VIRTUOZO DIGITAL PHOTOGRAMMETRY SYSTEM AND ITS THEORETICAL FOUNDATION AND KEY ALGORITHMS

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ABSTRACT:

In the 1990's, photogrammetry strides into the digital age, having seemingly outgrown the analog and analytical generations. Digital photogrammetry processes digital images by specialised computer software ultimately producing the required digital maps and data. Such software, when bundled with prescribed hardware is termed a Digital Photogrammetric Workstation or DPW. The fully automated production of topographic maps with DPW's is still limited to the production of orthophoto maps. During the evolution of photogrammetry into the digital phase, a DPW (the Wuhan Digital Automatic Mapping System -WuDAMS) was successfully developed at the Wuhan Technical University of Surveying and Mapping (WTUSM) in P. R. China. This DPW has entered the market with the trade name VirtuoZo. In this paper, the main functions and the theoretical foundation of VirtuoZo are introduced , then, based on the analysis of the weaknesses of traditional image matching algorithms, the probabilistic relaxation and Hopfield neural network techniques are discussed highlighting their application in image matching. Using these techniques, the spatial relationship and global consistency have been improved greatly. Based on the neural network method, zero matching can be contained, and break-lines and occlusions can be processed. The stability of image matching has been enhanced. For a practical DPW, effectiveness is an important factor. The algorithms in three of the most innovative modules of VirtuoZo are introduced. They can enhance the effectiveness of VirtuoZo by a factor five. Some of the applications of VirtuoZo are also outlined before a short conclusion.

1. INTRODUCTION

The development of photogrammetry has experienced three successive stages, namely the analog stage, analytical stage and digital stage. During the period of the analog stage (from about 1900 to 1965), the typical photogrammetric instrument was the universal stereoplotter. This piece of equipment, simulated the bundles of straight lines through an object point, the perspective centre in the camera and its corresponding image points. This was achieved by optical, mechanical or optical-mechanical equipment. The analytical stage of photogrammetry started in 1957 when the concept of the analytical stereoplotter was proposed by U. V. Helava. Although the collinear equations were computed by a computer instead of analog projectors, the manual operation was nearly the same as in the universal stereoplotter, and the processed materials were still photographs. An advance was digital output in the form of the Digital Elevation Model (DEM) and mapping file, which was stored in the computer. This could be transmitted to a digital plotter to produce hardcopy output, as was required. This technique could be referred to as computer aided mapping. In the 1990's, photogrammetry strides into the digital age. Digital photogrammetry is referred to variously as pixel photogrammetry, softcopy photogrammetry, soft photogrammetry, rastergrammetry, fully digital photogrammetry or (as coined by VirtuoZo Systems) virtual photogrammetry. Scanned images are processed by specialised computer software to produce the required products, namely, digital maps. Such software, when bundled with the required computer, is collectively termed the Digital Photogrammetric Workstation or DPW. An obvious advantage in the DPW is the automatic measurement by computer instead of the eyes, hands and brain of the operator. As the technique of automatic object recognition within an image has not yet matured, the fully automated production of topographic maps is still limited to the production of orthophoto maps.

During the evolution of photogrammetry to it's current digital state, a DPW, the Wuhan Digital Automatic Mapping System, or WuDAMS, initially proposed by Prof. Wang (Wang Z. 1978; Wang Z., 1995), was successfully developed at the Wuhan Technical University of Surveying and Mapping (WTUSM) of P. R. China (Zhang Z., 1986; Zhang J., 1993 and 1994). This DPW has now entered the market and is commercially known as VirtuoZo (the VirtuoZo Digital - or Virtual - Photogrammetry System). In this paper, the main functions and the theoretical foundation of VirtuoZo are introduced. These main functions include automatic interior and relative orientations, automatic measuring and transferring of the tie points for aerial triangulation, relative rectification to get the stereo model, image matching, interactive editing of the match results, automatic generation of digital terrain models (DTM), digital orthoimage generation, contouring, mosaic functions, landscape draping and semi automatic feature extraction. In the past fifteen years, countless theories and computational methods in digital photogrammetry have been developed, such as the theory and practice in one dimensional pixel arrangement along conjugate epipolar lines, the use of the bridging mode image matching method, global image matching by way of dynamic programming, probability relaxation and neural network techniques, etc. It is quite evident from the speed of VirtuoZo that one of our most significant achievements has been in solving the problem of image matching.

