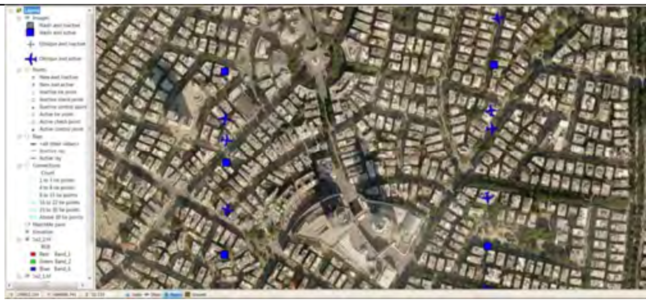
The method described above can yield thousands of points between the image pairs whilst the bundle adjustment solution requires only several dozens for each image. Therefore, an educated selection of the points can be made so that only points with the highest level of confidence are chosen (i.e. the points which have the most connections and are part of closed sequences). The position of the points is also taken into consideration since a large and uniform dispersion across all images is desired. The MatchMe™ module enables the user to define the desired pattern to complete the solution process. The module utilizes memory resources locally for each instance, which removes any limitation for maximal number of images used as input.

In addition, the proposed method has been modified so that it can handle homogenous areas with low texture by increasing the kernels used for extraction.

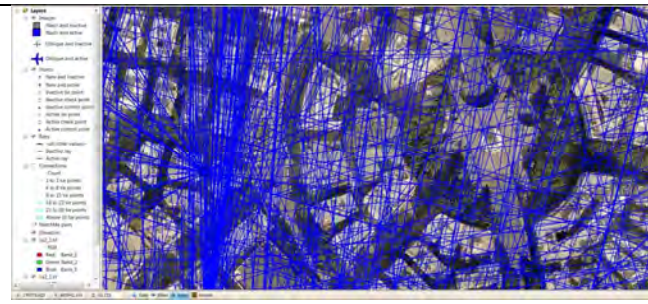
Analysis and User Interface

The user interface enables the user to show the image centers on top of an underlying reference Orthophoto (see Figure 1A). The image centers symbology is determined according to the direction in which the image was taken. If the image direction is nadir then it is marked with a rectangle, if the image is an oblique view it is marked with a plane heading to the direction of the view. In addition, several analysis tools have been implemented in order to help in estimating the quality of the extracted points:

1. Connections between extracted points and their associated images (rays) are shown geographically (see Figure 1B). This method can only be used after the bundle adjustment process finished and may be incomprehensible when large amounts of points and images appear in a small area. This view is implemented in many commercial software packages.
2. Connections between image centers using varying line widths and colors are shown geographically (see Figure 1C). This method is much more comprehensive in large projects, but it is not suited in cases of oblique imagery because of the distances between image centers.
3. Connections between image centers are shown geographically as they are projected on the ground with symbology for direction of the camera (see Figure 1D). This tool clearly visualizes the quality of the tie points and reveals potential problems in the project.



A: User Interface Showing Image Centers



B: Connections Between Extracted Points and Image Centers - Zoomed in for Clarity

C: Connections Between Image Centers

D: Connections Between Images Centers Shown Projected on the Ground

Figure 1. A, B - Classical User Interfaces; C, D – MatchMe™ Enhanced User Interface.

In addition, the module gives the users the ability to enhance areas which have not yielded sufficient points by enabling them to enter only selected images into the MatchMe™ module as input and change the module parameters (see Figures 2A and 2B)). The module also creates an output file, which can be used for DTM production.