Image matching is an important basic step in the three dimensional data reconstruction problem. Based on the theories and methods of pattern recognition, this paper discusses the weaknesses of traditional image matching algorithms. That is, the results from traditional image matching algorithms are inharmonious and unreliable because they do not take spatial relationships into account when they do not use neighbourhood matching to adjust the global matching results. In this paper two algorithms, probabilistic relaxation and the Hopfield model in neural network techniques (which are used frequently in pattern recognition) are discussed in detail with respect to their application in image matching. Relaxation processing is a useful technique for using contextual information to reduce local ambiguity and achieve global consistency in global image matching. It is basically a parallel execution algorithm. On the other hand, the neural network is a computational model with massively parallel execution capability. Being applied in gray-level based image matching, they give consideration to spatial relationships and as such, global consistency has been improved greatly. There exist certain common properties between relaxation processing and the neural technique. A mapping method that makes the Hopfield net perform relaxation processing is proposed in this paper. One advantage is that relaxation processing can be performed in real time since the Hopfield net can be implemented by conventional analog circuits. Based on the new concept of zero matching, not only the correct matching result can be contained, but also break-lines and occlusions can be processed. Because of these aspects, the stability of image matching has been greatly enhanced.

Not only is VirtuoZo one of the most exciting and innovative DPW available today, it is also a superb visualisation tool. VirtuoZo has been used on many projects, such as mapping, management of land, scaling Australia's Ayers Rock, corridor measurement for trains, resource management, measurement of dinosaur tracks, highway and railway design, etc. VirtuoZo can process not only aerial images, but also SPOT images and close range photography.

2. FUNCTIONS AND THEORETICAL FOUNDATION OF VIRTUOZO

VirtuoZo, which was written in C, X-windows/OSF Motif and OpenGL (for the stereo graphics) is a Unix based application. VirtuoZo accepts scanned stereo photography, stereo SPOT satellite imagery or scanned close-range stereo photography as input and very simply and quickly produces DTM, ortho-rectified imagery (orthoimage), and contour maps as it's primary output. Secondary output consists of dynamic three dimensional visualisation techniques in stereo of the modelled object, and digitised vector data.

2.0 Input

VirtuoZo processes standard 24-bit colour and 8-bit black-white digital images. TIFF, IRIS RGB, SUN Raster, BMP and JPEG graphics files can be converted to the necessary format from within VirtuoZo. Scan resolutions between 7 and 200 microns have been tested, yielding excellent results. The parametric input through the VirtuoZo tools menu includes control data, camera calibration data, block and model data.

2.1 Interior Orientation

The interior orientation in VirtuoZo is predominantly an automatic procedure of recognition and location of fiducial marks on digital images from the metric camera. For each kind of fiducial mark, the system has to learn only on the first processed image under the guidance of the operator by simply pointing and clicking two fiducial marks using the mouse. The features inherent in the fiducial mark will be analysed and stored, and used in the pattern matching of subsequent fiducial marks. Semi-automatic and manual measurements are also available. In the semi-automatic mode, an approximate position of the fiducial mark is pointed out by the mouse and the accurate position is located by the system. In the manual mode, the accurate position of the fiducial mark is pointed out by the mouse and then optimised very simply by incremental pixel shifts. The results are displayed in real time.

2.2 Relative Orientation

In VirtuoZo's automatic relative orientation, distinct points are selected, and their conjugate points are matched automatically. The feature extraction operator, the feature location operator (Zhang J., 1992), area-based matching, local multiple point matching and least square matching are applied based on the dynamic image pyramid. A forced condition is used in standard positions to ensure necessary points are acquired. The interactive actions in both semi-automatic and manual modes enable the user to add, optimise and delete user-defined related points, if required. Points selected by the operator can be made on either the left or right image. Conjugate points will be automatically matched by an area-based matching method in the other image automatically, or may be selected by the operator manually. The entire overlap of the image pair is displayed on the computer screen for the overview, and a high resolution image window is popped for optimal selection after the approximate position is pointed out. The results are calculated in real time and displayed to allow the optimisation of individually related points.