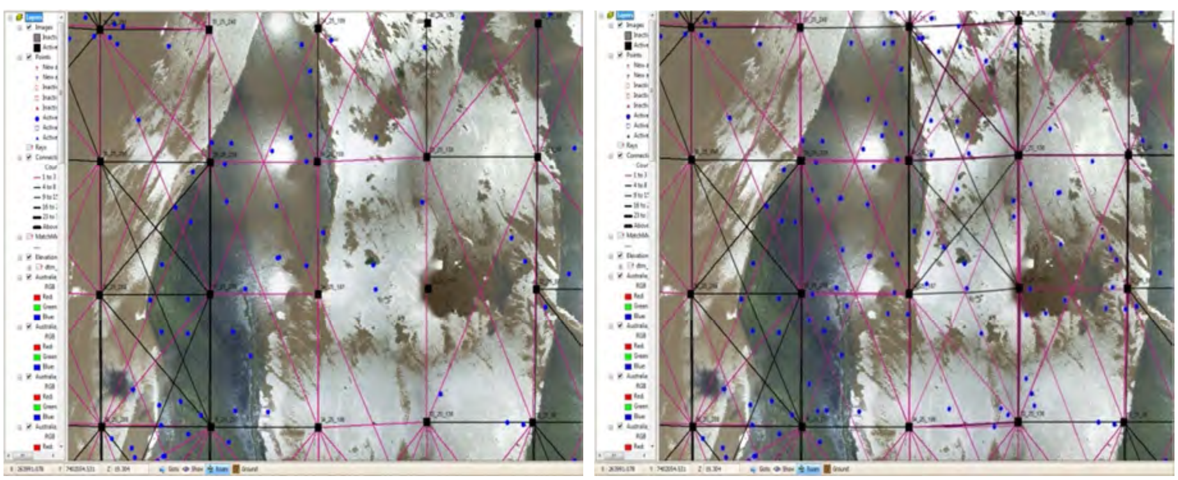


Figure 2 Floods in Australia 2011; A - Area with Insufficient Tie-Points (in blue); B - Same Area After Running MatchMe™ on Some of the Images.

TIEING IMAGE TO ORTHOPHOTO

Another feature, which is available in MatchMe™, is the option to align a new image block to an existing Orthophoto. The module receives the new images and existing Orthophoto as inputs, and matches them with adjusted parameters. The results of this procedure are new 2D control points, which can be utilized, in the new project. This option is still undergoing some development but has already been tested and Figure 3 shows a proof of the concept.

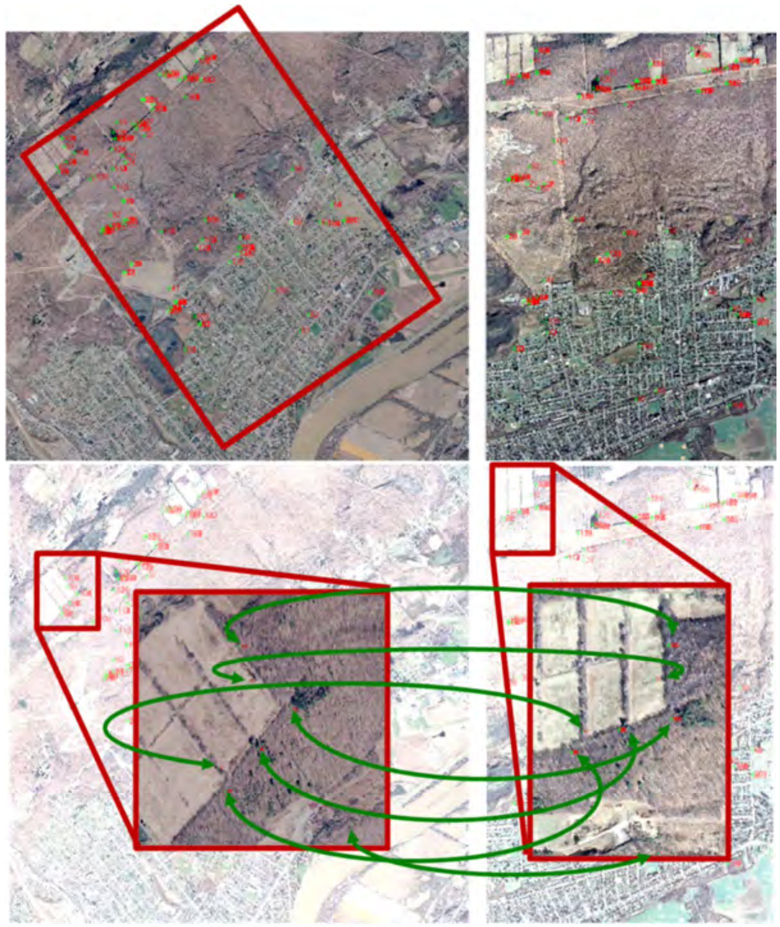


Figure . Upper Left - Old OrthoMosaic Made by an Analogue Camera; Upper Right - New DMC Image of the Same Area Captured 4 years Later. Lower Left and Lower Right - Zoom in to One of the Areas.

CASE STUDIES AND BENCHMARK TIMES

The Icaros Photogrammetric Suite was initially released by Icaros Inc. in 2007 and since then has been part of many successful projects. The software has been used by many companies around the world and with various sensors. This section will show examples of these projects, which utilized the entire software package and the MatchMe™ module in particular.

Tel-Aviv Oblique

In this project (courtesy of SightVision Israel Ltd.), 3200 images covering the entire Tel-Aviv metropolitan area were captured from 5 small-format 16 MP cameras (4 oblique and 1 Nadir) and solved with sub-pixel accuracy (RMS = 0.8 pixels). The Nadir camera has a focal length of 65 mm while the oblique cameras have a focal length of 85 mm. The oblique cameras were positioned on all sides of the plane to cover all viewing directions (North, South, East and West). The GSD for the Nadir views was 15 cm. The images were run with the MatchMe™ module, which gave an output file of 36,673 points after 4.5 hours. Figure shows an area of Yarkon Park with extracted tie points from an Oblique image and a Nadir image. The upper left image is taken from a Nadir camera and the lower right image is taken from an oblique camera. The upper left and lower left images are zoomed in areas marked with a red rectangle for reference. The points extracted from MatchMe™ clearly show that the module ignores bodies of water and can handle homogenous areas such as grass and sand.