2.3 Absolute Orientation

The absolute orientation is effected by the user interactively nominating control points by way of unique identification, point and click methods, similar to the interactive actions of the relative orientation. Optimisation of the absolute orientation is performed using a point and click technique to introduce incremental shifts of one fifth of a pixel. The results are calculated and displayed in real time.

2.4 Automatic Aerotriangulation

The tie points for aerotriangulation are automatically selected using the feature extraction operator after only one pair of conjugate points is measured interactively in the side lap of two images in each of two neighbouring strips. Four images can be displayed on the screen for the interaction, two are from one of the strips and the others are from the neighbouring strip. Both the images and the strips can be selected. The tie points, selected in automatic mode, are located in three columns on each image, the middle, the left and the right, if the conjugate points exist, and there are at least five points in each column (excepting in low contrast regions, such as water). Tie points are automatically transferred by using local multiple point matching based on dynamic image pyramids, and a coplanar restraint condition is used to ensure reliability.

Post-processing includes check, add, transfer, delete and refinement of tie points and semi-automatic measurement of control points. All of the image windows (two to eight) related to a tie point will displayed on screen after the tie point is picked by the mouse on any image. These can be selected randomly and are displayed on the screen. All of the interactions can be semi-automatic or manual, similar to the relative orientation. Control points can be automatically transferred to the relative images after having been identified on the digital image. Refinement is the same as for tie points.

2.5 Relative Rectification

Once the relative orientation is complete, an automatic process resamples the left and right portions of the stereo model to produce left and right epipolar images. In essence, y-parallax is removed from the original images, so that the subsequent image matching routine can be implemented in one dimension. Also, the visual stereo model can be displayed for checking. A fast epipolar line rearrangement method has been developed for use with aerial images, close range images and SPOT images. The epipolar line parameters are computed on the basis of the coplanar condition.

2.6 Image Matching (Automatic Measurement)

The matching algorithm within VirtuoZo is an area, feature and bridge mode based global image matching procedure using probability relaxation and neural network techniques. To ensure the reliability of the matching results, as well as fast processing, an image pyramid is used in the image matching procedure. The image pyramid is dynamically generated according to the rule of minimum workload. At the top of the image pyramid (with lowest resolution), a coarse grid is established in the left image and matched to the right image. Matching results on higher levels are approximations of a finer grid on subsequent levels with higher resolution. The geometry distortion caused by ground slope is rectified approximately by a bridge mode method. The compatibility coefficients used in the relaxation matching consist of matching quality and geometry condition restraints. The reliability factor for each conjugate pair describes the matching reliability and helps the operator to edit unreliable results.

2.7 Editing of the Match Results

The editing of the match results is a computer aided procedure to correct errors resulting from the image match. The major portion of the screen (centre-right) is a stereo window of the image pair, which can be zoomed in and out, while the entire epipolar image pair is reduced and displayed in the lower-left for a global stereo view. The buttons initiating the editing functions are arranged in the upper-left portion of the screen, and a popped menu includes other editing tools. Any single point, profile, polyline, rectangle or polygon selected by the user can be edited with measurement, smoothing, interpolation, surface fitting and rematching under the guidance of the operator. The stereo visualisation includes match iso-lines (effectively parallax contours), true contours, "pegs" (match points colour coded to confidence levels) and profiles. At any time the user can undo modifications iteratively, back to the start of the session.

2.8 DTM Creation

The DTM created by VirtuoZo is a regular grid. The grid interval and direction of the DTM can be input by the user or computed by the VirtuoZo software. Before interpolating the DTM, a random retrieval table of reference points is established for the fast generation of the DTM, and a moving curved surface fitting technique with medium value filtering is used to create the DTM. The features extracted from editing and digitising are applied in the procedure and break-lines can be processed.

2.9 Orthoimage Creation

The orthoimage is created based on the DTM and the corresponding original image. The user nominates parameters as to whether the left or the right image is to be orthorectified, what is to be the scale of the output image and what is the resolution of the plotting device (if any). According to the theory of digital orthorectification, the coordinates of the point projected on the original image are computed with collinear equations based on its ground coordinates. Height is interpolated from the DTM. To reduce the processing time, suitable algorithms are used, so that the orthoimage can be acquired quickly.

2.10 Contour Creation

The parameters for contour creation and their annotation can default to be system generated or, more realistically, may be nominated by the user. Contour vector data are produced from tracing the intersections of contours on the DEM grid. A contour image is created by rasterising the contour vector data, and a cubic spline function is used to smooth the raster contours. If required, the vector data can be converted to a number of proprietary vector formats. DXF, MOSS and Civilcad are some that are currently supported.

2.11 3-D Digitising of Objects

The digitising of objects has the same functionality as that within the analytical stereo plotter. However, in VirtuoZo, stereo measurement is based on the digital epipolar image pair instead of the photographic pair, and the height of the digital float mark is automatically controlled by the results of the image match, or by the operator, manually. An attribute code is input before measuring objects for eventual input to a database or GIS or drawing to a map through some vector plotter at a later time. All of the digitising operations can be accomplished in photo space or ground space. Semi-automatic methods are available for some kinds of objects, such as buildings, roads and rivers. The editing functions are suitable for correcting measurement errors. A symbol library can be conveniently created and edited. The graphics, symbolised from the vector data of objects, can be superimposed on the stereo model or displayed as a map sheet. In essence, the digitising module replaces the analytical plotter, without the optical-mechanical units.

2.12 Mosaic

It is difficult to seamlessly mosaic orthoimages in analog and analytical photogrammetric instruments. This is a routine operation within the VirtuoZo Digital Photogrammetric System. After the stereo models, namely the DTMs, have been created and the areas of interest have been nominated by the user in a graphic window in which the DTM area of all the relevant models are

drawn, a seamless orthoimage, contour image and combined orthoimage with contours can be mosaiced automatically. Geometric and radiometric corrections are made along the seam line on the overlap regions. The geometric correction are based on the DTM merging. The differences between the DTMs can be adjusted in the overlap region by recreating that part of the over-riding DTM according to all coincident points of the overlapping DTMs so that any small geometric misalignment can be eliminated. The mosaic process eliminates the radiometric differences of the orthoimages by a weighted average algorithm. The geometrically continuous and radiometrically seamless orthoimages are then mosaiced over the entire required area.
Any type of original images or rectified images can be mosaiced after interactively measuring some conjugate point pairs semi-automatically (in a way similar to that in the relative orientation). The transformation is determined by the measured points. A relative rectification ensures that the mosaiced image is seamless. Processing is performed randomly between two neighbouring images, step by step, to ultimately generate the mosaiced image of the entire block..

2.13 Visualisation

Users can view the results of every stage of the photogrammetric process from raw images, through epipolar images in full stereo, orthoimage, contours, orthoimage combined with contours and the landscape perspective model (as shown in Figure 1). The dynamic landscape (in mono or stereo) is usually based on the DTM and orthoimage, but can be generated earlier in the process from the match results and an epipolar image.