The output Orthophoto and all image orientations were delivered after only a couple of days and a 3D city model was extracted from it by a third party (see Figure 5).

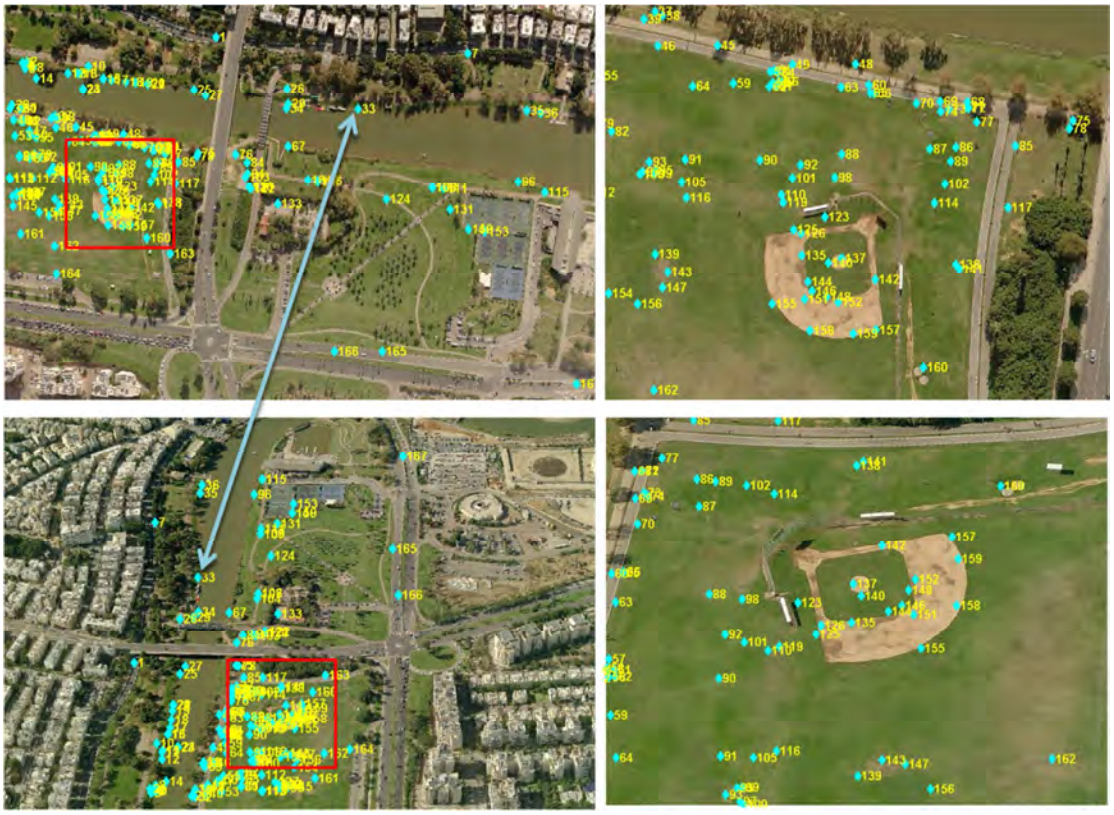


Figure 4. Oblique and Nadir Images with Extracted Points from MatchMe™.

Figure 5. 3D City Model Created After the Entire Processing by MatchMe™ and IPS™.

Congo

This project is an example of imagery taken under extreme conditions such a clouds and precipitation. The client was a leading Energy company in Congo, which needed to map the area around a planned pipeline. The area was captured in 4,950 images using a 21 MP Cannon MK III camera, which has a focal length of 50 mm. The GSD for the project was 30 cm and it was solved with sub-pixel accuracy (RMS = 0.4 pixels). The images were run with the MatchMe™ module, which gave an output file of 54,450 points after 7 hours. Figure 6 shows two images which have poor viewing conditions and the resulting points extracted by the MatchMe™ module. The enlarged areas show that even in areas with clouds the algorithm is able to detect the same points in the two conjugate images.