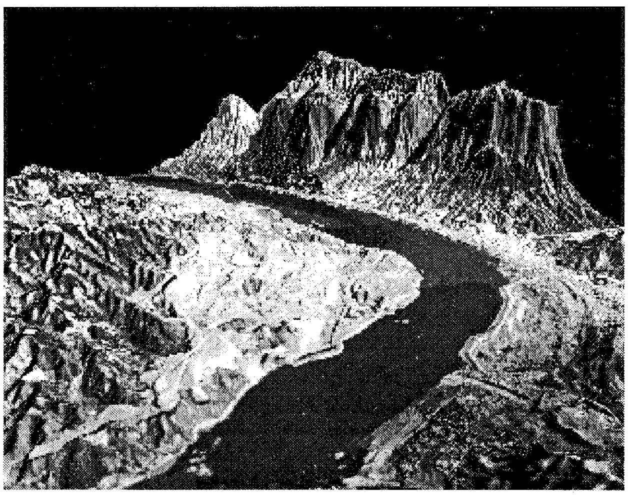

Figure 1. Three Gorges - China

2.14 Output

Raster data can be superimposed with vector data. Combining orthoimage, contours, graphics of objects, grid and map frame with necessary annotation input by the user, the image map can be output as hardcopy, or converted to many image formats, such as TIFF, IRIS RGB, SUN Raster, BMP and JPEG. The stereo landscape can be "grabbed" from any aspect and ground distance for output. The vector data, including contour data and digitised points, lines and polygons can be plotted for traditional vector maps with a frame and annotation. The output symbol library is the same as that in the digitise module. The DTM and vector contours are stored in ASCII format, and the vector data can be converted to other proprietary vector formats.

3. IMAGE MATCHING

The most important function of a DPW is image matching for three dimensional data reconstruction. Previously, there have been some weaknesses in traditional image matching algorithms. New robust image matching algorithms are now being researched and used in a practical DPW to attain reliable results. The global image matching algorithms are suitable for this purpose.

3.1 The Weaknesses of Traditional Image Matching Algorithms.

Image matching, as in plate matching, is a pattern recognition problem. Grid points on the left image are samples of the objects, and the points on the right image are their classifications. The image match determines which sample belongs to which classification. In traditional image matching algorithms, some criterion, such as the maximum correlation coefficient, is used to decide that a sample is or is not to belong to a certain classification. Firstly, they do not take spatial relationships into account, and further, they do not use the matching results in the neighbourhood to adjust the global results of the match. Secondly, it is virtually impossible for the probability that the error classification is zero for any criterion of classification, and therefore wrong results for the image match are unavoidable. The results from traditional image matching algorithms are therefore inharmonious and unreliable.

3.2 Bridge Mode of Image Matching

The most important difference between images in a stereo pair is the effect of geometric distortion by ground slope. Therefore, the sizes of conjugate image windows should usually be different. The method of creating the image windows in a rectangular form centring the target on the matched point did not consider this distortion. This has been classically referred to as the Centre Mode of image matching. The image windows in the Bridge Mode (Zhang Z., 1989 and 1990) are created between two target points and their candidate conjugate points separately. For example, `i` and `k` are two points in the same epipolar line of the left image, and `j` and `l` are their candidate conjugate points in the conjugate epipolar line of the right image. The image segment `(i, k)` is defined as a target window and the image segment `(j, l)` is defined as search window. The size of the search window `(j, l)` is different to the size of the target window `(i, k)`, thus a resampling for `(j, l)` relative to `(i, k)` should be completed to ensure their same size before comparing their similarity. The distortion caused by ground slope will be rectified, and the quality of the image match will be improved. In fact, with the concept of bridge mode, each interesting point being matching can be related with its neighbourhood to extend a single point matching into global image matcing.

3.3 Probabilistic Relaxation of Global Image Matching

Probabilistic relaxation is an effective method used frequently in image segment, edge extraction, analysis of light flow and pattern recognition. Relaxation processing should be a useful technique for using contextual information to reduce local ambiguity and achieve global consistency in the global image matching problem. It is basically a parallel execution algorithm. Being applied in gray-level based image matching (Zhang Z., 1992), it gives consideration to spatial relationships, and global consistency has been improved immensely. Probabilistic relaxation can be used in not only feature based image matching, but also area based image matching. An outline of the latter follows.

The set of candidate points on the right image for point i on the left image and corresponding similarity measurements are J = {j1, j2, ... jm} and ρ (i, j), where j = j1, j2, ..., jm, and ρ (i, j) can be the correlation coefficients of two image window centring in point i on left image and point j on right image separately. The initial probability that point j is the conjugate of point i is the normalised similarity measurement:

$$P^0_{i,j} = \frac{\rho(i,j)}{\sum_{k=0}^{m} \rho(i,j_k)}$$

The consistent coefficient c is defined as the similarity measurement by bridge mode:

c(i,j; k,l) = ρ { (i, k), resampling (j, l) }

where (i, k) is the segment of the left image (j, l) is the segment of the right image, resampling (j, l) is the resampled image segment of (j, l) relative to (i, k) and ρ{} is the similarity measurement by bridge mode. The correct form of the probability in each iteration is:

$$q_{i,j} = \sum_{D} (\sum c(i,j;k_m,l_n) * P_{k_m l_n})$$

where D is the neighbour area. Then the probability in r-th iteration is:

$$P^r_{i,j} = P^{r-1}_{i,j}(1 + a * q_{i,j})$$

where a is a constant relative to the speed of the convergence. The probabilistic relaxation of global image matching is a iterative procedure. Because the probability is relative to the matching results of neighbouring points and the Bridge Mode of image matching is used for correcting the geometric distortion, the globally consistent results acquired after the processing converges.

3.4 Neural Network Method of Image Matching

The neural network is another effective method used frequently in many fields including pattern recognition. Similar to relaxation, the Hopfield model of neural networking can be used in global image matching. Suppose that there are m*n target points on the left epipolar image, and the range of x-parallax is [-p, p]. A neural network with m*n*(2p+1) neurones, corresponding to all possible candidate conjugate points, is created. The initial stage of each neuron is:

$v^0_{i,j} = 1,$ if point j is candidate conjugate point

$v^0_{i,j} = 0,$ if point j is not candidate conjugate point

The strength of the connection between neuron (i,j) and (k,l) can be defined as the same as the consistent coefficient in probabilistic relaxation:

W(i,j; k,l) = ρ{(i,k), resampling (j,l)}

where (i,k) is the segment of left image (j,l) is the segment of right image, resampling (j,l) is the resampled image segment of (j, l) relative to (i, k) and ρ{} is the similarity measurement by bridge mode. The stage of each neuron will change according to the following rule:

$$v_{i,j}(t+1) = 1, if \sum_{k \neq i} \sum_{l \neq j} W(i,j;k,l) v_{i,j}(t) + \theta_{i,j} > 0$$

$$v_{i,j}(t+1) = 0, if \sum_{k \neq i} \sum_{l \neq j} W(i,j;k,l) v_{i,j}(t) + \theta_{i,j} \leq 0$$

where θ is the threshold of neuron (i, j).

The energy function is defined as:

$$E = -\frac{A}{2} \sum_{i,j} v_{i,j} (\sum_{k \neq i,l} W(i,j,;k,l) v_{i,j} + \frac{B}{2} \sum_{i} (\sum_{j} v_{i,j} - 1)^2$$

where W represents the consistent strength between neuron (i,j) and neuron (k, l). The more consistent they are, the smaller the first term of the formula above is. The second term of the formula means that there is only one conjugate point corresponding to grid point i on the left image, that is, only one neuron, or one of the candidate points corresponding to grid point i, is active with the value v=1 and others are not active with the values v=0.
In this case, the second term is a minimum. According to the rule of minimum energy in the network, iterative calculation may change the stages of the neurones until the network tends to be stable and converge, that is:

$$v_{i,j}(t+1) = v_{i,j}(t)$$

All of the points, corresponding to v=1, are the optimal global solution. From above it can be seen, through defining the consistent coefficient as the strength of the connection, that the Hopfield network can perform relaxation processing. An advantage of this technique is that relaxation processing can be performed in real time since the Hopfield network can be implemented by conventional analog circuits. Further, not only can the correct matching result be contained, but also break-lines and occlusions can be processed, based on the new concept of the zero matching with v ≡0. Because of these aspects, the stability of the image match has been enhanced.

4. EFFECTIVENESS OF THE VIRTUOZO DPW

Effectiveness is an important factor for a commercial DPW. Although the capability of computers will improve in the future, processing in real time needs effective algorithms. Currently, if the effectiveness of a DPW is low, it is not viable. Fast algorithms are necessary. It is quite evident from speed of VirtuoZo that this is one of our most significant achievements within digital photogrammetry. In comparison with other similar systems, the effectiveness of VirtuoZo is better by a factor five.