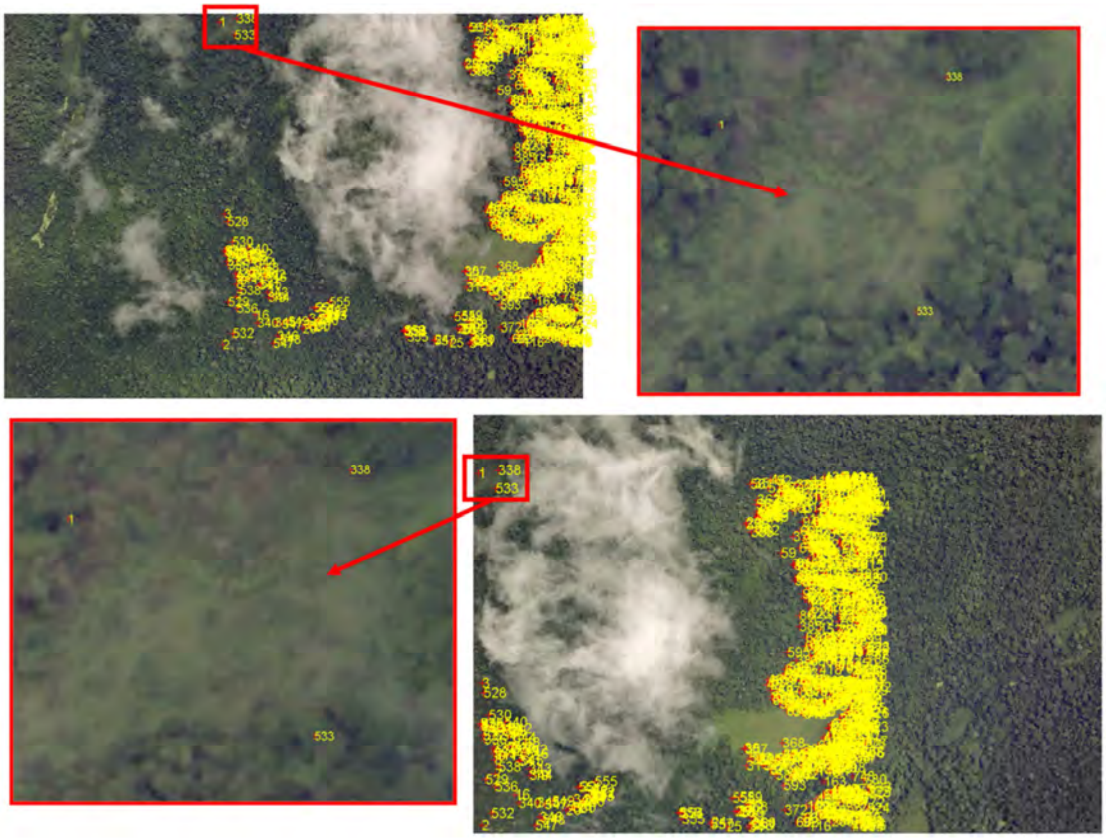


Figure 6. Extracted Points from MatchMe™ in Congo project.

Benchmark Running Times

Table 2 shows results from a series of MatchMe™ runs on an Intel i7 QuadCore machine with 12 GB Memory and a NVIDIA Tesla C1060 graphics board:

Table 2. MatchMe™ Running Times

Sensor Type	Image Size	Run Time per Image
DMC	106 MP	23.5 sec
Phase One P65+	60.5 MP	18.6 sec
Phase One P45+	39 MP	13.1 sec
Cannon 1Ds Mk III	21 MP	5.2 sec

SUMMARY

In this paper we have presented a method for tie point extraction using the MatchMe™ module which is part of the Icaros Photogrammetric Suite (IPS) created by Icaros Inc. IPS is a comprehensive software package for a fully automated photogrammetric workflow which includes modules for Aerial Triangulation (Solution Manger™), Automatic DTM Generation (DTMe™), OrthoRectification and Mosaicking (StitchMe™) and QA and Patch Correction (Patching Tool™). The proposed method enables, for the first time, processing of images, which were captured by airborne oblique systems and non-standard platforms such as UAV's utilizing off-the-shelf cameras. It has been shown that the MatchMe™ module can provide output for the Aerial Triangulation stage even in extreme cases with wide base lines and large perspective differences between images.

Most commercial tie-point extraction software packages have been proven useful under ordinary conditions found in most standard mapping projects. However, these projects typically rely on the use of precise location and orientation measurement instruments. The MatchMe™ module does not require any initial location and orientation values and if they do exist the module only uses them to reduce the amount of matching assignments in order to speed up the entire process.

The presented workflow can be divided into the following stages:

1. Keypoints extraction performed on each image separately
2. Creation of descriptors for each Keypoint
3. Matching between the images' descriptors to find conjugated points
4. Unifying the matches to create multi-ray points

The module has an intuitive user interface enabling different levels of user interaction from manual re-extraction of points to fully automated extraction of points in an area of interest using different parameters.

The method has been proven to give robust and high quality results with sub-pixel accuracy for an unlimited number of images in the same block even under extreme conditions. The module has shown very fast computational times compared to existing commercial software even though it requires less initial parameters.

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