4.1 Fast Resampling along Epipolar Line

The angle and increment in the y direction for each epipolar line is required so that the coordinates of every pixel in the epipolar line can be computed with an add operation instead of multiplication and division operations. Then, keeping the relative position in the x direction, the required pixel is acquired by linear interpolation in one dimension (the y direction) with it's two nearest pixels, instead of a bilinear interpolation in two dimension with four pixels resampling along epipolar lines by image rectification. This procedure yields a factor two improvement in speed.

4.2 Fast Image Correlation

Potentially, the most time-consuming step in a DPW's bag of tricks is the image match since a great number of correlation coefficients have to be calculated and there is a lot of repeated computation. To relieve this repetition, the necessary storage space is retained for the calculated intermediate results. These stored results can be used directly. Effectiveness will increase four to ten times according to the size of the match window.

4.3 Fast Orthorectification

The normally time-consuming operation of orthorectification is replaced by a simple add operation, therefore the repeated calculation for the photographic coordinates of the DTM grid points is avoided. The times of pixel input from disk to memory is reduced to a minimum. The interpolation of the height corresponding to each pixel on the orthoimage is replaced by interpolations of photographic coordinates to avoid the time-consuming calculation of collinear equations. Such a procedure increases the speed by a factor two.

5 APPLICATIONS OF THE VIRTUOZO DPW

The dominant use of VirtuoZo is to create DTMs and Contoured Orthoimages for mapping purposes, and as a data source for proprietary Geographic Information System (GIS). Not only is VirtuoZo one of the most exciting and innovative DPW available today, it is also a superb visualisation tool. VirtuoZo has been used on many projects, such as the colour stereo modelling and orthoimage generation of the Three Gorges of the Yang Zi River in China based on more than forty images (depicted in Figure 1); the maps of the Loess Plateau area with scale 1:50,000 and a height accuracy of 3.7 metres; the DTM and digital orthophoto generation from panchromatic SPOT imagery with the 5-7 metre accuracy in height; the solid modelling of individual objects in a workshop or laboratory environment, explosive blast crater measurement, management of land, the rapid DTM of Ayers Rock in Australia (depicted in Figure 2); resource management; dinosaur footprint archival and measurement from close range images; architectural facade reconstruction; transport corridor measurement; highway and railway design, etc.

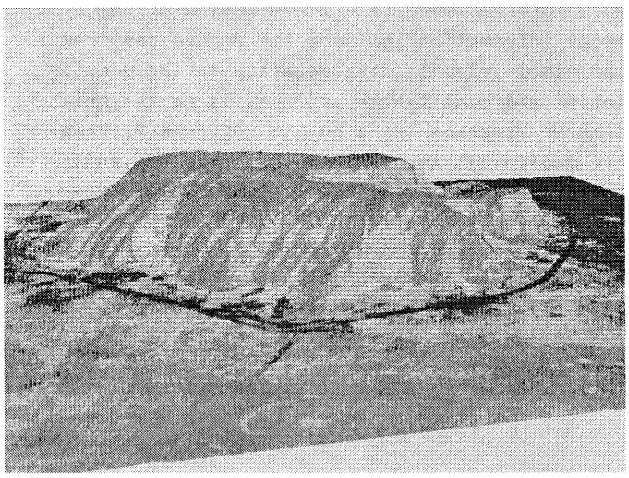

Figure 2. Ayres Rock, Australia

The number of new applications is limited only to the imagination of the user. According to the experiments of some users, the accuracy of VirtuoZo is at least as good as some of the more famous digital photogrammetric systems of the world, and VirtuoZo has a speed advantage.

6. CONCLUSION

Research results of the theory and algorithms used in digital photogrammetry support a practical and commercial DPW. Already, DPW's are available and affordable. Their capabilities allow them to produce all types of conventional photogrammetric products, as well as some new products, such as stereo landscape drapes. DPW can now offer the most exciting, innovative, efficient, practical and cost effective photogrammetric solutions available. Some of them are fast, reliable and dead-easy to use. One of them is the VirtuoZo Digital Photogrammetry System.

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